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Rebuilding and Retrofitting the Transportation Infrastructure

Summary of the 11th University Transportation Centers Spotlight Conference

September 25–27, 2017
Keck Center of the National Academies of Sciences, Engineering, and Medicine
Washington, D.C.

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Washington, D.C.

Kathleen L. Hancock
Virginia Polytechnic Institute and State University
Rapporteur

Organized by the
Transportation Research Board

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Preface

The Transportation Research Board (TRB) hosted a conference, Rebuilding and Retrofitting the Transportation Infrastructure, at the Keck Center in Washington, D.C., in September 2017. This meeting was the 11th in a series of Spotlight Conferences funded by the U.S. Department of Transportation's (DOT) Office of the Assistant Secretary for Research and Technology, University Transportation Centers (UTC) Program. The UTC Program awards grants to universities across the country to advance state-of-the-art transportation research, to conduct technology transfer activities, and to educate the next generation of transportation professionals.

The planning committee for this conference was chaired by Joseph Schofer of Northwestern University. Committee members provided their expertise in condition assessment and evaluation of transportation infrastructure, its rehabilitation and restoration, and managing its assets.

The planning committee was responsible solely for organizing the conference, identifying speakers, reviewing submitted poster abstracts, and developing topics for the breakout group discussions. Kathleen Hancock of Virginia Tech served as the conference rapporteur and prepared this document as a factual summary of what occurred at the conference. Responsibility for the published conference summary rests with the rapporteur.

Agency and private-sector personnel joined faculty, researchers, and students from UTCs and other universities to explore issues and opportunities associated with rebuilding and retrofitting the nation's transportation infrastructure. The conference attracted approximately 104 participants, reflecting organizational diversity as follows:

U.S. DOT	15%
Federal other	1%
State DOT	4%
State other	2%
Local, regional, port	2%
Association/nonprofit	6%
University	40%
Student	8%
Industry/commercial	4%
Consultant	16%
Other	2%

This event provided an opportunity to share ideas and needs about transportation infrastructure and to explore opportunities to enhance transportation performance, offering an interactive format to engage in productive dialogue. It brought together those who generate new concepts and address transportation problems and opportunities and those who own and manage transportation systems. The conference, which was characterized by broad and active participation and discussion, considered potential research to address issues associated with rebuilding and retrofitting transportation infrastructure.

The conference included plenary sessions focused on the role of policy and guidance and emerging and future technologies. Conference participants had the opportunity to hear about and discuss issues and areas for further research in four concurrent breakout sessions and to interact with poster authors. Speakers in the closing plenary session highlighted the topics and research ideas discussed in the breakout groups.

This report consists of edited presentations from the plenary session and summaries from the three sets of four concurrent breakout sessions. Abstracts from posters are also provided. The views expressed in this document are those of the individual speakers and discussants, as attributed to them, and do not necessarily represent consensus views of the conference participants, the conference planning committee members, TRB, or the National Academies of Sciences, Engineering, and Medicine. The conference PowerPoint presentations used by speakers and video recordings can be accessed online through the links embedded in the final program at http://onlinepubs.trb.org/onlinepubs/conferences/2017/UTC/Program.pdf. Scroll to the presentation of interest and click on the title.

Responsibility for the final content of this summary rests entirely with the authors and the institution.

The conference planning committee thanks Kathleen Hancock for her work in preparing this conference summary report and extends a special thanks to the U.S. DOT Office of the Assistant Secretary for Research and Technology for providing the funding support that made the conference possible.

PUBLISHER'S NOTE

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Opening Session

OPENING SESSION

Introduction

JOSEPH SCHOFER
Northwestern University
Conference Planning Committee Chair, presiding

The imperative to rebuild and retrofit U.S. transportation infrastructure is clear and pressing. Demands on that infrastructure continue to grow, and it is well established that effective and efficient transportation facilities and services are essential to economic, social, and environmental well-being of our nation. Measures of facility condition and performance, as well as the consequences of natural and accidental disruptions, continue to warn us of problems, needs, and opportunities.

At the same time, science and technology are advancing rapidly, bringing us new concepts, materials, designs, and methods that—when properly evaluated and deployed—can assist in addressing many of the infrastructure challenges we have in front of us.

The academic community is an important source of new ideas for transportation infrastructure, but important research goes on elsewhere in businesses and transportation agencies. The perspective of those agencies, the infrastructure owners, is critical to advancing the field, for practitioners own the problems and play a central role in selecting and advancing innovations and infrastructure priorities.

Successful management of transportation infrastructure assets must blend these perspectives, bringing useful information about both infrastructure condition and the expected performance of new materials and methods to action decision processes.

Bringing problems and solutions together is what this conference was about. It offered the opportunity for exchanging ideas, clarifying current and emerging challenges, and identifying the barriers to innovation in transportation infrastructure. This event is the 11th in a series that has brought researchers together with transportation managers, leaders, and policy makers for the purpose of knowledge transfer, helping researchers understand the problems of the industry, and moving research ideas into practical application.

The information contained in this summary captures much of the richness of the conference itself, presenting many ideas, challenges, and opportunities for creating an effective and resilient transportation infrastructure.

OPENING SESSION

ASCE Grand Challenge

ANTHONY BARTOLOMEO
Pennoni Associates

INTRODUCTION

Approximately 4 years ago, the Industry Leaders Council at ASCE was asked to advise the Board of Direction about where ASCE should focus its resources for the good of the civil engineering profession and the good of the built environment for which civil engineers are stewards. Two considerations guided their efforts. First, the mission of ASCE is to hold paramount the safety, health, and welfare of the public, and strive to abide by the principles of sustainable development in the performance of civil engineer's duties. Second, was the awareness that repeated calls for increased funding has resulted in limited success in the past. With these in mind, the council developed the following Grand Challenge:

> Reduce the life-cycle cost of our nation's infrastructure by 50% by 2025 and foster the optimization of infrastructure investment for society.

This was adopted unanimously by the Board of Direction, and was one of ASCE's three strategic initiatives for 2016 along with Raise the Bar and Sustainability.

ASCE branded the Grand Challenge and began a public relations campaign to inform, educate, and motivate constituencies to embrace the concept. These constituencies include ASCE membership, owners of infrastructure, elected officials, and the general public. Because these constituencies have different levels of interaction with and understanding about infrastructure, the message was customized for each, accordingly.

IN CONTEXT

Every 4 years, ASCE reports on the condition and performance of the nation's infrastructure, assigning letter grades based on the physical condition and needed investments for improvement. From the most recent report card, the state of the infrastructure received an overall D+, which remains unchanged from the previous report and is only a nominal improvement from the D received in earlier assessments. This reflects a significant backlog of needs facing the nation's infrastructure, particularly in the three categories that experienced a decline in grade—Parks and Recreation, Solid Waste, and Transit—the latter receiving the lowest grade of D-.

ASCE updated its Failure to Act report in 2016. The critical finding was that failing to close the infrastructure investment gap brings serious economic consequences including the following:

ASCE GRAND CHALLENGE
Rethink What's Possible

Cost to the economy	$3.9 trillion
Cost to businesses	$7 trillion
Cost to workers	2.5 million jobs
Cost to families	$3,400 per year

In particular, instead of improving the quality of life for families, the $3,400 is being consumed in car repairs, wasted time, and gas, and increased cost of goods when these goods cannot be brought to market efficiently.

ASCE has framed the debate around what is needed to close this infrastructure funding gap and the Grand Challenge complements this without directly calling for more funding. Instead, the concept is to shift from making decisions based on lowest-first cost to making them based on greatest life-cycle benefit. This can be difficult given the nature of the American democratic political system and the fact that lowest-first cost typically results in more project starts within election cycles. But ASCE reasoned that by doing this, in the long run, reduced life-cycle costs will result in more funds available for more projects.

In the private sector, this concept gets traction, especially with the public–private partnerships (PPPs) where the investor looks at 20, 30 or 50-year design–build–finance–operate costs before turning infrastructure back to the public-sector partner. They consider life-cycle costs, understanding that investing 10% more up front for an innovative material, system or technology embedded in the project is likely to save the initial investment plus result in a greater return over the 20, 30, or 50 years of operation. Because the private-sector goal is to optimize investment, maximize the rate of return and minimize their risk, this concept fits readily into the private sector financing side of the funding/financing investment equation which was formally implemented by President Obama. Public-sector infrastructure owners, which traditionally have relied on the funding side of the equation, are more conservative because of the lack of certainty in the amount and timing of public-sector funding. Currently, President Trump is relying on $200 billion in public funding and $800 billion in private financing for his proposed trillion-dollar infrastructure program. Without an increase in public-sector funding, infrastructure owners may find it difficult to perform the long term planning and assessment required for life-cycle performance analysis that is necessary to improve decision-making about capital projects.

The key to the Grand Challenge is having more money available and being able to do more with that money over the life cycle of the nation's infrastructure. Essentially, the four elements or target areas of the Grand Challenge that can transform the profession are performance-based standards, resiliency, life-cycle performance, and innovation, which will be discussed in more detail below. Bringing about this transformation is critical as demonstrated in Figure 1. The top solid line indicates infrastructure needs and is increasing and will keep increasing as operation and maintenance is postponed and deterioration of the system continues. As indicated, the cost to bring the infrastructure to a state of good repair escalates rapidly. The bottom solid line shows available funding, and the divergence between the two lines represented becomes apparent. The dashed lines indicate the potential impact of adoption and implementation of the ASCE Grand Challenge. Policy actions could help redirect the top curve. An example of a policy action, expediting permit reviews and approvals, was initiated under President Obama and is continuing under President Trump. Instead of these processes proceeding in series, they can now be done in parallel across the federal, state, and local levels and this is done without compromising public health, safety, and welfare, or negatively impacting the environment. New funding sources increase the rate of change of the lower line. In

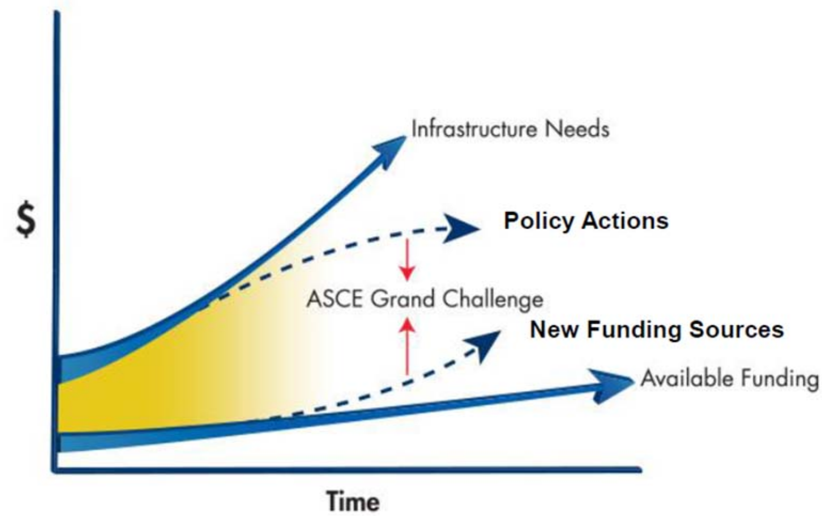

FIGURE 1 Benefit of the Grand Challenge.

the November 2016 election, more than 70% of state and local ballot issues that proposed increases in user fees or taxes to fund infrastructure improvements were passed by the voters, indicating that the message to the general public about the benefits of having an upgraded infrastructure is being heard.

ASCE and its member partners and collaborators will be the leaders of this transformative change that will result in significant improvements in the delivery of infrastructure investments through the use of life-cycle and performance-based approaches. It will enhance resiliency, innovation, and training of our workforce and our future engineers. Additional benefits include the development of professional colleagues as well as students.

INNOVATION

Innovation means not only technologies but also systems and processes, doing business in a new or different manner. Part of the Grand Challenge outcomes recommended by the Industry Leaders Council was the institution of an innovation contest. The goal of this competition is getting out the message that innovation is critical to achieving the goal of the Grand Challenge. These are funded by ASCE and ASCE corporation sponsors.

Two have been completed and a third was launched on September 1 of this year with submittals due no later than March 1 of next year. The five topic areas for this competition include:

1. Innovative Business Models and Technologies;
2. The Internet of Things (IoT);
3. Sustainable Engineering;
4. Next Generation Transportation; and
5. ASCE's Role in Innovation.

The first year had approximately 80 submittals from over nine countries around the world. This increased in the second year and is expected to increase again this year. Many of the submittals were from professor–student teams, and the age and experience of last year's winners spanned the breadth of civil engineers in the field today. ASCE is currently mining the content gathered from last year's event to raise awareness of the need to support innovation as well as to market the 2018 innovation contest.

One of the unique aspects of innovation is that it is not necessarily researching and developing something new. It can also be looking at what has been developed by other sectors and innovatively applying those tools to civil engineering problems. An example is the use of structural health monitoring for bridge assessment which is now being incorporated into the specifications for bridges such as the replacement for the Tappan Zee, Bayonne, and Gordie–Howe Bridges and so on. This was a powerful innovation by civil engineers that brought to bear the ability to monitor the system more closely, collect data, and do the analytics to develop actionable intelligence to improve decision-making on allocating resources.

PERFORMANCE-BASED STANDARDS AND PRINCIPLES OF LIFE-CYCLE PERFORMANCE

ASCE is currently reviewing standards and codes to identify which are amenable to migration from prescriptive to performance based. Members of the profession are involved in these analyses to ensure that the selection is appropriate and that the migration is considered, with a clear understanding of positive and any potentially adverse impacts and that the results will remain protective of public safety, health, and welfare and of the environment.

One example is the seismic retrofit of existing buildings. The performance-based standard requires articulating the owner's desired outcome while holding life safety paramount in decision-making. For a one-story warehouse, considerations are associated with life safety and structural preservation of mechanical–electrical systems and the warehouse enclosure. For a six-story hospital, considerations include life safety and evacuation of patients, which require a more stringent and demanding standard. The seismic retrofit of a hospital is going to be more demanding and costly than a one-story warehouse. Either of these has an impact on the life-cycle cost of managing assets whether warehouse or hospital.

Another example of a performance-based standard or criteria can be demonstrated by the specifications for the replacement of the Tappan Zee Bridge. The New York State Thruway Authority developed a relatively simple technical specification that included the following:

- Connect Point A to Point B across the Hudson River with a twin-span bridge that will be X lanes in each direction.
- The bridge will be capable of supporting public transit in the future.
- The bridge can be either cable-stay or tied arch.
- The bridge will last 100 years.

The engineer's estimate for design–build was $4.5 billion. The three pre-qualified teams came in at $4.2, $4.0, and $3.2 billion. The low bidder had completed the $6.5 billion Bay Bridge in San Francisco, and for that project had designed and built a water-borne crane capable of lifting and placing a 320-ft long bridge deck section. The other two bidders had access to cranes that could handle 120-ft sections. If the project had been design–bid–build, the 120-bridge span would have been specified. By having a performance-based standard based on the outcome as opposed to specifying the design requirements, the low bidder was able to design for 320-ft bridge deck sections, which saved time and materials even though the longer span required more steel. A large percentage of the savings were attributable to the crane, dubbed in California as the Left Coast Lifter and rechristened as I Lift New York when it arrived on-site in the Hudson. The bridge is currently on schedule and under budget and will be named the Mario Cuomo Bridge. Use of the 320-ft spans also impacts life-cycle costs to the owner. Longer reaches of bridge deck result in fewer joints which are one of the more susceptible areas of bridge deterioration. Fewer joints mean reduced operation and maintenance costs, thus reducing life-cycle costs.

TRANSFORMING CULTURE

Desired outcomes from the Grand Challenge include developing processes to positively transform the state the nation's infrastructure and establishing a resilient network committed to a culture that inspires sustained and accelerating innovation. Part of transforming the culture of the civil engineering industry is through expanding and strengthening the triad of research–develop–deploy and ensuring that technological innovation is in step with needs in the industry whether addressing current needs or anticipating future opportunities. This includes expanding and nurturing ongoing interaction between private industry, public agencies, and academia within a dynamic marketplace.

ASCE is addressing the Grand Challenge. They are leading the transformation to life-cycle performance-based standards and promoting the use of life-cycle cost analysis (LCCA) through committees which are developing and evaluating possible standards and guidance. ASCE is promoting innovation, not just through the contest, but by making sure all constituents understand the critical need to be creative and to think beyond the norm and the accepted. And, finally, ASCE is transforming how the industry prepares its workforce and is partnering with academia to ensure that students are prepared to enter that workforce.

My closing statement to you is that if we do not appreciate how quickly technology is advancing in our realm, we are going to be left behind. We don't necessarily need to be the leader but if we are cognizant of how quickly technology is advancing, we will be open to the evolving and transformational tools and will have the great advantage of implementing and deploying them into the marketplace. The exponential growth of technology is unbelievable. Consider that just 10 years ago, the most powerful super computer on Earth pales to what is available today, which will pale in comparison to what will be available 5 years from now. So if we understand that and take full advantage of the research being done in our research institutions, the private sector partnering with the public sector owners can ensure that this transformation occurs through deployment in the field.

NOTE: Transcribed and edited by Kathleen Hancock, Virginia Tech.

OPENING SESSION

Southeastern Pennsylvania Transportation Authority
Pushing Past Just Survival

JEFFREY KNUEPPEL
Southeastern Pennsylvania Transportation Authority

As reported in the most recent ASCE report card, the transit industry received the lowest grade assigned, a D–. This demonstrates not only the problems that currently exist for the nation's transportation infrastructure, but also the challenges that public transit agencies encounter as they address increasing operating expenses and aging infrastructure and vehicles. The industry is faced with extending the life of this infrastructure and when necessary, replacing it as efficiently and as cost-effectively as possible.

SEPTA IN CONTEXT

Southeastern Pennsylvania Transportation Authority (SEPTA) is the sixth largest transit agency in the United States. It is a legacy agency with a large proportion of old infrastructure. It is also currently recognized as a model transit agency and is tied with Boston, Massachusetts, for owning and managing the most modes under a single agency; has 1.1 million daily riders (330 million annually), 2,800 vehicles, and 9,500 employees; and a combined Operating plus Capital Budget in FY2018 of just over $2 billion.

It is also a system "borne of bankruptcy." Figure 1 shows the history of SEPTA and its acquisition of property and service. Much of the acquisition resulted from private companies going bankrupt because they could not survive the suburban sprawl resulting from Interstate highway construction. Suburban bus and light rail was added in 1970 while commuter rail was added in 1983 when Conrail was divesting itself of its passenger service. As a result, SEPTA inherited infrastructure that was in dreadful condition.

Obtaining adequate resources to improve the situation in Philadelphia was a long, tough road that required much of the agency's innovation, cooperation, and commitment. Infrastructure could not be replaced on time. Operating budgets were unpredictable while the capital budget was insufficiently funded. Service was continually reduced to meet basic requirements. Consideration was given to dismantling the rail network because it was too expensive to keep operating. For years, SEPTA's future was uncertain. Finally, in 2013, the state passed the transportation funding bill, Act 89, which changed the trajectory of the agency and allowed SEPTA to move past survival.

Figure 2 provides a stark image of where SEPTA was in relation to its peer agencies before passage of Act 89. At approximately $300 million, SEPTA had less than a third of the annual capital budget of most of these peers. To add perspective, during the previous year, APTA had labeled SEPTA as the Large Property of the Year. Surviving required that the agency stretch every single dollar through hard work and with a workforce that never gave up. At $300 million, the agency did not have sufficient resources. With the passage of Act 89, the agency now has $700 million and its fortunes are reversing.

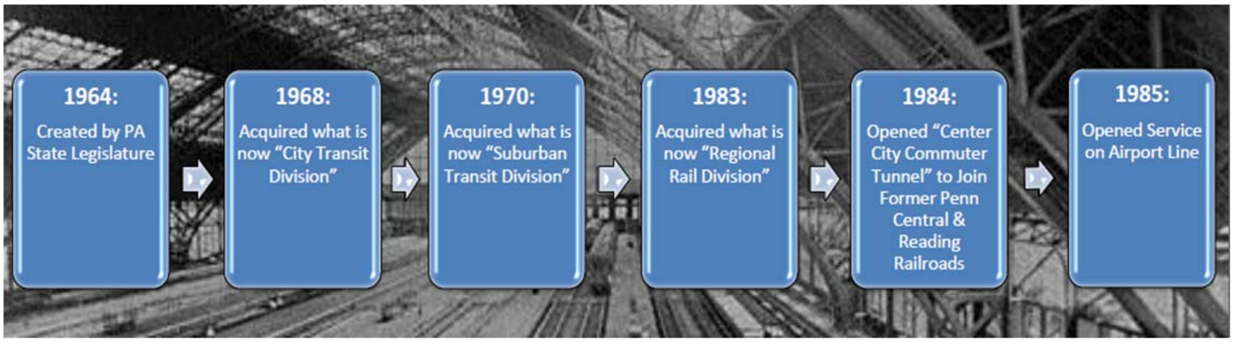

FIGURE 1 History of SEPTA.

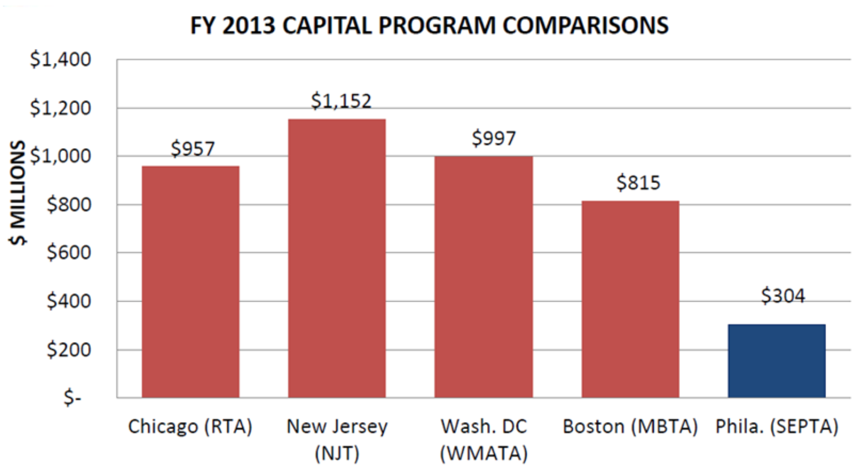

FIGURE 2 Funding shortfalls.

Now SEPTA's challenge is to catch up on a $5 billion backlog of state of good repair (SGR) needs. Figure 3 provides a breakdown from 3 years ago. As indicated, the biggest single item is vehicles at $2 billion. The challenge with this category is that vehicle contracts are extremely expensive. Replacing the 231 vintage 1970 Silverliner IV vehicles alone will cost almost $1.5 billion. The remaining items combined show the infrastructure backlog of over $3 billion. This number has gone down since the chart was created because SEPTA immediately began addressing this backlog when the funding bill was passed and has been actively working through these requirements. With safety considerations paramount, SEPTA has replaced every signal system and manages the only commuter railroad east of the Mississippi that currently has the federally mandated positive train control (PTC) in revenue operation.

INFRASTRUCTURE SURVIVAL TACTICS

How did SEPTA survive through the tough years with the overwhelming odds and numerous challenges? Their employees get the majority of the credit. For instance, SEPTA employees did whatever it took to complete necessary maintenance and while also performing critical construction projects, even though the qgency lacked resources to hire addition workers. An

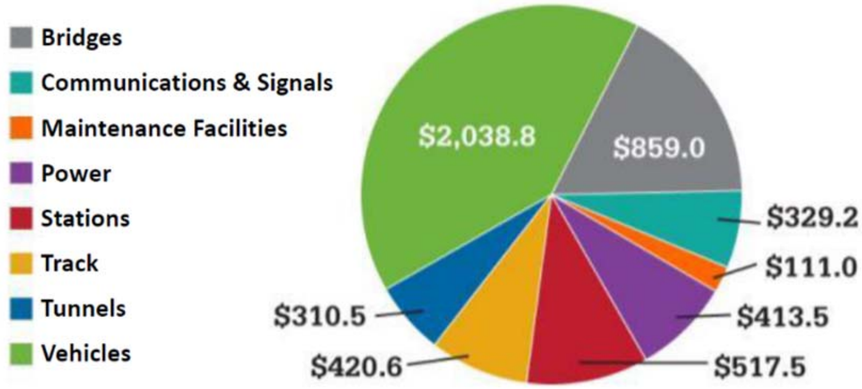

FIGURE 3 SGR needs. (Source: AECOM.)

example of the level that employees went to is demonstrated in the overhead catenary. When doing repairs, the crew would not take the lines up to full tension. When asked about it, they replied that they did not want to lose their heads; there were cracks all along the catenary and they did not trust tensioning to more than about half. The resulting decision was to stop maintaining the existing lines and to replace them instead. This was done with SEPTA employees who worked night and day and who were given the latitude to innovate as necessary.

Other examples include communications and signals work, station work, and track work. By necessity, SEPTA has developed this capability in house. An added benefit is that this work can be done more quickly in house. Projects can be started quickly without the need for extensive design documents or bidding. Materials are ordered while the design is being finalized resulting in optimizing timing. Big projects still go through more conventional third-party design and construction but SEPTA has learned to take advantage of things like scheduled construction outages to perform in-house work in the same area on another project. This balance of doing work in unconventional ways that take advantage of any possible situation has proved to be efficient and cost- and time-effective.

Another method that has evolved at SEPTA is combining in-house and third-party construction. An example of this hybrid approach is the Ryers Station where the foundation, ramp, and wall work were performed by a third party while the work near the tracks was done by the SEPTA workforce who now routinely does this type of work. The hybrid approach typically results in cost savings, which, in this case was used to buy land next to the station for additional parking. For the 61st and Pine bus loop, the drainage work and most of the curbing was handled by a contractor while SEPTA staff finished everything off and assembled and installed prefabricated components, including the bathroom. Where possible, SEPTA used pre-cast components near the tracks that are brought in and installed by SEPTA operators. This not only allows SEPTA to use in-house employees, but it is more efficient because time is not required for forming and allowing the concrete to set. A final example is SEPTA's commitment to safety and the requirement to implement PTC. They split the work and the automatic train control work was performed with SEPTA employees while the Advanced Civil Speed Enforcement System overlay that was required to have a PTC-compliant system was done by a third party. By dovetailing the two efforts, the project proceeded swiftly and ahead of pace when compared with peer agencies.

The hybrid approach extends beyond construction to design, and it works because of consistency of leadership, building and maintaining the trust of union workers, and fostering an enabling work environment. Engineering companies that want to work with SEPTA are told to be flexible. To be successful, they have to abandon their preconceived ideas and be open to alternative approaches.

The key to SEPTA's survival has been innovation in all things, not just in new ideas, but in mixing concepts and combining ideas in ways that improve efficiency and save resources.

VEHICLE SURVIVAL TACTICS

SEPTA rail vehicles are among the oldest in the country. Addressing this challenge required a different approach. By working with the state, SEPTA developed a 5-year overhaul cycle that is funded through the state. Every 5 years, vehicles get a mini-rehab to return them to original equipment manufacturer standards. This has extended the life of the fleets, both rail and bus. The work is performed by SEPTA employees who have become proficient in this type of repetitive work and have legacy knowledge of the vehicles they service.

The trolley fleet consists of 141 Kawasaki light rail vehicles built in 1981 and 18 President's Conference Committee cars built in 1948 and rebuilt in 2000. In 2012, the mean distance between failures (MDBF) was unacceptable to SEPTA's standards. After reviewing the failure statistics, staff from engineering and maintenance was brought together to study what the problems were and to tailor the 5-year overhauls to specifically address these problems, including identifying chronically failing components for replacement. After implementing this process, the mean distance has gone up 84%. The review also resulted in establishing a remedial trolley system for vehicles that are failing too much. Vehicles that are placed into the remedial program are reviewed in detail and remediated by a SWAT team. Approximately 11 vehicles have gone through this process, contributing to MDBF improvements.

The Broad Street Line fleet includes 125 well-constructed Kawasaki B-IV cars that were built in 1981. They operate at 55-mph on express tracks under Broad Street and, because of their quality, SEPTA wanted to extend their service to the end of the cycle of fleet replacements. To ensure that they were safe at high speeds, SEPTA needed to know whether the cars were crashworthy to current standards and whether any crack issues existed or were likely to develop during the extended use period. LTK was hired to perform the assessment, which consisted of loading and extensively strain-gauging one of the cars to measure the strains and resulting stresses that developed during normal operations. Another car was completely dismantled and through additional studies, it was determined that Kawasaki was ahead of its time and the cars meet current crashworthy standards. With targeted investments, these cars will remain in service for at least another decade.

STRATEGIC PLANNING FOR THE AMERICAN RECOVERY AND REINVESTMENT ACT

Speed is another great saver of money. The American Recovery and Reinvestment Act (ARRA), also known as the stimulus program, was voted on and passed in February 2009, but SEPTA strategically began preparing for it months in advance. The call was "All Hands on Deck" through the holidays for staff and consultants. Designs were initiated and submittals were expedited. An accelerated permitting process was also implemented. Because of the coordination and cooperation from the beginning of the process, the rate of change orders did not change and design costs were about 25% of normal.

Through strategic decision and competitive bids, SEPTA was awarded 32 projects (they originally submitted 26) within 1 year of ARRA approval on February 17, 2009. By June 8, 2012—only a little more than 3 years later—all projects were substantially complete. This work occurred before the passage of Act 89 and layoffs were still a consideration. Because of the agency's stellar performance in efficiently delivering quality projects, SEPTA was awarded several discretionary grants and layoffs were no longer considered. SEPTA was also dubbed by industry leaders as the "Gold Standard" for stimulus. That reputation remains to this day and was absolutely essential in the funding battle in 2013.

In this case, innovation was considering a situation in a new way and capitalizing on the culture of bringing everyone together at the beginning to establish clear expectations and address issues before they become problems and created roadblocks. SEPTA still uses a more traditional approach when necessary and negative consequences can still happen when projects drag on. However, timely communication and rapid response to issues can minimize such negative consequences.

ACT 89, PUSHING PAST SURVIVAL

Prior to passage of Act 89, SEPTA had developed a realignment plan to help address its $5 billion backlog. Figure 4 shows the plan as it would affect Regional Rail and Rail Transit. Although the details are not readable in the figure, the resulting impact is clear. SEPTA has some of the oldest rail cars in operation today with substations that have been running since their original electrification. Insufficient funds were available to address the corresponding backlog.

A critical factor to the success of the funding campaign was that the highway side of the equation stood together with transit on this bill. The Act provides a total of $2.3 billion per year with $1.8 billion for highways and $500 million for transit. Highway and transit stayed together and the region stayed together. Without this uniform front, the bill probably would not have passed given how close the votes were.

Figure 5 shows how SEPTA has ramped up funding to the $700-million level. Although the past 4 years show the programming of the new funds, both SEPTA and Pennsylvania DOT anticipate that it will take 20 years to achieve SGR.

An early example of the impact of Act 89 is the Crum Creek Viaduct. The original structure was built in 1854 and was replaced in 1895. It consisted of 17 spans and was 975 ft long. When the bridge was acquired in 1983, SEPTA performed a 25-year life extension project and then had to perform emergency repairs in 2013 for corrosion, cracks, and bolted connections. How was safety ensured? How were operations maintained? Throughout the time SEPTA owned the viaduct it was closely monitored and tested. A regularly scheduled ballast train was redirected to the opposite span when loaded. As soon as funding was available, SEPTA sought a design–build bid for the replacement viaducts which resulted in a $10 million savings and a 1% change order rate. The contractor used accelerated bridge construction and the project was completed in less than 3 years from passage of the act.

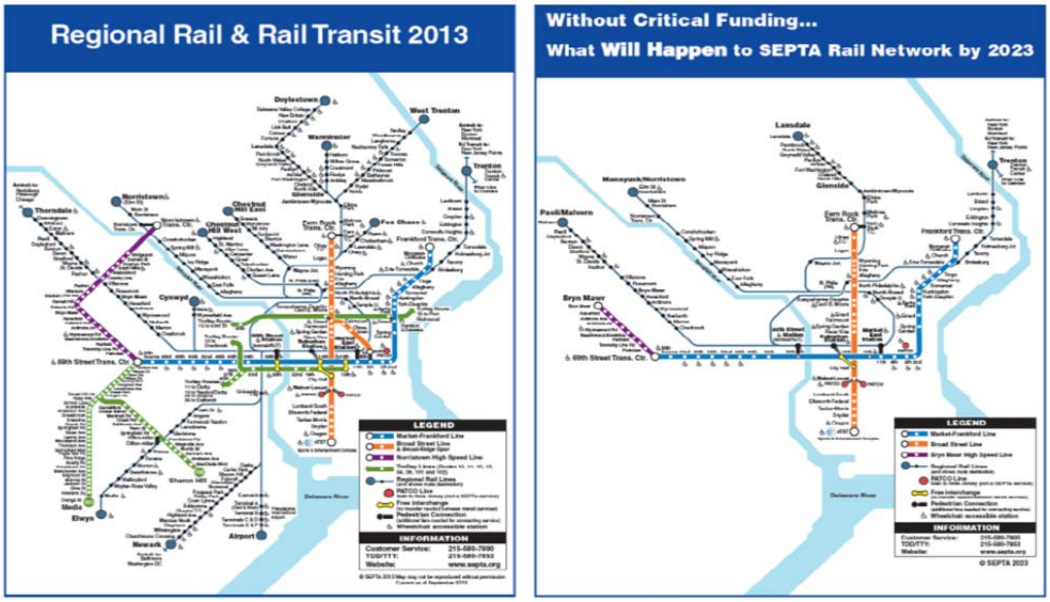

FIGURE 4 SEPTA service realignment plan (September 2013).

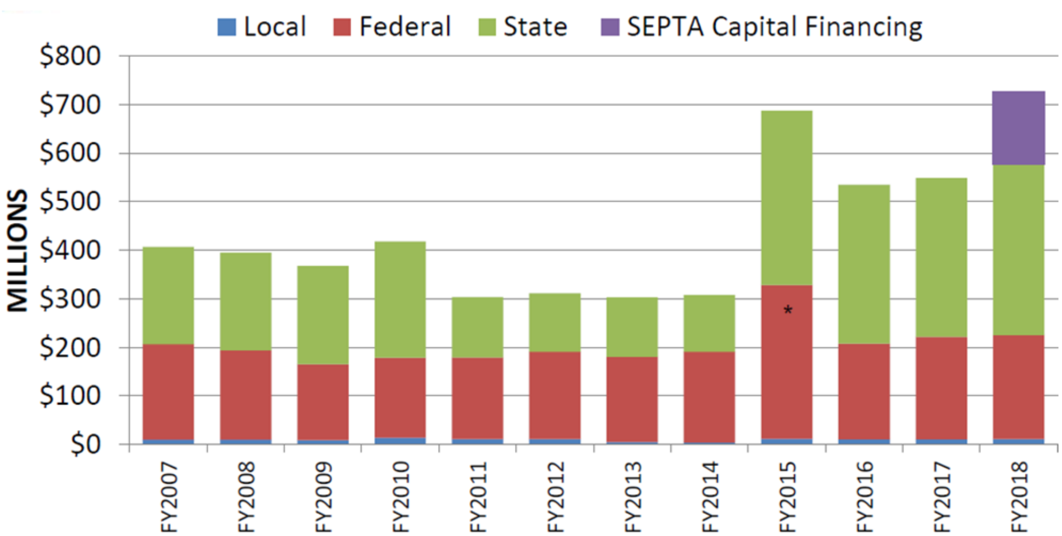

FIGURE 5 SEPTA capital budget.

THE NEW CHALLENGE

As indicated in Figure 5, SEPTA is now able to develop a plan forward for reaching SGR. However, the facts that Philadelphia is less expensive than many other cities in the northeast and a desirable place to live have created a new challenge for SEPTA. Philadelphia is growing faster than the infrastructure can support. The two largest employment centers in the metropolitan area are Center City and University City. From 2010 to 2017, Center City has seen employment growth of 7.3% and population growth just over 10%. It is the second-densest downtown area in the United States and is home to the Comcast Tower and now the Comcast Technology Center, the country's ninth tallest building. Both buildings have direct connections to the Suburban Station underground. This proximity has redefined transit-oriented development (TOD) where development is no longer within 3 mi of a station but instead is directly adjacent to and integrated with the development. At the same time, 4,171 downtown public parking spaces have been eliminated due to development which has resulted in approximately 62% of workers in the two employment centers taking transit.

As a result, the Market–Frankford subway has experienced a 41% increase in ridership since 2000 while the Broad Street subway has experienced a 29% increase. Based on Census Tract numbers, the biggest proportion of population growth for Pennsylvania is along these two lines. So the new challenge is not just to replace in kind but to effectively manage growth. On the Market–Frankfort Line, interior seating was reconfigured to increase capacity by 8%. Platform extensions are being considered to go from six- to eight-car trains. Although the $1 to $1.5 billion to fund this is not yet available, SEPTA is working locally on a 15-year plan. And this only accounts for current growth, not the 40% in additional projected growth. Over the same period, regional rail has gone up 52%, in part because of the explosion in TOD associated with rail stations. For the first time, SEPTA is adding multilevel rail cars to increase capacity.

The story is now persistent improvements at SEPTA, not just reaching and maintaining SGR. This is the new challenge.

I've had a long career in engineering at a public agency and things are changing rapidly. Irrespective of the issues discussed above, one of my biggest challenges is our rate of retirement and people leaving our business. I've had a 16% turnover in the last 2 years and 25% in the last 3 years. To educators and institutions of higher learning, I want to send this message: Your graduates are being put to work almost as soon as they are hired. This is challenging for both the graduate and the agency. In the complex environment that agencies now operate, we do not have the time to mentor and train new engineers in all the various aspects such as understanding communities, obtaining consensus, and understanding all the parts of a large system, all while maintaining transparency and accountability. Without understanding the bigger picture and broader consequences, young engineers often flounder. I encourage you to remember this when evaluating and evolving curricula today. I've seen a lot of good things happening and I've seen things moving in the right direction. It's important to the success the young engineers of today and the decision makers of tomorrow.

In closing, I want to pass on the statement printed on the back of my business card:

Don't celebrate the idea, celebrate when you make the idea a reality.

NOTE: Transcribed and edited by Kathleen Hancock, Virginia Tech.

Track Breakout Sessions

TRACK BREAKOUT SESSIONS

Needs, Advances, and Opportunities Before Us

KATHLEEN HANCOCK
Rapporteur

The goal of this Spotlight Conference was to engage, share ideas, learn, and help define a path toward more-effective and -efficient transportation infrastructure for the future. With this in mind, four tracks were established and the majority of the conference was structured to allow participants to self-select their tracks and to learn through presentations and then to engage and share ideas through discussion. To ensure the latter, the tract sessions were divided into three breakouts. The first two breakouts were held on the first day and consisted of presentations followed by discussion. Attendees were then brought together for a plenary session that shared observations about the state of the practice and ideas for advances that were discussed during the two breakouts. With this information and the opportunity for participants to interact with researchers and practitioners during the poster session, the second day started with a recharge to the attendees followed by the third breakout session where the focus was on identifying ideas that were ready for implementation and those that could warrant more research.

The information summarized in the discussion sections consists of comments from individual attendees and, where appropriate, are categorized and reported under themes that emerged from those discussions. The summary and categorization do not imply consensus, ranking, or agreement from other attendees and are provided for the convenience of the reader. This section presents the summaries from the breakouts.

TRACK BREAKOUT SESSION 1

How Are We Doing?

Condition Assessment and Evaluation

SREENIVAS ALAMPALLI
New York State Department of Transportation, presiding

DAVID KOSNIK
CTLGroup, recording

This track focused on considering innovative and practical technologies and approaches to evaluate current and future infrastructure conditions to assure safe and reliable infrastructure and to support informed asset management.

BREAKOUT SESSIONS 1 AND 2

Infrastructure Monitoring and Assessment: State of the Art and Future

Farhad Ansari
University of Illinois, Chicago

Ansari presented current practice and future trends in sensor-based monitoring of bridges and related structures in the context of several case studies. Civil structures present some particular challenges compared to other fields where structural instrumentation and monitoring are common, particularly aerospace. Specifically, civil structures are large and complex—much larger in physical space than most airframes, for example. The size and complexity often require measurements at a large number of points, which may be widely distributed across the structure. In addition to the hardware challenges associated with many measurements, long-term monitoring results in voluminous data, which becomes overwhelming without careful consideration and strategies.

Judicious selection of sensing technologies can reduce some of the complexity of monitoring systems. In each of the case studies presented, fiber-optic sensors were deployed due to their intrinsic support of distributed measurements (e.g., point measurements at various distances along the fiber optic cable), immunity to electrical noise, and other characteristics. Case studies on a bridge weigh-in-motion system, i.e., using live-load response data from an instrumented bridge to calculate gross weight and other characteristics of trucks passing over the bridge, and monitoring of cracks in historic masonry vaults on the approach to large bridge were presented, providing examples for monitoring dynamic and quasi-static responses, respectively.

In particular, the historic masonry vault case study illustrated how monitoring could answer a specific question about the behavior of the structure, and thus address implications for ongoing management of the structure. Monitoring showed that the crack behavior was driven entirely by seasonal temperatures, and thus the cracks did not represent active deterioration. It is likely the cracks originated from settlement early in the life of the structure and have long since stabilized. As a result, resources that might have been directed toward costly rebuilding of the arches were available for use elsewhere.

Accelerated Testing for Infrastructure Applications: Challenges and Opportunities

Frank Moon
Rutgers University

Moon discussed the motivation, challenges, and possible benefits of accelerated testing for prediction of long-term in-service performance of bridge superstructures and decks and for evaluation of novel designs and materials. Keeping in mind that data collection is not a goal in itself—the purpose of data collection is to test specific hypotheses—several critical open questions were articulated.

- What are primary factors that lead to poor durability? How do those factors interact?
- What are best practices in design and maintenance for good long-term performance?
- What are the most reliable techniques to identify and predict onset of deterioration?
- What are best practices to mitigate deterioration once it starts?

Success of testing efforts will be judged by questions answered, not terabytes of data collected. By constructing full-scale bridge superstructures and decks in a laboratory where field conditions can be simulated in a time-compressed manner, controlled experiments can be conducted to support understanding of bridge performance as a function of intrinsic attributes such as age, design details, and materials and inputs such as live and environmental loads and maintenance.

Moon characterized bridge management strategies into two complementary but distinct approaches—top-down and bottom-up—where top-down represents consideration of entire populations of bridges such as bridges on the National Highway System or bridges within a certain network or geographic region, and bottom-up consists of detailed study of individual projects or structures. Voluminous data are available for top-down studies—for example, 30 years of National Bridge Inventory (NBI) data—but characteristics of the population, including trends in bridge design and construction over time, make it difficult to compare one cohort of bridges to another as they age. A growing number of bottom-up studies are available which characterize and evaluate performance of individual bridges. But these are costly and time-consuming, although automated field testing and data collection can help. Accelerated testing can help bridge the gap by simulating long-term deterioration on individual full-scale bridges. Possible approaches include:

- Longitudinal studies. Evaluate performance of specific details or materials over a compressed time.
- Comparative studies. Evaluate different materials or details side-by-side.

SESSION 1 DISCUSSION

Several themes evolved during the discussion after the presentations. Observations from individual attendees are summarized under these themes.

- Obtaining the right data and providing value.
  - Identify the right measurements in a timely fashion.
  - What is measured, where on the structure is it measured, and how is the data recorded?
- Barriers to adoption and possible solutions.
  - Communicating value of monitoring to owners of bridges and related structures remains a challenge. Researchers and consultants tend to focus on the technologies and methods employed, particularly in their areas of expertise, and are not as effective at describing to owners how monitoring can support specific decisions to reduce life-cycle cost and promote ongoing serviceability.
  - Commercialization of monitoring systems and moving toward off-the-shelf components should reduce costs and lead times.
  - Specification and contracting. It can be challenging for bridge owners and builders to include provisions for a well-considered monitoring system in contract documents. Could design–build contracting and PPPs provide new mechanisms for including monitoring in projects?
- Supporting specific decisions.
  - Consider what decisions or "forks in the road" can be informed by monitoring data.
  - Measurement types should be driven by decision types, not vice versa.

Condition of Our Bridges and of Their Conditions: An Owner's Perspective

Bojidar Yanev
New York City Department of Transportation

Yanev discussed implications of various approaches and metrics for evaluating bridge condition for management of bridge maintenance, rehabilitation, and life extension. In particular, he examined the assumptions inherent in various condition evaluation approaches and how differences between systems can complicate network-level asset management.

The definition of "bridge condition" varies among different evaluation metrics and reflects the original purpose for development of and intrinsic assumptions within those metrics. As such, comparison of conditions as evaluated by different methods without a comprehensive understanding of those methods can be misleading. Rating systems vary over time and between various bridge-owning agencies. Examples of superficially similar but ultimately distinct condition metrics include the NBI sufficiency rating, the New York State DOT rating scale, and AASHTO condition states. Translation between condition definition systems is nontrivial because different systems emphasize different aspects of condition. For the purposes of evaluating an individual structure, engineers can use judgement based on professional experience to inform condition assessment; however, variations between systems may contribute to confusion when examining entire populations of bridges.

Some approaches to improve asset management in light of the variability between condition metrics include:

- Consideration of lowest ratings such as using the lower bound of a condition-versus-time scatter plot when developing maintenance budgets because the lowest-rated bridges tend to require the most money.

- Consideration of element-level condition data, where available, with special attention to trouble spots: joints, wing walls, back walls, bearings, scuppers which fail in less than 10 years versus longer-lived primary members and decks.

Extending Life of Bridges Through Robotic Condition Assessment and Minimally Invasive Rehabilitation

Nenad Gucunski
Rutgers University

Gucunski presented a summary of capabilities and benefits of robot-aided nondestructive evaluation (NDE) and data collection to identify and characterize deterioration of highway bridge decks. As maintenance, repair, and rehabilitation of concrete bridge decks consume a majority (50% to 80%) of funds designated for bridge maintenance and repair, improved understanding of deterioration modes and underlying mechanisms may yield substantial rewards, both in term of improved durability and reduced life-cycle cost.

The robot-aided NDE technology and complementary data visualization methods that were developed in the project include provisions to address each of the primary modes of bridge deck deterioration: rebar corrosion, delamination, and concrete deterioration. The advantages of the technology include:

- Ability to compare result maps from multiple NDE methods to better identify trouble spots and characterize damage mechanisms. For example, areas of delamination corresponding to areas of high corrosion activity suggest that the delamination is driven by corrosion. In other cases, delamination without corrosion activity suggests damage from overloading.
- Ease of data visualization across various measurement techniques and over time.
- Panoramic "stitched" photographs and NDE maps become permanent records, or snapshots, of deck condition at a particular time. A series of snapshots not only documents ongoing deterioration, but also shows maintenance or repair history by documenting patches and other repairs.
- Ability to develop condition indices such as weighted averages of percentage of deck area in different conditions. Gucunski noted that weighting of various deterioration modes may be agency specific.

SESSION 2 DISCUSSION

Several limitations within and opportunities to improve condition assessment were identified by individual attendees.

Scatter in condition-versus-time data when considering populations of bridges can present difficulty in interpretation and summarizing data from data sets; that is, different bridges deteriorate differently, and it is important to consider differences from one subpopulation to another. Another consideration is variation of weighting between different forms of deterioration and different deterioration mechanisms (e.g., cracking versus delamination) from one agency to another. As one participant phrased it, "No matter how much you try to quantify a certain phenomenon, sooner or later you have to throw in a factor to qualify it."

Deterioration—corrosion, for example—is a complex process, and the ability to identify what data are necessary to inform decision-making depends on the limit state of interest. It may be helpful to consider what data are "mission critical" to understand each limit state. In addition, consideration of mechanistic models (e.g., for chloride diffusion) in addition to statistical examination of records of field observations may be helpful in scheduling maintenance interventions.

As technologies and methods for condition assessment evolve and improve, engineers sometimes consider new technologies as replacements for traditional or existing technologies. However, progress need not mean abandoning proven technologies; new technologies can complement existing ones. In other words, it may be useful to avoid either–or thinking with particular tools but instead to consider these as additional tools in the toolbox, not as replacement for something else. In a similar vein, a participant noted that condition monitoring is interesting because it is constantly evolving, but that it is also frustrating: agencies hesitate to implement a technology because it may be obsolete very soon.

BREAKOUT SESSION 3

Cross-cutting themes were presented to attendees to provide context for the discussion during Breakout Session 3 and included:

1. Minimizing life-cycle costs;
2. Fostering procedures, standards, codes, or methods to enable use of innovative technologies and methods;
3. Expediting construction and repair;
4. Developing and adopting performance-based approaches as opposed to prescriptive approaches;
5. Supporting decision-making;
6. Having the right data for the purpose which is typically, but not always, quantitative; and
7. Managing, aggregating, distributing, mining, and drawing conclusions from the data.

Introduction

Based on the cross-cutting themes, attendees were tasked with identifying specific research and action priorities. Specifically, attendees considered minimizing life-cycle costs, fostering procedures and methods to enable use of innovative technologies, developing and adopting performance-based approaches, and supporting decision-making.

Discussions during Track 1 sessions tended to focus on condition assessment of highway bridges, reflecting the experience and interests of many of the participants. However, most of the challenges and innovative approaches are applicable to transportation structures in general and some aspects may be relevant to other fixed transportation assets such as pavements.

Future Research Topics and Goals

The following ideas resulted from individual contributions to the discussion.

Identify Links and Interactions Between Top-Down (Network–Population Level) and Bottom-Up (Individual Structures–Projects) Aspects of Condition Assessment

Participants discussed the links and interactions between two complementary approaches to condition assessment of transportation infrastructure: top-down and bottom-up, where top-down refers to consideration of infrastructure at the network level examining current state and trends of a population of bridges, and bottom-up refers to in-depth examination of individual structures or projects within the population. One idea was the creation of a synthesis of in-depth project-level monitoring of a cohort of similar structures and accelerated testing of specific designs and materials which could then be used to create stronger connections between top-down and bottom-up.

Move Toward Comparability of Measurements and Derived Metrics Among Asset Populations and Data Sets, to Allow for Making Comparisons and Drawing Conclusions Between These Assets and Data

Participants identified several challenges associated with understanding condition data obtained from different sources. For example, a participant stated that it is nontrivial to compare measurements from different sensing technologies, or condition ratings obtained from different coding schemes. Another participant indicated that it would be useful to have schemes to visualize and communicate changes among point measurements and area–volume measurements over time—i.e., to visualize evolution between "snapshots" of condition. Also, the importance of retaining the raw data used to calculate reporting metrics, such as NBI rating for bridges, or a remaining service life prediction, was identified in case underlying assumptions or other considerations change, the metric (or an alternative metric) could be recalculated without reinspecting the asset.

Consideration of Serviceability and Durability, Not Ultimate Capacity, as the Limit States of Greatest Interest in Condition Monitoring

Due to professional commitment to the safety of the traveling public, focus is placed on detecting and preventing incipient failure. However, true bridge disasters are extremely rare and, in practice, bridges that are known to be unsafe are removed from service well in advance of failure. The kinds of decisions that can be supported by condition monitoring are usually not "close the bridge" decisions, but matters of serviceability and durability. Can the bridge last another 5 years, until funding is available for a replacement? Will increasing load limits on a particular corridor significantly shorten the service life of bridges along the route? How long do concrete deck patches last under in-service conditions? These are some of the questions raised by participants related to this theme.

Barriers

Similar to above, the following barriers were identified by individual participants and grouped under common themes.

Adoption of Novel Technologies and Methods

Specific challenges to the adoption of innovative technologies and methods, including sensor-based monitoring of structure behavior were classified into the following subcategories:

- Organizational resistance to change in general, commonly taking the form of institutional inertia or the “not-invented-here” syndrome.
- Lack of a clear benefit.
- Disconnect between promotion of new technologies and the corresponding decisions to be supported (the “gee whiz!” and “so what?” aspects, respectively, of the technology). One participant noted that instrumentation-oriented people tend to promote novel sensors.
- Time required to realize benefits of long-term monitoring: there is a lack of contracting mechanisms for long-term (e.g., 10+ years) monitoring. A suggestion from a participant was to consider a series of short-term contracts with periodic renewals with a requirement that a result must be shown early enough in each term to justify renewal.
- Lack of widely accepted certifications or guidelines from highway agencies and other infrastructure owners on use of condition monitoring.

Workforce Development

A number of participants expressed concerns about the ability of the near-future engineering workforce to work effectively with current and future condition assessment and monitoring tools. Specific questions and issues raised by individuals included:

- Are engineering students being prepared to evaluate structural performance and maintenance needs from monitoring and NDE results?
- Will they be adequately equipped to interpret results from sensor-based monitoring as part of careers in bridge engineering or asset management?
- Will they understand the strengths and limitations of various measurement schemes?
- What more can be done to provide on-the-job training in basic instrumentation and monitoring techniques among recent engineering graduates?
- The importance of mentoring for recent graduates in the first years of their careers was also discussed.
- A few participants indicated that a number of universities are implementing ways to expose undergraduates to some basics of instrumentation, whether as part of a small number of lab projects associated with mechanics of materials or theory of structures classes, a seminar series, or a dedicated course in instrumentation.

TRACK BREAKOUT SESSION 2

Rehabilitation and Restoring the Current System

ALI MAHER
Rutgers University, presiding

KAMAL KHAYAT
Missouri University of Science and Technology, recording

The focus of this track was to identify methods, designs, and materials to rebuild and retrofit transportation infrastructure that will deliver effective and efficient performance and preserve resources for future generations.

BREAKOUT SESSIONS 1 AND 2

The two presentations in the first session dealt with concrete construction and repair materials. The first involved a roadmap for the use of new test methods that can be used to determine intrinsic characteristics of concrete and use of models and specifications for concrete durability performance. The second presentation considered performance-engineered concrete mixtures (PEMs) that can be used in patching repair of transportation infrastructure.

The two presentations in the second session dealt with reasons for slow implementation of innovations in materials, design, and construction within DOT organizations, including some new innovative technologies, such as the use of ultra-high-performance concrete (UHPC) for the upgrading of the structural performance of bridge elements.

A Roadmap for Test Methods, Models, and Specifications for Concrete Durability Performance

Jason Weiss
Oregon State University

Weiss indicated a need to integrate the durability-based design process in infrastructure. This could be done through design practices or codes. The majority of pavements and structures are failing due to durability. The mixture proportioning of modern concrete is changing from traditional four-component simple systems to complex engineered mixtures that meet multiple requirements, including fresh and hardened properties. AASHTO's standard practice, PP-84, has adopted performance-based specifications. He presented the following four-step approach to develop for performance specification for concrete durability:

1. Develop simple and repeatable test methods that can be used to assess performance;
2. Convert test values to fundamental properties of concrete using vetted models;
3. Relate properties with different exposure conditions that are experienced across the country; and

4. Establish performance grades and use test methods for quality control to ensure that design properties are obtained.

Weiss stressed the importance of fundamental understanding of factors affecting concrete deterioration such as capillary porosity and surface tension of pore solution, and the development of mitigation strategies such as use of shrinkage reducing admixtures (SRAs) or saturated lightweight sand for internal curing (IC) to mitigate shrinkage, instead of simply reducing paste volume.

The four-step approach to durability design was demonstrated through the following:

- Determination of electrical resistivity and formation factor to estimate time to corrosion of reinforcing steel given geometry of the concrete element, relative humidity, temperature, concrete cover, etc.
- Integration of shrinkage and cracking measurements and use of probability-based shrinkage specifications to estimate risk of cracking.
- Understanding the fundamentals behind concrete deterioration associated with new deicing salts leading to the formation of calcium oxychlorides (CaOxy) and new concepts involving freeze–thaw saturation models to reach critical saturation and frost damage, including in air-entrained concrete.

Innovative Approaches

The innovative characteristics of the approach to design for concrete which ensures greater durability and longer service life from the presentation are summarized below.

- Conceptual. Promising progress was made to understanding new modes of deterioration of concrete associated with the use of new de-icing salts and pre-salt practices. More work is necessary to quantify CaOxy and develop test methods and appropriate mitigation strategies to reduce such deterioration. New insights were gained based on the demonstrated ability to predict time to freeze–thaw damage after time to reach critical saturation of concrete, but more work is needed.
- Emerging. Promising ongoing research includes additional development of specifying concrete durability and moving towards performance-based specifications from performance specifications. Development of performance specifications are starting to include consideration of variability of material composition (e.g., water-to-cement) and properties such as air content as well as variability in production issues. More work is required to integrate probabilistic approaches to concrete deterioration and to integrate stochastic analysis into performance specifications. Weiss stated that age of cracking, or time to crack determined by restrained shrinkage, should be replaced by probability of cracking. The use of simple resistivity tests and the resulting values to determine the formation factor and time to onset of corrosion is promising. This approach has been used in some bridges as a proof of concept and can be further implemented in other projects leading to further adoption. The test is simple and can potentially replace the rapid chloride ion permeability test. Life-cycle cost assessment should be used more, which could result in, as an example, extending the service life of a bridge from 25 to 75 years by increasing resistivity which is currently necessitated by a limited capital investment of about 2% of cost of project.

- Practice-ready. Use of SRA and IC that have been implemented in several bridge decks and can be used across states that were not involved initially in these projects. Such advances, new test methods, and practices should be identified as best practices for further implementation. There is, however, a need for long term monitoring of these systems. IC application has been used by Indiana DOT, the Illinois Tollway, and New York DOT. One of the challenges is that nonparticipating DOTs did not benefit from lessons learned during the project and may be starting over again.

Data Concerns and Issues

Weiss identified the following issues:

- Lack of sufficient quality data to calibrate models based on different novel test methods.
- Importance of considering variability of test results and need to develop probabilistic approach to durability specifications.
- Need for test-beds or demonstration projects that can be monitored in the long term as well as locations where data can be maintained.

Action Items

Weiss provided the following ideas for possible action items:

- Implement additional educational modules about practice-ready technologies such as webinars and certification of LCCA (possibly as initiated by ASCE).
- Consider more field validation projects in different exposure conditions.
- Integrate quality assurance–quality control (QA/QC) test results into decision-support tools and specifications.
- Consider QA/QC guidelines for plant and jobsite testing.

The primary take-away from the presentation included a greater need for structural health monitoring of infrastructure to calibrate long-term service life prediction models to further understand effectiveness of various mitigation techniques and to better correlate simple QA/QC methods for long-term durability.

Performance Engineered Concrete Mixtures for Transportation Infrastructure Repair

Matthew D'Ambrosia
CTL Group

D'Ambrosia explained that performance characteristics required for repair materials are different from those for new construction. Of special importance to repair materials are constructability characteristics including *finishability and workability retention*, *cracking resistance*, *elastic modulus*, *shrinkage*, *stress relaxation*, and *tensile strength*. Performance-based mixture design does not directly address risk of cracking and durability. The presentation discussed calcium aluminate cement (CAC) for patching of pavement where compressive strength of 2,500 psi after

4 h, 4,000 psi after 6 h, and high resistance to cracking are required. Strength development and conversion from meta-stable to stable state of CAC concrete that cause strength loss are temperature dependent. The PEM approach to use latex in CAC patching materials can secure high electrical resistivity and prolong time to cracking (ring test). D'Ambrosia pointed out the need to use a single sand given the silo limitation in mobile mixers necessitating 100% replacement of sand by lightweight sand (LWS) which can lead to deficiencies in rheological properties of concrete.

Innovative Approaches

A PEM based on CAC, latex, and LWS was developed for a concrete patching application:

- Conceptual. Promising progress was made to incorporate LWS and latex to enhance performance of this engineered repair material. Further work is needed to ensure adequate properties for longer than 5 years at different environmental conditions. The stated goal is 15 years. More work is needed to enhance robustness and processing of CAC repair materials.
- Emerging. D'Ambrosia indicated that the potential increase in use of holistic design of construction and repair materials could meet complex rheological, physical, mechanical, and durability requirements. Cost-effectiveness and robustness should also be considered.
- Practice ready. CAC materials for patch repair have been implemented. However, work is needed to address strength reduction over time at different placement temperatures and exposure conditions, understand the effect of coarse aggregate types and moisture level of LWS and sand gradation on robustness and performance, and mitigate early cracking related to large temperature changes such as rapid heating and cooling resulting in restrain.

Data Concerns and Issues

D'Ambrosia stated a need for more data about short-term and long-term field performance of CAC materials at different environmental conditions in accelerated or on-site test beds.

Action Items

He identified the following action items:

- Producers should consider taking ownership and responsibility for their performance-based mixtures.
- Installers should consider improved methods for field control of moisture content of LWS, such as simple testing with centrifuge, and enhanced robustness of CAC mixtures.
- Designers should consider designing CAC patches for service lives greater than 15 years.

SESSION 1 DISCUSSION

Observations from individual attendees are summarized below.

- Identify ways to accelerate acceptance of new test methods through organizations like AASHTO and ASTM.
  - Academic researchers are less motivated to work on standards with other organizations, such as ASTM.
  - One participant stated that it takes about 20 years on average to integrate innovation into civil engineering.
- Modify specs to promote durability and service life of construction materials.
- Consider use of electrical resistivity on fresh concrete.
  - How would the test method be calibrated?
  - This method can be used for fresh concrete but care should be taken to account for temperature, aggregate type, etc.
  - Care should be taken about factors affecting electrical resistivity such as temperature, relative humidity and alkalis leaching in curing tanks.
  - Measurement of any variability is essential.
  - Some of these factors are less variable in hardened state.
- Design experiments for large-scale testing that can integrate new test methods and approaches.
- Perform long-term performance monitoring on accelerated test beds or actual projects
- Work closely with owner agencies.
- Encourage and expand interdisciplinary work of comparing ground-penetrating radar data to Weaner probe resistivity testing to further enhance reliability of test methods.
- Establish better exchange and information systems.
  - More than one participant expressed the need for best practices of transferring research findings to minimize duplication of work in other state DOTs.
- The most common use of CAC is in fast repair where service life is limited.
  - One participant indicated a preference for service life of patches to be 10 to 15 years as opposed to 5 years because of funding constraints. This would be a consideration for PEMs.
  - Another comment related to the desire for early-age strength at 4 to 6 h versus 24 h for use of portland cement. This is important when considering costs and timing associated with traffic closures.
  - A participant suggested using dry LWS that are not presaturated to reduce workability issues associated with saturated LWS. This can be compensated for by using extra mixing water that can be absorbed into the LWS during mixing. This can enhance the robustness of the CAC concrete.

The Slow Race: Implementation of Innovations in Materials, Design, and Construction Within DOT Organizations

Tyson Rupnow
Louisiana Transportation Research Center

Rupnow indicated that, on average, it takes 20 years to implement something new or different within a DOT organization. Implementation or innovation is traditionally not seen as a priority. He offered a unique perspective on some of the reasons behind slow adoption of innovation and implementation of new materials, design, and construction technologies by state agencies.

Contributing factors include culture, laws such as use of PPPs being illegal in some states, policies, politics, and industry pushback. Also, within a DOT, multiple divisions such as planning, construction, maintenance, operations, research, intelligent transportation systems (ITS), transit, research, and others, have different priorities and needs. Implementation or innovation is also affected by a culture of conservatism, nonwillingness to own it, being told to adopt it by the research division, lack of specifications, and perceived higher initial cost.

Rupnow then identified mitigating factors that can help drive innovation. State Transportation and Innovation Council and Every Day Counts programs and other initiatives from FHWA and AASHTO can offset the perceived cost aspects of new technologies. Finding a champion that is high up in the organization such as the chief engineer, chief executive officer, or secretary of transportation to promote a culture of innovation is key for success.

Action Items

Rupnow provided the following ideas.

- Strive to identify new construction materials, design, and construction technologies that can lead to faster construction, greater safety, greater quality, or cost savings.
- Consider incorporating LCCA approach to demonstrate value-added technologies.
- Consider developing generic specifications to encourage competition.
- Promote a culture of innovation that is driven from the leadership of DOT organizations.
- Consider improving bridging silos between departments and addressing any issues in a timely manner.
- Consider incentivizing DOT employees to reduce costs, both to the project and to the organization, through innovation.
- Consider involving industry to help drive innovation and implementation.
- Consider enhancing education curriculum of civil engineering students including construction materials and latest technologies of alternative test methods, modeling, and LCCA.
- Consider expanding continuing education of DOT engineers to recognize and implement new innovations.

Accelerated Bridge Construction: National Perspective and ABC–UTC Activities

Atorod Azizinamini
Florida International University

Azizinamini offered examples on how accelerated bridge construction (ABC) can enable fast construction, rehabilitation, and upgrading of bridges. Faster construction is related to greater safety during every stage of construction, including work zone related accidents. He indicated that UHPC can be used to upgrade structural elements in existing transportation infrastructure and can be used to fill in space between precast panels in ABC construction to ensure effective transfer of stresses. At the same time, it is essential that the engineering community be proactive and take timely actions to make the transportation infrastructure resilient to natural hazards, such as storm surge during hurricanes and challenges created by sea level rise.

These challenges are important when building new bridges and repairing and upgrading existing bridges. It is essential to accomplish these tasks without compromising workers and public safety and without significantly affecting public mobility. It is also important that resulting bridges have long service lives.

One of the new technologies being developed to repair damaged bridge elements is the use of UHPC shells. This places a layer of protection on bridge elements that substantially extends their service lives with minimum maintenance. This technology can be applied to new construction and used to repair and upgrade existing bridges. In the past, service life design of bridges was secondary to strength design. Azizinamini considered that service life design should be the primary factor. Currently, one aspect of ABC-related research focuses on developing guidelines for putting the service life design of bridges in proper perspective. He indicated that if many of the bridge elements were designed for service life, the resulting strength in those members would be a bonus.

Innovative Approaches

ABC and UHPC offer new and innovative approaches to bridge construction and repair.

- Conceptual. Development and implementation of novel and sustainable construction materials and designs can enhance durability and service life and enable rapid construction through automation. The example provided by Azizinamini was ABC which focuses on repair and upgrade of existing bridges safely without interrupting traffic.
- Emerging. Among new emerging technologies are repair of damaged bridge elements using fibrous composites, such as UHPC. For example, use of UHPC shells as a protective layer on bridge elements can allow for longer service life (up to 100 years) with minimum maintenance. This technology can be applied to constructing new bridges or repairing and upgrading existing bridges.
- Practice ready. Currently two main obstacles have prevented widespread adoption of UHPC composites: workability and cost. However, workability has been overcome by using self-consolidating mixtures, and recent advancements in materials engineering have resulted in fiber-reinforced composites that are more cost-effective with improved performance. Both have been implemented in demonstration projects through UTCs and other research initiatives.

Data Concerns and Issues

While there is a growing body of research on the performance characteristics of UHPC under service conditions, Azizinamini stated that there is a lack of quality data on the long-term performance of UHPC structural elements. Having high-quality performance data is necessary to develop reliable design specifications and guidelines which is then necessary for reliable asset management. There is also a need to develop cost-effective UHPC mixtures.

Action Items

Azizinamini provided the following ideas:

- Build a larger long-term performance data-base of ABC related technologies, such as UHPC, that are used for upgrading bridges.
- Address workability and initial cost issues related to broad implementation of UHPC

technology.

- Encourage expanded use of service life design. SHRP2 *Design Guide for Bridges for Service Life* was completed and has the framework and process for quantitatively predicting service life of concrete. New opportunities are also available through FHWA's LTBP (long-term bridge performance) Program (https://www.fhwa.dot.gov/research/tfhrc/programs/infrastructure/structures/ltbp/).
- ABC–UTC at Florida International University has monthly webinars on ABC-related research and development. The webinars are a useful resource for researchers and practitioners to exchange best practices and discuss barriers for implementation.

SESSION 2 DISCUSSION

Observations from individual attendees are summarized below.

- MAP-21 required the development of asset management that will be implemented soon.
- In response to a question about use of UHPC for reconstruction of bridge superstructure, the current application for UHPC is to upgrade existing structures with the possibility of using it in thin shells for durability with the remaining construction being carried out with conventional concrete.
- Discussion between some participants re-iterated the need to concentrate on life cycle costs and to look beyond the initial capital cost. The use of UHPC for repair instead of the replacement of the structural element or structure using conventional concrete was identified as an example of evaluating life-cycle costs versus initial costs.
- A question was asked about the main barriers to implementation of new technologies. Examples from participants included:
  - A conservative culture.
  - Lack of top-down advocacy. Acceptance of innovation and implementation is highly dependent on top to bottom approach. State DOTs are motivated by safety and are conservative, such as following the Load and Resistance Factor Design (LRFD) AASHTO Bridge Design Specifications and not adopting ABC. This can slow down the process.
  - Broken promises of proposed technologies.
  - Lack of nonproprietary products. An example is that Ductal is currently the only UHPC product and is proprietary. Nonproprietary UHPCs are possible but the perception is that their use may come with larger liability.
- A participant indicated that a useful approach for research project selection for a state DOT consists of proposals that are peer-reviewed by a panel from DOT divisions with input from industry and some external faculty members to evaluate and rank projects.
- The ABC–UTC at Florida International University is maintaining a clearing house of ABC technologies which are reviewed and vetted before inclusion.
- Apprenticeship programs could enhance education of undergraduate students and promote workforce development in the transportation sector. A traditional co-op program is available through the Louisiana Transportation Research Center, which has a high retention rate of co-op students after 5 years of employment. New engineers working in Louisiana DOTD also have a 6-month rotation program to work in different sections or divisions.

BREAKOUT SESSION 3

The third session was based on presentations from the two earlier breakout sessions, breakout session discussions, the plenary session discussion from the first day, relevant poster presentations, and input from the participants.

Introduction

The underlying theme from this track is that rehabilitation and restoration activities should be driven by sound understanding of fundamental principles and data-driven asset management. While most states still use a fix-it-first approach for maintenance and upkeep of their assets, a balance between maintenance, capital, and operations is important. Research is leading to a focus on preserving, restoring, and expanding existing systems through such a balance. Using advanced tools and technologies for data-driven asset management and decision-making is at the center of these efforts.

Innovative Approaches

Emerging methods, designs, restoration, and rehabilitation techniques which contribute to extension of service life, sustainability, and resiliency were provided by individual attendees and are summarized under general categories below.

Cementitious Materials: Infrastructure

- Sustainable construction materials. Continue development and implementation of novel and sustainable construction materials and designs that can enhance durability and service life and enable rapid construction and automation. Examples include the ABC technique with the focus on repair and upgrade of existing bridges. Such approaches can promote greater safely and reduce traffic interruption. Among new technologies that have been developed and implemented in some bridges, tunnels, and other critical structures is the repair of damaged concrete elements using fibrous composites, such as fiber-reinforced concrete. Currently, two main obstacles have prevented widespread adoption of such composites: workability and cost. Workability can be overcome by using self-consolidating mixtures and super-workable concrete. Recent advancements in materials engineering have also resulted in fiber-reinforced composites that are more cost-effective with improved performance. Examples of these have been implemented in demonstration projects through UTCs and other research initiatives.
- Durability-based design. Integrate durability-based design processes and codes since a majority of structures appear to be failing due to durability. A four-step approach to integrated durability design was demonstrated through the use of simple and field-oriented test methods and fundamental understanding of governing principles leading to concrete deterioration. For example, simple electrical resistivity measurement can be carried out in the field to evaluate the formation factor to estimate time to corrosion of reinforcing steel, given geometry of concrete element, relative humidity, temperature, concrete cover, etc. Research improved durability of concrete bridge decks by mitigating cracking issues and rebar corrosion, which are the largest components of bridge maintenance costs.

- PEMs. Continue the design shift toward integrated PEMs for transportation infrastructure repair. The focus is no longer on strength but rather on durability and crack mitigation. An example is the use of CAC for patching and rapid repair. CAC gives high early stage strength (4- to 6-h strength for most patching requirements). The challenge is that strength can decrease from meta-stable to stable hydration products which are temperature dependent. Further research is needed to address early-age drying shrinkage and CAC specifications which can result in minimum scaling. Furthermore, producers will need to consider the performance of their products related to performance-based concrete. Communication and credible data are important.
- Deck joints. Continue research into deck joints. Leaking deck joints are a frequent root cause of deterioration of superstructures and substructures. Potential solutions that were identified include:
  – Short-term: timely maintenance in terms of repair and replacement;
  – Mid-term: more use of joint-less design for replaced or new decks; and
  – Long-term: better joint product development.
- Steel bridges. Consider options for improved steel bridge performance. The current coating repair–replacement work has significant negative impacts on the environment and costs.
- Protective coatings. Consider improving QC/QA practices for protective coatings during the prefabrication work in the shop and repair work in the field. According to the FHWA's 100-year coating study, performance of many legacy coating systems was superior to new coating systems when installed correctly. Consider more research and development for metallic coating systems.

Materials: Pavements

- Pavement preservation. AASHTO Materials Reference Laboratory programs have developed a pavement preservation component as part of their accreditation program to ensure acceptable practices, designs, and materials. Consider improving standardization of these components.
- Intelligent compaction. Monitoring compaction to achieve better and more uniform density. Although complicated and not well developed yet for asphalt, this approach is useful in unbound materials.
- Better density. An important development is FHWA's initiative to emphasize the importance of ensuring the field compacted density of asphalt pavements.
- Higher recycled materials. With the increased awareness of the importance of sustainability, more emphasis has been placed on using greater amounts of recycled materials to reduce landfills and minimize use of virgin materials.
- In-place recycling. Hot-in-place and cold-in-place recycling (HIPR and CIPR) are becoming more popular because they recycle asphalt pavements in-place without the need for milling and removal. Combined with thin overlays and other pavement preservation techniques, HIPR and CIPR are becoming reasonable options for low-volume roads.
- Design:
  – Performance-based designs. Consider more research and development related to developing material specifications that are tied to performance indicators such as rutting and fatigue cracking for asphalt.
  – Mechanistic pavement design. Implementation of AASHTO's Pavement

Mechanistic–Empirical (ME) design program allows users to design and evaluate their pavement structure for rutting, fatigue cracking and thermal cracking.

– Automated pavement evaluation tools. State agencies are moving towards automated distress collection during network-level pavement evaluations. Consider new NDT (nondestructive testing) technologies such traffic speed deflectometer and 3-D imaging.

Implementation of Innovations in Materials, Design, and Construction Within State DOTs

A high-level agency champion is considered necessary for research to be implemented at DOTs. Individual participants identified the following considerations.

- State DOT perspectives and focuses are widely variable. Construction and maintenance have different priorities than planning, operations, ITS, transit, and other divisions. However, all divisions rely on research.
- It can often take 20+ years to implement something new or different within state DOTs because of
  - Culture,
  - Regulations such as PPPs being illegal in some states,
  - Policies,
  - Politics, and
  - Industry pushback.

TRACK BREAKOUT SESSION 3

Rapid Repair and Keeping Things Moving

JOHN BULINSKI
Caltrans, presiding

STEVEN GILLEN
Illinois Tollway, recording

This track focused on technologies and decision tools for quick restoration of deteriorated infrastructure, while assuring network resilience during repair activities, infrastructure failures, and natural disasters.

BREAKOUT SESSIONS 1 AND 2

How the Illinois Tollway Rebuilds–Expands a Metropolitan Expressway System Using $20 Billion of Private Funding with Minimal Impact to Daily Commuters

Paul Kovacs
Illinois State Toll Highway Authority

Kovacs summarized how the Illinois Tollway has rebuilt, expanded and re-retrofitted much of its expressway infrastructure through multibillion dollar capital programs over the last 14 years with minimal impact to the traveling public during construction operations using many new innovations supported by research. Important elements that he covered included factors that contributed to reduced traffic impact before the start of construction, which included planning, design and maintenance of traffic strategies. He also summarized innovative construction processes that the Tollway implemented to minimize traffic impact or to expedite work on reconstructed, newly constructed, and rehabilitated roadways. Reference was given to the design and construction of SmartRoad corridors to keep traffic moving better after construction.

New material and construction initiatives, many that were developed by recent or active research, were highlighted for application to the near future I-294 expressway reconstruction and widening project to further reduce traffic impact. Kovacs discussed important considerations during the planning, design, and construction phases of an urban roadway project. Figure 1 summarizes the important research innovations applied by the tollway that contributed to a more-sustainable reconstruction–re-retrofit project. He also articulated the economic and environmental benefits resulting from the many innovations used by the tollway that allowed for projects to be built greener, faster, and with less impact to traffic.

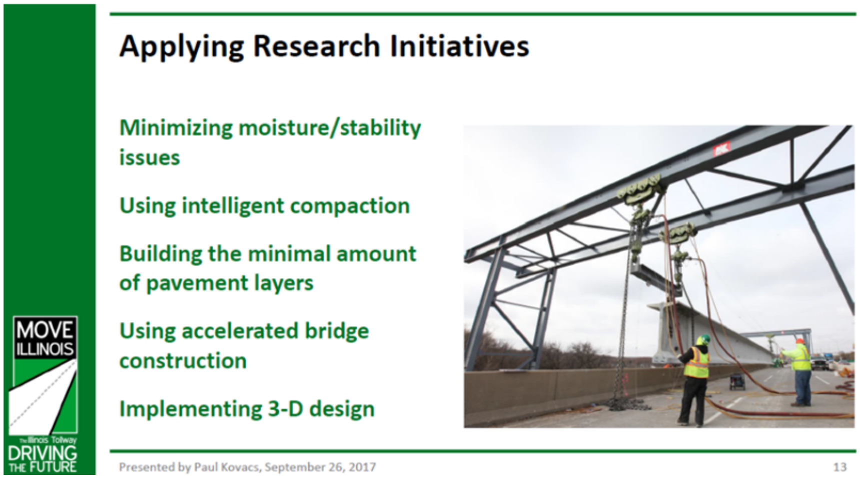

FIGURE 1 Important research initiatives.

Illinois Tollway Life-Cycle Assessment: Tool Development and Implementation

William Vavrik
Applied Research Associates, Inc.

Vavrik initially noted how research and cost savings were the catalysts for the tollway to develop a sustainability program as their massive capital programs proceeded. He followed with examples of material engineering initiatives and cost savings. A measure of environmental benefits was needed for the program, which resulted in the tollway's development of a sustainability rating system (INVEST) and the life-cycle assessment (LCA) tools through the University of Illinois and Applied Research Associates.

Vavrik then discussed how the LCA tools were developed. He discussed the use of pay items and related data that were used in the tools to calculate greenhouse gas emissions for the life of a roadway. The Tollway's reconstructed and widened I-90 corridor was used as an example of how gas emissions from construction were significantly reduced compared to older baseline projects of similar size. He closed with detailing future plans for the Tollway to use the LCA tools.

Data Concerns and Issues

Issues raised by Vavrik included the following:

- Monitoring or procedures for measurement need further development for performance related specifications (PRS).
- Data control or web based data management systems need to become more widespread for implementation of PRS.
- An LCA rating system that uses data to determine sustainability scores for various methods and materials is needed.

SESSION 1 DISCUSSION

From the first presentation, a participant asked about educating the contractor on the many new initiatives applied to rebuild with minimal traffic impact by the Tollway. The response was that most of the new initiatives and related specifications/policies supported by research are discussed and developed in collaboration with the related industries from concept to implementation and that meetings with the industries are frequent.

Kovacs also clarified that maintaining the same number of traffic lanes that existed before reconstruction or re-retrofitting was because the Tollway is a user fee system that must satisfy the customer and not lose revenue. This policy applies to all projects. Little if any cost impact was seen by maintaining the same number of lanes in the projects discussed. He did state that it is easier to do this with full paved shoulders on both sides of the road.

After the second presentation Vavrik indicated that weigh-in-motion data and geotechnical data are heavily used to provide the optimum design for the planned future 50- to 70-year life of any new roadway.

Innovative Approaches

The following initiatives were identified by individual participants during the discussion after presentations 1 and 2 along with their estimated status where appropriate.

- Development and implementation of LCCA programs for
  - Bridges: conceptual/emerging,
  - Pavements: practice ready, and
  - ITS elements: conceptual.
- Development of PRSs for
  - Materials: emerging,
  - Construction of concrete pavements: emerging,
  - Construction of asphalt pavements: conceptual, and
  - Structures: emerging.
- Development and application of innovations for expedited construction for
  - Reconstruction including intelligent compaction, stabilized subgrades, and accelerated bridge construction.
  - Rehabilitation including precast pavements, HES concrete mixes that are durable, and warm-mix asphalt.
  - Design including 3D design modeling and reduced pavement layers with optimal thicknesses with a roadway design.
- Implementation of PPPs and design–build contracts where feasible: practice ready.
- Incorporation of traffic engineering for better barrier systems and incident management: emerging or practice ready.
- Design of smart roads to accommodate automated vehicles: conceptual and emerging,
  - For dedicated lanes,
  - With better contrast pavement markings, and
  - With embedded sensors.
- Development of LCA tools to measure the environmental pillar of sustainability for a constructed roadway, conceptual to emerging.

Rapid or Overnight Renewal of America's High-Volume Roadways Using Innovative Precast Concrete Pavement Technology

Shiraz Tayabji
Advanced Concrete Pavement Consultancy, LLC

Tayabji started with an explanation of why precast concrete pavements are critical to use and develop for rehabilitation or with new construction in urban environments under heavy traffic for long-term pavement repairs with minimal impact to traffic. He presented several case studies along with examples of where and alternatives of how to apply the concepts. Fabrication and construction factors were highlighted for the different precast systems that have been developed to date.

Near the end of the presentation, Tayabji focused attention on costs and performance of precast pavements. In the summary, he mentioned that the technology is ready for widespread implementation and that even though experience with such systems is limited, easy training allows for inexperienced contractors to quickly learn how to install panels overnight successfully.

Data Concerns and Issues

After the presentation, the following points were raised by individual participants.

- A concern of contractors is that high early strength (HES) cast-in-place (CIP) concrete is not considered durable and more research could address this concern.
- This concept was developed independent of academic input or research, but there is room for research in developing the concept further.

Action Item

One participant thought that working with academia to develop the following research opportunities would be helpful:

- Include instrumentation for data analysis and optimizing panel configurations.
- Identify applications for continuously reinforced concrete pavements.

Accelerating Construction Using Prefabricated Bridge Elements Connected With Ultra-High-Performance Concrete

Gregory Nault
LafargeHolcim–Ductal

Nault defined UHPC and stated that it is manufactured as a proprietary product (Ductal) by LafargeHolcim. He then focused on successful applications and case studies for typical uses of UHPC to expedite structural construction. How the product is produced, controlled, and commonly placed for typical applications was then covered followed by unique applications that contribute to more rapid construction. Physical properties of the UHPC product that make it unique include high strength, flow, and early age strength gain and were described in more detail. Nault then summarized the applications of UHPC for ABC and provided numerous references, workshops, and webinars where more detail for applications could be obtained.

In response to a question about cost, Nault stated that mobilization and material costs were the primary contributors to high costs. He also indicated that many alternative sources are currently developing UHPC.

Data Concerns and Issues

His primary concern was a lack of information about the product's long-term performance.

SESSION 2 DISCUSSION

The following innovations were referenced by individual participants during the discussion after presentations 3 and 4 along with their estimated status where appropriate.

- UHPC: emerging and practice ready.
- Better resiliency through more rapid repair techniques, ABC structures, and with techniques for reconstruction or repair during extreme weather conditions: emerging or practice ready.
- 3-D modeling for pavement design:
  - Sharing data from the design concept through construction: practice ready;
  - 3D printing: emerging; and
  - Robotic maintenance: conceptual.
- Precast pavements for
  - Jointed pavements: practice ready; and
  - Continuously reinforced concrete pavements: emerging.

BREAKOUT SESSION 3

The questions that were presented to participants were (1) What are the initiatives or innovations that need research support or implementation support that were most important relative to the theme of the track or workshop; (2) which of those initiatives are of the most importance to focus on; and (3) what was identified as knowledge gaps or barriers to getting these initiatives implemented.

Introduction

Because the theme of this track was very broad, participants initially listed initiatives that individuals considered as needing research support to promote implementation at some level. Many of the topics or ideas related to specific innovations or to broader subjects where numerous technologies could be applied.

The focus then shifted to considering gaps or barriers relative to the many technologies that relate to the design and reconstruction or re-retrofitting of pavements and materials so that the traveling public gets the most of what they pay for both during and after construction.

Future Research Topics and Goals

Specific ideas from individuals that are ready for implementation but could be expanded with additional research are followed by general subjects compiled from individual ideas.

Specific Ideas That Could Be Expanded With More Research

Many of the ideas such as LCCA programs, PPP projects, design–build and A + B contracting, UHPC, and HES concretes, and precast paving systems are, for the most part, ready for implementation but still have room for research and deployment support. For instance, objective LCCA programs have commonly been applied for new pavement designs but have not yet been developed for structures or other areas of transportation like ITS. A participant mentioned that HES concretes have been developed and implemented but need more research to improve the durability of such mixes. Another example was precast pavement systems that have been developed for the rapid repair of jointed concrete pavements but have not yet been developed for continuously reinforced concrete pavements.

Other initiatives that were mentioned by individuals included:

- Development of performance specifications that
  - Contribute to the application of design-build contracts and PPPs,
  - Promote innovation by the contractor as opposed to coming from the agency, and
  - Promote more data measurement and control technologies be developed for both materials and construction.
- Traffic engineering research as an area that could benefit from improvement of barrier systems for both permanent and temporary traffic as well as for better incident management on high volume roadways.
- Design of roadways to accommodate automated vehicles would require pavement markings with better contrast and durability as well as a need for pavement embedded with wireless sensors.
- Resiliency requires more rapid repair techniques, new standards for ABC bridge design–construction, and better materials or construction techniques that can be applied during extreme weather conditions.
- 3-D modeling, printing and robotic construction.
- Development of sustainability measurement tools.
- Development of pavement–bridge design standards to account for higher freight loads anticipated in future years.

General Subjects and Related Technologies

Participants were asked what topics could benefit the most from research or further development relative to the conference theme, and which need the most focus for implementation. Three general areas were readily identified with ideas offered by individual participants.

Expediting Construction or Rehabilitation

Expedited construction–rehabilitation was one of the themes that emerged and included references to and discussion of many individual technologies such as:

- Intelligent compaction for earthwork, unbound aggregates, roller-compacted concrete, and asphalt pavements;
- Deployment of stabilized subgrade soils;
- ABCs;
- Precast pavements;
- Improved HES concretes;
- 3-D design modeling;
- Better development of warm-mix asphalt processes; and
- Designing a roadway with reduced layers.

One participant noted that speed of construction can be used as a cost saver for innovations that are applied for the purpose of expediting construction without sacrificing quality.

Developing and Deploying Life-Cycle Cost Analysis Programs

Mention was made that objective LCCA programs have been developed and applied widely for large-scale pavement construction and rehabilitation projects, yet more research and deployment is needed to develop similar programs for bridge structures and for other new technologies being applied to transportation. A participant noted that LCCA systems for bridge structures are, for the most part, subjective related to data input and would benefit from development of more data and measures for better decision-making. An example of an emerging technology that needs the development of an LCCA program is the area of ITS.

Expanding Development and Implementation of Performance-Related or -Based Specifications

A participant indicated that basing specifications on performance induces more innovation and makes the application of design–build contracts more attractive to the contractor, especially for larger-scale projects. Another comment was made that performance specifications are emerging, especially relative to concrete materials and concrete pavements, but that performance specifications for asphalt materials and construction and the technologies needed to measure performance are in the conceptual stage for the most part.

Additional technologies like web-based data management systems, tools for performance measurement, and more efficient material data bases were noted as important to improving implementation. Reference was made to the successful implementation of performance related specifications by the Illinois Tollway for jointed concrete pavement construction and for concrete mix designs. As a result, the tollway is developing performance specifications for continuously reinforced concrete pavements and for asphalt mix designs currently in the conceptual stage by tollway researchers and consultants.

Barriers

Individual input was grouped into the following general categories for barriers or gaps. Each category includes ideas from individual participants. With the many initiatives or ideas that were noted during the session that warrant the need for more research, there were many suggested barriers or knowledge gaps also mentioned by participants. Many of these were general that apply to overall implementation of any transportation related technology, while others were related to specific innovations that could use attention of some kind for more rapid deployment.

Deployment of Innovations

Mention was made that implementing any innovation would benefit from leadership at the U.S. DOT providing clear guidance to its administrations and state DOTs about improving the process for deployment of that innovation and measuring its effects. A participant suggested that too many barriers exist at every level of government due to federal regulations or rules, at FHWA division offices due to lack of education about deployment of innovations, and most predominately at state DOT's due to the fears of change and lack of the same education. A participant commented that division offices have to comply with multiple regulatory requirements when approving or evaluating state projects with innovative elements while state DOTs are often unwilling to use a federally funded project as a research test bed because of the need to preclassify those projects as an experimental feature project which could delay the project or potentially result in losing funding if the designation is not provided.

Communication

Another barrier that was identified by more than one participant is a need to better educate the public, politicians, designers, agencies, and industries about the innovations and their benefits. A comment was made that too often state DOTs reinvent the wheel by researching innovations that have already been proven successful or adopted by other states. Asphalt-related technologies were given as an example. More provisional standards, specification templates, or more use of available databases on previous research were suggested as ways to prevent this. Another comment was that education about the importance of innovation should start at the top of a transportation agency and work its way down while the education of specific innovations might have to start at the bottom of an agency and work its way up. More webinars and seminars through UTCs on deploying or educating others on new specific initiatives was one idea.

Collaboration

Better collaboration between contractors, suppliers, agencies, consultants, and researchers is important to the development and deployment of innovation. The importance of the need for getting all parties to collaborate on using the roadway or production yard as a test bed for new transportation related innovations and getting researchers involved with a study to use field applications as their laboratory in collaboration with industry or agency was discussed. Design–build contracts were mentioned as a good means to encourage better collaboration between parties which in turn encourages innovative practices. Another idea to promote innovation through improved collaboration was to involve the consulting world more directly with agency practices and with academia research projects, especially relative to pavements and structures. A participant provided the following maxim that "you can't try what isn't specified instead of you can't specify what you don't try" is followed too often.

Bidding or Contracting Process

Including the value of innovation combined with the value of time into agency contracting procedures was identified as a way to overcome the barriers associated with lowest capital cost accounting. Individuals also identified including more performance specifications in contracts, using more design–build contracts, implementing more PPP projects, and using A+B bidding more often as methods to reduce this barrier to innovation. With design–build contracts it was mentioned that the time element for construction needs to be emphasized more.

Specific Innovations

- One participant noted that the predicted service life of structures needs to be understood and better quantified for objective LCCA and for LCA programs to be developed. In response, a comment was made that UTCs could help with data collection from multiple agencies which could then be used to develop more accurate service life projections of bridges and pavements needed for LCCAs as well as for performance specifications.
- Current performance measurement is resource intensive. More research for methods that are cost-effective and easy was emphasized as an important need for performance specifications to be developed.
- It was mentioned that the UTCs should consider developing a unified format for technologies (like precast concrete pavement repairs) and evaluate the risk of deployment based on each states' individual circumstances.
- Accurate monitoring sensors for pavements and bridges was noted as a gap that needs to be filled to make performance easier to measure and to adequately implement automated vehicles in the future.

TRACK BREAKOUT SESSION 4

Managing the Assets

SHAUNA HALLMARK
Iowa State University, presiding

SUE MCNEIL
University of Delaware, recording

This track focused on strategies and tools for tracking and managing infrastructure assets to ensure the long-term preservation of transportation infrastructure.

BREAKOUT SESSIONS 1 AND 2

Asset Management Plans: Improving System Performance—Are We There Yet?

Butch Wlaschin
Federal Highway Administration (retired)

Wlaschin began with the definition of asset management, the concepts involved, including the ties to life-cycle cost and managing the assets over the long term, and the elements of a risk-based asset management plan (AMP). He focused on the elements of the transportation AMP (TAMP) and the six requirements, listed below, that are aimed at moving the numbers toward better performance:

1. Collecting, processing, storing, and updating inventory and condition data for all National Highway System (NHS) pavement and bridge assets.
2. Forecasting deterioration.
3. Determining the benefit–cost over the life cycle of assets to evaluate alternative actions (including no action decisions), for managing the condition of NHS pavement and bridge assets.
4. Identifying short and long-term budget needs.
5. Determining the strategies for identifying potential NHS pavement and bridge projects that maximize overall program benefits within the financial constraints.
6. Recommending programs and implementation schedules to manage the condition of NHS pavement and bridge assets within policy and budget constraints.

He stated that deadlines for submitting plans are April 30, 2018, for the initial TAMP, and June 30, 2019, for a fully compliant TAMP. His closing assessment related to the question asked in his title was “We are not there yet!”

Innovative Approaches

TAMP offers an opportunity to integrate innovative approaches including the following.

- Keep good roads good!
- Getting everyone from upper management to field staff on board.

Data Concerns and Issues

As this is a data driven process, Wlaschin indicated that one of the challenges is measuring success. Similarly, challenges exist with determining what is meant by "good roads."

Action Items

Several questions remain unanswered including the following:

- How can bridge and pavement systems be addressed in the TAMP? What are minimum acceptable standards?
- What are risk-based plans?
- How is data used to make longer-term strategic systems?

Gaps

Because the TAMP process has not yet been implemented, many uncertainties exist and will become more apparent as the process proceeds. Some that Wlaschin identified include:

- Technical gaps include infrastructure condition, whole-life planning, risk management, finance plans, and investment strategies;
- Change of culture;
- Implementation;
- Updating; and
- Training.

Implementing a Transit Asset Management Program at a Legacy Transit System

Laura Zale
Southeastern Pennsylvania Transportation Authority

Focusing on SEPTA's AMP, Zale provided background on SEPTA including its size, responsibilities, and history. SEPTA is a data-rich environment. Recognizing the challenges in using this data, the asset management program was born. As part of its development, it included a process assessment. The strengths of the plan are that maintenance practice is well defined and key performance indicators were developed. However, gaps include different practices, granularity for different units, and areas where data are collected by other units.

Zale indicated that software proved to be an enabler. Selection of the underlying process was based on compliance, ability to use existing processes, experiences in other agencies, flexibility, and capacity to build on successes. Condition data of vehicles and infrastructure feeds into the SGR database, which informs capital planning and implementation. Ultimately implementation will feed back into inventory. Examples of the benefit of the program include coordinating projects during an outage, addressing reliability and safety concerns, and addressing systemic problems.

In summary, Zale stated that SEPTA is well positioned to meet compliance.

Innovative Approaches

She identified the following innovative approaches.

- Structuring the process and
- Developing a data-driven process.

Data Concerns and Issues

She also raised the following issues.

- Lots of data but the challenge is how to use this data in a productive way.
- Data are sometimes collected by other units.

Action Items

Action items included:

- Integration of the process into the inventory component of the National Transit Database reporting.
- Completion of the AMP.
- Making collection of data an integral part of the project deliverable.
- A simplified estimation of expected life is currently used to make decisions. This will become more sophisticated over time.

SESSION 1 DISCUSSION

The discussion consisted of participants sharing observations related to their experience with asset management.

When considering transit versus highway, one participant brought up the point that transit was originally behind in effectively using data but now highway is lagging. Perhaps the highway industry could consider what the transit industry is doing including:

- Tools used by the transit industry go beyond inventory. These tools should be made widely available.
- The industry could become more forward looking.

The discussion focused on the fact that the historical context makes the implementation different. Tools are out there but there are many constraints in implementation.

From a Class I railroad perspective, a participant indicated that railroads learned the importance of asset management in the early 1980s as they paid for deferred maintenance. The rail asset management structure has evolved over 40 years from level 1(collecting the data and responding based on thresholds) to level 2 (developing and using track indices), and finally to level 3 (forecasting to help plan for the future needs). Their next stage is incorporating big data into the process to more effectively support broader strategic decisions.

One important observation is that the railroads are driven by their profit margin, so this is a direct incentive to innovation. Toll roads have a similar incentive but public-sector organizations have to also be driven by the desire to serve customers.

Another participant explained that decentralization is a real problem in the highway industry. There is extensive data from multiple sources and across all divisions and functions but the industry is not yet able to use it effectively. There is also a cultural aspect in that data is not used for feedback. For instance, agencies may collect data and do projects yet in the end it is frequently left to the engineer in the field to decide how to allocate resources. As a result, there is often a focus on poor and structurally deficient bridges rather than attempting to allocate resources using a data-driven approach. Additionally, there are more than 30,000 owners of bridges and roads in the United States and as a result, it is difficult to get a consensus.

An interesting anecdote was shared by a participant about airports that also indicates the diversity of responsibility: An interesting anecdote was shared by a participant about how airlines pay for the terminal while the authority pays for pavement at the airport through public funds, indicating the diversity of responsibility.

Other observations by participants included:

- Keeping water out of the pavement is an important engineering function but is not going to be the answer for all asset management activities. Asset management needs to recognize the diversity of actions.
- Timeframes are tricky. For example, the metropolitan planning organization has a 27-year timeframe.
- It is important to recognize that different locations have different problems.
- Start small to avoid trying to do everything. Avoid getting down in the weeds.

Data Concerns and Issues

The following questions and observations were raised by individual participants about data and related issues.

- Big data. What role does big data play?
- Data analytics. How does the industry effectively incorporate data analytics?
- Additional highway data. Data is often not available in areas other than pavements and bridges. Other areas include lighting, culverts, signs, and guardrails. This is driven by where the money is spent.
- Performance-based data collection. Consider basing data collection on the last data collected such that more data is collected if the performance is poor. Examples include:
  - Transit uses different frequencies by type of asset.
  - For highways, the Highway Performance Monitoring System data collection has

changed in response to what is needed.
  - Original NBI data was focused on safety not decision-making. The bridge data collection has fundamentally changed.
- Automated data collection. There is no consistency in how automated pavement data is collected.

Action Items

Individual participants identified several areas that they thought may warrant further action.

- Consider expanding research in the use of available data for long-range planning.
- Consider documenting existing processes and data before the legacy knowledge base is lost to retirements or when data becomes inaccessible or unusable.
- Consider expanding research in relating currently collected data to performance-based measures. An example is determining whether International Roughness Index can be used to evaluate potential life of pavements.
- Build on experience gained in the transit and rail industry to come up with standardization in data collection and projection.
- Consider documenting lessons learned or case studies within and across modes for effective asset management and its uses.
- Consider documenting best practices, lessons learned, or case studies about collection and use of data considering the following:
  - Understanding the use cases for data.
  - Identifying the right data.
  - Determining the best way to collect the right data.
  - Processing data includes new methods, new relationships, and quantity. For example, video is useful for derailment analysis, which uses unique techniques for processing and analysis of video.
  - Use for risk-based decisions.
  - "Data is the new oil." How is data converted to information?
  - Update models without having to store all the data (machine learning).
  - Business process change (right data, right accuracy, etc.).
  - Data standards and regulations and links between them.

Asset Management and Resilience: Connecting the Concepts to Building and Rebuilding Decisions

Sue McNeil
University of Delaware

McNeil explained that resilience is receiving a lot of interest but there is currently no consensus on its extent or context or how to measure it. Two examples, one at the project level using pavement condition and capacity, and one at the network level using additional travel time and vehicle miles of travel were used to illustrate how difficult it is to interpret these measures. Both examples were based on floods: the first on recurrent flooding in Delaware and the second on the flooding due to Hurricane Matthew in North Carolina. Different resilience measures demonstrated that the measures are difficult to interpret and connect to decisions. The presentation concluded with several questions.

- How do state, regional, and local governments operationalize the concept of resilience?
- What measures do they use, how do they interpret the measures, and how do they use the measures of resilience?
- What does resilience mean for life-cycle cost?
- Is resilience just another level of service, or performance measure?

Data Concerns and Issues

Computing resilience is a data-intensive process. In the illustrative examples, the data used are realistic not necessarily real. One of the challenges is to balance the need for consistent, accurate data, and computational intensity with the precision needed to making decisions.

Action Items

McNeil identified the following items:

- Identify simple rules.
- Consider the difference in resilience before and after an event.
- Consider how resilience relates to and with development and economic growth.
- Consider the need for standards for resilience.
- Establish the links between resilience, vulnerability and risk.
- Consider case studies for resilience associated with disasters and disruptions other than floods.
- Consider ranking methods to capture relative importance of assets as they relate to the network and to the users. Should one measure be cost–benefit?

SESSION 2 DISCUSSION

The discussion mostly centered on what resilience means. Participants identified several contexts including:

- Seismic and climate change resilience.
- Resilience includes flexibility and redundancy.
- Resilience goes far beyond transportation: energy, commerce, etc.
- The addition of resilience in the FAST Act was in response to concerns related to climate change.

Concerns about how "resilience" is used included:

- Is resilience an appropriate metric? It is just one metric that can be used in a multi-attribute decision-making process. Applying benefit cost analysis can provide important context, as can performing scenario analysis to support the decisions.
- Concern was expressed about pitting one asset against another based on resilience.
- Consideration of a range of alternatives with a focus on critical infrastructure was raised specifically with respect to consideration of redundancy

The question of how to get different organizations involved in resilience was raised and it was stated that National Institute of Standards and Technology had established an interagency working group. There is also the National Academy Resilience Roundtable.

Action Items

In addition to the action items identified from each presentation, participants offered the following:

- Establish working definition(s) of resilience;
- Consider developing performance measures and standards;
- Consider assembling studies of past events and case studies, with lessons learned;
- Consider defining methods to quantify impacts of disasters and disruptions; and
- Consider forecasting.

BREAKOUT SESSION 3

This session opened with a call to each participant to provide input about potential needs and solutions tracking and managing infrastructure assets to ensure the long-term preservation of transportation infrastructure including research and education needs. The comments were generally grouped based on the technical aspects of assets, data, and education. Each bullet represents the input from an individual participant.

Technical Considerations

- Presentations in Session 1 suggested that the highway side of asset management is not as comprehensive in identifying needs and seeking allocation of resources as transit. The transit industry has been more progressive, particularly for capital improvements despite its late start. A consideration is how to go beyond tabulation of assets, considering funding constraints and funding prioritization. Both industries still have opportunities for improvement recognizing their different structures and constraints.
  - Research: Consider research that crosses all asset classes and seeks a global optimal solution. For example, transit could consider operating and maintenance as well as capital costs.
  - Education: Is undergraduate curricula addressing these issues?
- “The future is not what it used to be.” The focus should be on current management and mix of assets but with consideration for the changing system such as the introduction of automated and connected vehicles. These changes will cause a significant disruption and many

of the assets will potentially become obsolete.

- Several questions face practitioners.
  - Will pavements and bridges have to be designed or retrofitted for different vehicle loads?
  - How will big data affect the process? How can data be combined and mined appropriately?
  - How do innovations and changes translate into a new "system"?
  - How can today's data be used for making decisions in the context of tomorrow.
  - What is the interface between data and decisions?
- With the imminent TAMP requirement, it is unclear of the role of risk in the process. Having a better understanding of risk and methods to quantify it could be very useful in not only fulfilling the requirement but in effectively using it for decision-making.
- The picture is not as bleak as it seems per below.
  - Some states are doing extensive analyses.
  - The next step is to optimize over a longer period.
  - Work is being performed on cross-asset trade-offs.

Gaps include migrating from short-term analysis to a longer term; a need for related data and models; integration into life-cycle planning; implementation of technologies; understanding return on investment; and understanding and prioritizing to meet future needs

Data

- Realistically, approximately only 20 years of good data is available for bridges so it is difficult to model deterioration over the life of a bridge. Consideration should be given to better understanding treatment options and using real data based on actual costs which, in turn, requires better cost data. Initial TAMPs will identify more needs.
  - Education: The education system does not cover maintaining assets.
- A challenge is integrating new data with existing data and processes as well as identifying new data needs. This should be based on an established criteria so that resources are allocated most effectively.
  - Education: Educating the workforce should be a shared responsibility. An example of a useful elective is Construction Economics.
- A gap exists between complexity of models and what DOTs want. This often includes an imbalance between data that is currently collected and historical records. This provides opportunities for data analysis and data mining as well as introduction of new technologies.

Education

- Hiring and maintaining an educated workforce is important. Educational challenges are broader than just universities.
- Although undergraduate students can use elective courses to expand on the core curricula, they are typically uninformed about what would be beneficial. Providing guidance associated with the broader context of technical requirements could inform the incoming workforce. Summer internships also provide good opportunities.
- Many universities have relationships with their DOTs to provide internships or other

opportunities for students to work within the DOT.

- Experiential learning for students is a useful educational tool. However, not all students have the option to participate in internships or summer jobs. Are there creative ways to scale the experience to make it accessible to a broader student population?
- Because vast quantities of data are now readily available to students without filters or vetting, they should be educated in discovering where the data comes from, why it was created and what its intended use is before using it. Teaching students to question data quality is important.
- Critical skills, such as understanding and making good assumptions, fact checking, ground truthing, and checking results to see if they make sense in the context of the problem, are more important than ever in today's information rich environment.
- Areas for additional education include data (critical thinking), data mining, constraints of existing infrastructure, and durability (how materials change over time).

Innovative Approaches

Individuals identified the following innovative approaches.

- Transport for London's work on optimization and
- Partnerships between UTCs and DOTs for workforce development.

Data Concerns and Issues

Several individual participants brought up a recurring concern about adding context to data including data people talking to decision-makers.

Action Items

A participant stated that we should consider what we already have by synthesizing research, projects, lessons learned, best practices, etc., and making it consumable.

Plenary Session

PLENARY SESSION

What Did We Learn?

KATHLEEN HANCOCK
Rapporteur

The presiders of the four tracks presented the critical outcomes from the presentations, discussions, and posters associated with their individual tracks as well as what they heard throughout the conference, specifically focusing on what was considered important, feasible, and useful to participants.

TRACK 1: HOW ARE WE DOING? CONDITION ASSESSMENT AND EVALUATION

Sreenivas Alampalli
New York State Department of Transportation

Alampalli indicated that the past several years have been very dynamic resulting in a daunting task for agencies, industry, academia, and researchers to keep up with the changes in technology and what is happening from the inspection and data perspective in the DOTs.

He provided the following points from Track 1.

- Decision-making should drive everything else that is done. The perspective should be providing better value to the user—the public—not to an owner, industry, or researcher.
- Top-down guidance and bottoms-up implementation co-exist and are interrelated, and should be recognized and cultivated.
- Establishing a base level of knowledge and then ensuring that the user is educated about that level is important to the future.
- Moving to more systematic use of LCCA and performance-based design will improve asset management and decision-making.
- Sensors and related technologies currently exist and provide the quantitative basis for the decision-making process. The field continually evolves and it benefits the industry to stay abreast of the changes. Case studies are a useful way to communicate both existing and evolving capabilities.
- Use and integration of multiple technologies such as visualization, virtual reality, axle data testing, 3-D modeling, etc., is important for current infrastructure assessment and has great potential for future prediction capabilities.

TRACK 2: REHABILITATION AND RESTORING THE CURRENT SYSTEM

Ali Maher, *Rutgers University*

Maher presented the following points from Track 2.

- Restoration and rehabilitation need to be driven by sound engineering principles and data-driven asset management. While most states use "fix it or preserve it" first for maintenance and upkeep of assets, it is important to maintain a balance between maintenance, capital, and operations. The direction is toward preserving, restoring, and expanding existing systems through such a balance.
- Using advanced tools and technologies for data-driven asset management and decision-making should be central to agency decisions and activities.
- There are a number of emerging methods, designs, and techniques that would contribute to extension of service life, sustainability, and resiliency.
- Implementing research at DOTs requires a high-ranking champion from the top. DOT perspective and focus is widely variable consisting of planning, construction, maintenance, operations, ITS, transit, and other divisions. However, the need for research is common across all the groups. On average, it takes 20 years to implement something new or different within DOTs due to cultural issues like regulations, policies, politics, industry pushback, and so on.

In response to his comments, participants offered the following thoughts.

- An example of the first point was provided related to bridge engineering. One participant stated that the main challenge is the high cost of maintenance. The focus from the beginning should be directed at service life design of the bridge and not durability of concrete, as is now being done for pavements.
- Another participant stated that understanding why bridges are being taken out of service would allow DOTs to address the specific issues causing them to be removed instead of considering one bridge at a time.
- Technology transfer was raised by two participants. The first indicated that if an innovation strategy had undergone an acceptable level of testing in one state, it could then be promoted more broadly. The second encouraged advertising and expanding awareness and usefulness of master research and technology transfer databases.

TRACK 3: RAPID REPAIR AND KEEPING THINGS MOVING

John Bulinski, *Caltrans*

Bulinski divided his discussion into tenets and barriers. He provided the following points from Track 3 under these categories.

Tenets

- Develop and institutionalize an incentive-driven performance-based specification. Some exist and are being used by some DOTs.
- Implement an LCCA approach and standardize the practice so that the true cost of projects is known, along with all its individual elements, from beginning to end. This includes formalizing a definition of life cycle, particularly for systems that may not have a foreseeable end such as bridges and pavements and for elements like ITS.
- Expedite delivery and construction. For design, the benefit is to reduce support costs

when projects are delivered faster. One option is using alternative delivery methods where possible, such as hybrid or design–build, PPP, construction manager–general contractor, etc. The benefit of the latter is that the construction manager is engaged early in the process which facilitates the introduction of innovation. Another option is incorporating some of the accelerated repair techniques.

- Educate new and current staff. In addition to the more traditional aspect of education and training for existing staff, it is often more important to unlearn what has been done so that new approaches can replace outdated or less effective approaches.

Barriers to Innovation

- Change is difficult.
- The need to identify risk associated with innovation and implement strategies to address those risks.
- The catch-22 that is encapsulated in "we can't specify what hasn't been tried and we can't try what hasn't been specified".

TRACK 4: MANAGING THE ASSETS

Shauna Hallmark, *Iowa State University*

Hallmark presented the following themes that evolved from Track 4 discussions.

- Synthesize what has been done and coalesce information about technology, tools, and data. Educate academics, practitioners, and decision-makers about what is available before reinventing it, to reduce potentially wasted resources on things that have already been developed. Communicate the resulting information.
- Perform a comprehensive look at asset management and develop as comprehensive a plan as possible that encompasses all needs and all assets with the understanding of budget and funding constraints as well as operational life-cycle costs.
- Consider the long-term management of assets and obtain the necessary data to support long-term modeling and decision-making.
- Ensure that those who use data connect with those who collect data. In particular, users should understand data quality and applicability.
- Understand risk and uncertainty (which are different) as they relate to asset management and develop methods to quantify and incorporate them into the asset management process and decision-making.
- Expand education to include:
  - Understanding asset management and asset life cycle including their impacts.
  - Understanding data. Students have ready unfiltered access to unvetted data which they use without understanding its source, quality, or context.
  - Educating nonengineers about the value of engineering.
- Inform agencies about the incorporating technology including benefits and lessons learned.
- Look to the future. Agencies face many questions including:

– What is the impact of connected and automated vehicles? How will they affect asset management?
– What is the impact of generational shifts and the corresponding changes in user requirements?
– How do agencies make decisions when the whole transportation system may change?

Implementation Panel

IMPLEMENTATION PANEL

Where Do We Go From Here? How Can We Make Things Happen?

The panel was charged with thinking broadly about big opportunities that they heard during the conference with the goal of moving these forward and implementing ideas that were ready. They were also encouraged to think about why these opportunities are important. Each panel member addressed this charge from a different perspective.

Jason Weiss, *Oregon State University*

Weiss presented observations under the following categories.

Life-Cycle Assessment

The transportation design industry has done a good job over the years of developing codes and design processes that consider structural loads and structural system design for pavements and bridges. However, this is not as true for the consideration of the durability or service life of infrastructure elements. While it is useful to see that some empirical tests are now being used to consider more than strength in concrete mixture design, we need more than individual tests or empirical-based modeling to unravel what is happening over the life of transportation systems and their interrelated components. We have an opportunity to usher in new mechanistic models and innovative tests that can aide in attaining longer lasting infrastructure.

While substantial time is spent on deterministic assessment, it is the variability in the quality of materials and construction that is a primary driver in life-cycle assessment analysis. When evaluating why one bridge fails but another does not, performance specification models or service life models demonstrate that variability is critical. Understanding how we can reduce variability is currently not well understood or rewarded in construction specifications. How do we associate quality control procedures with reductions in variability and reward corresponding improvements?

Value-added materials are typically not selected for use based on simplistic initial cost analysis; however, many of these value-added materials or systems have the potential to reduce total costs over the life of a component or more broadly across systems. Understanding and assessing life-cycle costs of an element from design through asset management would allow us to more effectively evaluate the impact of changing 20% of our bridges to be internally cured or to be built using ABC construction or using more precast panels.

Integration

Attendees of this conference focused primarily on individual areas; specifically, materials, bridges, pavements, asset management and sensors, and, unfortunately as a profession, we mostly stayed in these silos. One of the challenges moving forward is that real progress will only occur when these silos become integrated. For example, sensors being used for more than one function are vital. This could include sensors that help the contractor with construction operation that can later be sued for structural health monitoring and material durability monitoring. The data from these sensors should be input into life-cycle models and compared with or integrated into appropriate asset management models. Resulting decisions should be data driven and based on sound fundamental mechanistic principles. Not understanding the broader context of the problem often leads to “solutions” that “solve” one problem while often creating three others. In the current age, new materials and new solutions are being introduced so rapidly that the only practical way to incorporate these is by having larger integrated frameworks that allow a plug-and-play approach to data, analytical tools, and processes.

Data

Not everyone sees data the same way. Traditionally, the approach has been to collect data for one purpose and then attempt to use it for other needs. A more strategic approach would be to understand the broader context and bring the appropriate stakeholders together to consider the data required to accomplish the overall goals instead of just that one purpose. At the same time, having the ability to mine existing and legacy data is important but can only be done effectively if it has appropriate metadata. A challenge is getting the different groups, including TRB committees and sections, to work together to address clearly articulated needs.

Automation

The role of automation is only going to increase. Use of robotics is expanding into multiple areas such as acceptance of materials, performance of maintenance and assistance with traffic safety activities. The idea should not be simply a replacement for labor. Rather, robotics can be used to support skilled labor by improving efficiency and job safety. Automation should make their job easier and safer and let them focus on the activities that require their skill sets.

Testbeds

One of the current challenges is having testbeds that can evaluate the long-term performance of materials or components, which are typically tested in the lab but not on or as part of an actual structure. Once these are implemented or built, everyone claims success and moves on to the next project. We rarely go back to see if they are behaving the way they were designed or expected. This is particularly important as we incorporate life-cycle assessment into the process. It is also useful when new tests are developed. Making sure the results of field trials are documented is important both for present assessments and for future research.

Implementing New Technologies

We need to find more efficient ways to implement new technologies. An example of the importance of improving information dissemination about new technologies is the relatively new test for resistivity of concrete. While the concept of using resistivity has been around for a century, this approach has not caught on or been standardized until recently. Research in earnest has been performed over the last one or two decades to develop the resistivity test. A recent survey found that numerous states have ongoing individual research projects, each focused on assessing the use of resistivity. We will do much better as a nation to build on research that has been done by others and to help in answering the remaining questions. Determining ways to coordinate and disseminate research would minimize duplication of effort and potentially allow researchers to coordinate research to address larger cross-cutting questions. Additionally, having subject matter experts define remaining problems that should be addressed is key. Further, building teams of researchers, specifiers, manufacturers, and contractors is important for moving research into specification and practice.

Education

With reduced time in the undergraduate curriculum, effectively educating the entry-level workforce to meet today's requirements is a challenge. One possible idea is developing and incorporating simple examples and problems that could be incorporated into existing classes using web-based models. Another idea is to develop a skills list for students who want to work in transportation and asset management, which links to core and elective courses that build on, enhance, or expose students to those skills. While the brick and mortar campuses will remain the fundamental training ground, we would be well served to supplement this with e-campus and hybrid e-campus–hands-on learning sessions.

Limitations

Weiss identified three characteristics that limit technology implementation.

1. Industrial inertia or opposition. If industry does not see the "win" during research and development, it is hard for them to support new approaches. Frequently the research is conducted and industry involvement comes in too late in the process. We need to find ways to partner earlier in the research process.
2. Agency inertia or opposition. Agencies are understandably resistant to new untested ideas, which is understandable. However, we need to develop protocols where new ideas can be proposed, followed by a method to obtain clear feedback on what information agencies would need to move the idea forward.
3. Research and manufacturers "over selling." Many research projects include the requirement for an implementation plan which assumes a positive outcome of the research. Sometimes the results are inconclusive, not appropriate for the problem, or not practical resulting in unmet expectations. Further, many manufacturers are 'overselling' materials where claims need to be more rigorously justified. We need to improve our practices to make certain that we quantify the level of confidence needed to move forward.

Robert Peskin, *AECOM*

Peskin identified six points for consideration.

Learn from the Federal Transit Administration Mandated TAMP

States and transit agencies are developing their initial TAMPs and are required to have them available for inspection by FTA by October 2018. As a result, there will be extensive documentation and information about processes and analytical methods. This presents an unprecedented opportunity for state agencies and researchers. There will be a lot to learn both in terms of the application of analytical methods and the documentation that will be included for the different business processes. Seeing the analytical methods will provide important information about what tools are available as well as the skill sets and levels of experience necessary to build, populate, and ultimately maintain an asset management system. Descriptions of the business practices will be useful to understand the resources that agencies are relying on. These plans will need to be updated over time which will provide an additional temporal dimension of information. Because of the mandate, a wealth of lessons learned should evolve from this process.

Continue Moving Toward a Cross-Asset or Pan-Asset View of Transportation Assets

This conference included extensive discussion about optimizing the use of limited resources for highways and bridges. Transit is just starting this process. Decision-support tools, such as the TERM Lite Access application (developed by FTA), the SGR Database SQL application (developed for the Massachusetts Bay Transportation Authority), and various commercial applications, provide platforms for analysis of all transit asset classes. The requirement by FTA for transit agencies to apply decision support tools to identify SGR needs and establish funding priorities provides an opportunity to study a cross-asset process from an industrywide implementation. Perhaps, this could inform state DOT efforts to manage across assets and to understand whether the allocation of resources across classes would be the same as for individual processes.

Increase Use of Sophisticated Analytical Platforms and Make Them More Accessible to Practitioners

FTA has done this with the TERM Lite tool. SEPTA has a Vehicle Maintenance Information System and an Infrastructure Management Information System which feed into their decision-support tool which supports the determination of investment priorities based on budget constraints. In addition to the analytical results of the model, other interactions include operational constraints, partnerships, adaptations such as climate change, regulatory mandates, and accommodation of growth. How are these considerations being applied in a context of sophisticated techniques? Many tools are doing a reasonable job of prioritization but not optimization. Incorporating optimization theory, simulation or other approaches are areas for further research.

Move from Tactical to Strategic

The current state of practice suggests there needs to be a continuing push on maintenance managers to move from a short-term–tactical–reactive posture mostly responding to pressures of the operating budget, toward a long-term–strategic–proactive posture more responsive to the needs of the capital program and moving in the direction of optimization. A short-term view focuses on identifying which assets are due for preventive maintenance and examining how assets are failing. Asset managers need to be moving in the direction of looking at longer-term trends. All too often, maintenance managers just don’t have the resources.

Expand Knowledge Transfer

State DOTs and toll agencies are using and creating sophisticated state-of-the-art materials, tools, technologies and processes. This knowledge needs to be pushed down to the more than 30,000 regional, county, and municipal operators of surface transportation systems. For example, could a comprehensive compendium of asset decay curves be assembled?

Incorporate Infrastructure into Undergraduate Education

In addition to planning, analysis, and design, students should be introduced to life-cycle assessment. This should be addressed in the ASCE Body of Knowledge for Civil Engineering. Although students are exposed to infrastructure, little time is spent on the topic of this conference. Managing infrastructure and its assets is more than planning, design, and operations.

Paul Kovacs, *Illinois State Toll Highway Authority*

Kovacs shared his perspectives, highlighting many take-aways from the conference.

Thoughts from Speakers

I was impressed by many of the quotes provided by the keynote speakers and would like to address how these influenced my take-aways from the conference. The first one was “timing is everything.” I joined the tollway before they had approved any large capital programs. Within the last 10 years, over $20B worth of work has been approved to rebuild the tollway infrastructure. I happened to be in the right place at the right time. The only reason that I’ve stayed as chief engineer at the tollway is because I continuously surround myself with people who are smarter than I am and I know and support good ideas when I hear them. Great ideas have come out of this conference. So where do we go from here and how do we make them happen both at the tollway and as an industry.

Reduce the Life-Cycle Costs of Infrastructure by 50% by 2025

I plan to circle the troops at the tollway around this challenge focusing on life-cycle costs. This should be formally incorporated and measured.

Don’t Celebrate the Idea, Celebrate When You Make the Idea a Reality

I plan to develop a format for introducing innovation into the project implantation process as early as possible. Ideally, this document would begin during the planning phase. Once you write it, it becomes real.

Speed Is a Great Saver of Money

The tollway is very aggressive in all construction schedules. We widened and rebuilt 62 Interstate miles in 4 years. I want to include time as part of the construction process. Even though the tollway does not have the ability to do design–build, there may be other ways to incorporate time into the regular bid process. One way would be to use A+B bidding more broadly.

Engineers Are Being Placed on the Front Line Faster Than Ever Before

I plan to develop a mentorship program at the tollway. We have to take care of entry-level engineers because the legacy knowledge is retiring and new engineers are the ones that ensure continuation of progress.

Measurement Allows Management

We will take advantage of the life-cycle assessment tools we have developed to track progress on sustainability with respect to life cycle of the infrastructure.

Research Results in Savings

We will continue to push for research dollars. Documenting savings from these initiatives provides leverage for further research.

Make Things Happen

At the highest level, leadership has to make a clear statement about what it wants out of innovation. Typically, jobs that run smoothly have the support of the boss. As long as there is a clear directive (this will be done in 2 years), success is achievable. To innovate in this country requires leadership commitment supported by measurable progress and accountability.

For consideration in how to eliminate barriers, Kovacs offered the following comments and possible next steps for participants.

- Focus on rapid deployment technology.
- Improve dissemination of information among individual states. Consider creating a central repository with a standard format which includes articulating the impact along with the risk of innovations.
- Adopt alternate bid options. If you want to bring innovation into projects, you have to bring the innovators into the process.
- Encourage focus on specifications. Provide a uniform format for states to use for alternate bid contracts and for performance-based specifications for materials and structures.
- Reduce and streamline regulatory requirements for adopting or implementing innovations.
- Make life cycle a key criteria in the development and implementation of new technologies. Nobody knows the life-cycle impact of new technologies. Consider that 500 cameras supporting incident management need to be replaced in 5 years. Is that cost programmed into operating budgets that are continually being reduced.

Charles Schwartz, *University of Maryland*

Schwartz began by asking how we can better implement research results. He then framed his response within the context of three truly high-impact research efforts and three areas that have been researched for decades but have yet to result in satisfactory results. From participants, projects that have significantly changed the business of transportation infrastructure engineering included:

- LRFD Bridge Design;
- SHRP1; and
- AASHTO Road Test.

Three projects that have had little or no impact were identified as:

- Stripping in asphalt;
- Moisture susceptibility; and
- Concrete durability.

Considering these, Schwartz presented the following considerations about research that effects change.

1. Start with the right questions. Consider questions that multiple stakeholders are truly interested in and that can actually impact the industry. The open "billion dollar questions" should be driving research. The research paradigm should be articulating the problem and identifying the appropriate tools and solutions as opposed to developing the tools and identifying a problem to solve. The critical aspect is that the problem has leverage.
2. Follow the appropriate approach in the research. Ideas for future research should be based on fundamentals, be data-driven, and be integrative. Complex problems need to be considered from a system integration perspective.
3. Recognize and reconcile the different needs and objectives of the stakeholders in the research space. This is best represented by considering needs and objectives from two of these stakeholders. State agencies are focused on solving problems that are typically very specific with short-term solutions. They typically are looking for an answer now that they can use in the field tomorrow. They operate in a risk-averse culture that is resistant to new innovations. Academia consists of faculty who are rewarded for scholarly publications in esteemed science-based publications. They are not rewarded for solving an agency's problems. The result is a disconnect: the ivory tower versus messy reality. If this is recognized at the inception, the stakeholders can work together to reconcile it and make progress.
4. Make the value proposition. Demonstrate how the research supports making better decisions for improving performance or extending life or reducing cost or all three.
5. Focus on fundamentals over empiricism. This is the best way to make research projects portable, extendable, and durable.

He also articulated additional considerations:

1. Enhance engineering education and training programs. The undergraduate curriculum is difficult to modify but alternatives include considering on-site or online certificate or masters programs. Results of research may not be implemented if practitioners do not understand them and their implications so appropriate education is important.

2. Promote appropriate national standards and approaches. This provides benefits from economies of scale by increasing transferability and interoperability of processes, innovations, and research results
3. Promote high-level research studies. Complex problems require broader and resource intense research that is typically beyond the scope and capabilities of individual agencies and researchers. NCHRP and FHWA pooled-fund studies are examples of mechanisms designed to focus on the big problems.
4. Systematize research project deliverables. Effectively and broadly communicating and sharing results of research has repeatedly been identified as a barrier to its implementation. Ensuring that project deliverables include implementation and training products would make these results more accessible and usable by a broader audience.
5. Continue performance monitoring research. Field validation is always the Achilles heel of implementation. Without performance monitoring over time to understand the true value and cost of components and systems, we can never truly optimize our decisions and resource allocations.

Note: Transcribed and edited by Kathleen Hancock, Virginia Tech.

In Closing

IN CLOSING

The Bottom Line on Transportation Infrastructure Renewal and Rehabilitation

JOSEPH SCHOFER
Northwestern University

Anthony Bartolomeo started the conference by reminding us that there are many transportation infrastructure problems that we have worked on for decades without solution. Foremost among these are the challenges of the durability and sustainability of infrastructure systems. At the same time, it is evident from presentations at this conference and prior knowledge that we do have the capability to design and build durable, sustainable, and efficient facilities. However, we have not always been able to make the case for implementing best practices that would produce enduring infrastructure because they may deviate from established standards or they may be more costly than conventional methods and materials in the near term.

Conference participants discussed the need to accelerate innovations. This requires that we understand and address the barriers, demonstrate convincing performance with new approaches, produce high-confidence information, and deliver it effectively to senior managers, policy-makers, and the public to support investments that are in society's best, long-run interest.

Some suggested the need for a cultural change in the transportation infrastructure community, welcoming positive change, learning from rapid testing and field experiments, enhancing analysis techniques, advancing our communications skills, and making a commitment to work with decision-makers to advocate innovations in methods and materials that will move us toward a more-sustainable transportation infrastructure.

This kind of systemic change requires an effective collaboration between researchers, practitioners, and the decisions-makers with whom we work. And the innovation needs to include the institutions and organizations that manage and advance transportation infrastructure, to streamline and simplify both lines of communications and processes for delivering projects.

Many attending the conference suggested that two analysis and design paradigms should play a larger role in the management of transportation infrastructure:

- LCCA to recognize, and minimize, the long-term multidimensional costs of facilities and systems; and
- Performance-based design, to focus on choosing the best ways to meet performance objectives, rather than being locked in to historical standards.

Some participants also suggested that these paradigms need to be integrated in both engineering education and professional practice, and they should be communicated to decision-makers and the public to help assure that these concepts are accepted by those who must act on them.

The idea is to go beyond "fix it now" to assuring durable, long-term facility and system performance.

The role of universities, and the UTCs, is not only to serve as a sources of new ideas, materials, and methods—their own and those developed by others—but also as producers of the next generation of professionals who have the latest and best knowledge about delivering enduring transportation infrastructure.

Poster Titles and Abstracts

How Are We Doing?
Condition Assessment

STRUCTURAL ASSESSMENT OF EXISTING ROAD BRIDGES IN GERMANY

Matthias Mueller and Juergen Krieger
Federal Highway Research Institut (BASt), Germany

The assessment of existing bridges frequently yields calculative deficits related to the load-bearing capacity. These deficits are due to steadily increasing traffic loads and simultaneous aging of structures and are also influenced by recent modifications of design standards. To take this into account, there is an urgent need to upgrade and or replace older bridges in a sustainable way. In Germany, a federal unified strategy for the improvement of road bridges has been developed. This strategy involves performing a risk analysis for the identification of structures to be examined, as well as establishing a uniform approach for recalculation and refurbishment. The key element for this task is the *Structural Assessment Guideline for Existing Road Bridges* (Edition 2011/05). This approach allows for the consideration of the characteristics of existing structures, which are not covered by current codes.

For assessing the extent of the necessary measures, a prioritization process has been developed to identify refurbishment needs of structures. Based on these prioritizations, bridges could be identified to be investigated for their load-bearing capacity. They represent 25% of the existing bridge stock, related to the total bridge deck area of federal roads in Germany.

The *Structural Assessment Guideline* covers all relevant construction methods and allows for a realistic assessment of existing bridges by considering a step by step refinement of the recalculation rules. Assessment Levels 1 to 4 have been introduced. They lead to a differently accurate approximation level. The required reliability level is unmodified regardless of the considered assessment level. However, the complexity of the calculation rises considerably with the accuracy of the individual stages, in particular in the higher Assessment Levels 3 and 4.

Assessment Level

1. Assessment considering recent design standards.
2. Assessment considering recent design standards and additional rules stated in the *Structural Assessment Guideline*.
3. Additional consideration of measurements on the structure.
4. Application of nonstandard scientific methods.
2. Specifically, Level 4 represents the future development opportunity of the Level 2 rules and is the basis for many activities in BASt and the Federal Ministry of Transport and Digital Infrastructure of Germany research framework.

Example

The shear capacity of new prestressed concrete bridges in Germany is calculated considering a strut-and-tie model. This model considers minimum shear reinforcement and hardly any additional shear resistance due to the concrete compression zone. In a large number of existing bridges the required minimum reinforcement is not covered. Actually, the shear carrying capacity of the uncracked compression zone is the main part of total shear resistance in this case. Therefore, new approaches to determine shear resistance considering the carrying capacity of the compression zone are currently being developed to calculate shear capacity for existing structures more accurately. After completion of a verification process in Level 4, the new approaches can be made available for Level 2 of the *Structural Assessment Guideline*.

ALLOWING 129,000-POUND TRUCKS ON OUR HIGHWAYS— WHAT IS THE COST? WHAT ARE THE BENEFITS?

Ahmed Ibrahim and Nicholas Saras
University of Idaho

A PRIMER ON CONCRETE PAVEMENT FORENSICS AND DETERIORATION

Timothy Martin
CTLGroup

This presentation provides viewers interested in pavement service life and pavement–asset management-specific information regarding the different pavement distress types, their causes and types of recommended repairs. A complete review of rigid pavement distress types is provided along with current pavement forensic guidelines. Case studies conducted to evaluate premature pavement deterioration are also presented, which include issues not covered by the current distress identification specifications or protocols.

The distress protocols referenced and covered in this presentation include the current U.S. Army Corps of Engineers' *PAVER Distress Identification Manual* (ASTM D6433-11) along with the FHWA's *Distress Identification Manual for the Long-Term Pavement Performance Program* (FHWA-RD-03-031). Forensic guidelines provided in this presentation are referenced from the *NCHRP Report 747: Guide for Conducting Forensic Investigations of Highway Pavements*.

The presentation is technical in nature and is intended for engineers and asset managers responsible for pavement assets. The attendees leave with an understanding of pavement distress types, mechanisms, and recommended repair strategies. This includes an understanding of the contributing factors that lead to pavement deterioration and how a forensic engineer interprets and applies their knowledge in identifying the causes and attributing liability.

Four learning objectives include the following.

1. Understand the different concrete pavement distress types.
2. Understand the different methods of collecting distress information.
3. Learn the different repair options for each type of distress.
4. Understand how forensic investigations are performed to investigate premature distress and how liability is attributed.

STATISTICAL METHOD FOR LONG-TERM MONITORING OF BRIDGE PERFORMANCE USING STRUCTURAL HEALTH MONITORING AND WEIGH-IN-MOTION DATA

Fiorella Mete and David J. Corr
Northwestern University

David Kosnik
CTLGroup

In this study, we consider metrics for structural performance of in-service bridges using a unique data set obtained from three years of combined structural monitoring and weigh-in-motion data collection on an in-service highway bridge. Specifically, we analyze the response of the bridge as it was subjected to a variety of trucks loads and under seasonal environmental changes in terms of some common parameters, and we introduce a new parameter related to the area under the strain–distance curve. The overall objective is to develop and employ useful metrics for structural performance to enable bridge owners to take steps to maintain the ongoing utility and good repair of the bridge inventory—in other words, the limit state of interest is serviceability, not strength or stability per se.

Weigh-in-motion recording of traffic loads and corresponding monitoring of the bridge's structural response were originally motivated by increases in allowable truck weights on the corridor, outside the original design considerations for the bridge. As the subject bridge is short-span structure typical of many small river crossings, it may be representative of many structures in the NBI. Thus it is hoped that the developed metrics will be widely applicable, rather than specific to this particular bridge.

Several challenges associated with long-term performance monitoring of in-service bridges are discussed in this study. In particular, some aspects of data filtering, scatter reduction and data interpretation in contexts where the system response is controlled by multiple variables simultaneously (e.g., traffic characteristics and environmental conditions) are addressed. The filtered data set is then analyzed in terms of well-known parameters such as simple peak strain measurements and AASHTO girder distribution factor as well as a proposed new parameter developed according to the influence line for bending moment. Given a recorded strain-versus-time waveform from the structural instrumentation, the recorded a strain-versus-distance ($\mu\varepsilon - d$) waveform is calculated using the recorded speed obtained from the in-pavement weigh-in-motion system. The parameter proposed is the measured area under the rectified strain-versus-distance curve, denoted as strain–distance area. The strain–distance area parameter is able to capture the response of the bridge taking into account not only the weight of the truck but also its axle configuration. As will be shown, use of the strain–distance area as monitoring parameter shows significant reduction of the scatter in the data; in addition, anomalies not readily identifiable from strain measurements alone are captured. In summary, consideration of the new parameter over time may provide an additional tool for monitoring structural performance as part of efforts to keep bridges in service under unanticipated loads and extended service lives.

AUTOMATED IDENTIFICATION AND EVALUATION OF FACTORS INFLUENCING HIGHWAY CONSTRUCTION PROJECTS

Ashraf Salem and Osama Moselhi
Concordia University

Roads are a vital component of the vast mass of infrastructure systems. Earth-moving operations are commonly encountered in retrofitting, expansion, and maintenance operations of these roads. Productivity monitoring is an essential process that significantly contributes to the success of earth-moving operations in highway construction projects. Modern advancement in computation, artificial intelligence, and remote-sensing technologies promises efficient automated potential for data acquisition and productivity analysis. Many studies have recognized adverse conditions as extensive influencing factors that dramatically affect the productivity of earth-moving operations. The majority of these studies have developed manual or semi-automated models. There is a need for the automation of the detection and evaluation of these adverse conditions.

Adverse influencing factors on productivity of earth-moving operations are varied, and the scenarios of these variances also vary due to the uniqueness of each project. The most significant and common factors have been documented through the authors' previous and ongoing research (Salem et al., 2017). The influencing factors on productivity of earth-moving operations have been evaluated using a fuzzy-set–based method that ranks these factors in a descending manner according to their influence. The automated data acquisition system has then been configured in a customized way based on that rank.

The proposed model automates the detection of adverse conditions and their influence on productivity of earth-moving operations. The proposed model provides a near–real-time identification and evaluation of different adverse conditions and their impact on productivity in earth-moving and highway construction projects. The model takes advantage of innovations in wireless remote-sensing technologies and the IoT to provide project managers and decision-makers with a near–real-time fully automated analyzer.

The kit consists of a low-cost open-source microcontroller, a series of smartboards and sensors, and a special router (Gateway) which has a local MySQL database for data storage and processing. This gateway can also transmit the collected data to servers. Each smartboard is dedicated to bundle a particular type of sensors.

The data acquisition system consists of portable components installed on hauling equipment and a fixed gateway located at the excavation site. The customized multisensory data prototype and the onboard diagnostic scanner OBDII are attached to all the hauling trucks in the earth-moving project, while the data receiver (Gateway) is installed near either the loading zone or the project gate. The proposed model integrates data acquisition as well as productivity analysis in a near–real-time and fully automated model.

HEALTH MONITORING SCHEMES FOR DOUBLE-TRACK STEEL RAILWAY BRIDGES

Daniel Linzell and Ahmed Rageh
University of Nebraska–Lincoln

Assessing the condition of railway bridges is commonly accomplished via visual inspection at a prescribed frequency, an approach that, while reliable, occurs at discrete points in time, is costly, can be unsafe, and is subject to human interpretation. To improve condition assessment, some railway bridges have been outfitted with a large number of sensors to quantify response and condition. These studies have largely focused on a single bridge, not a system of bridges, and have involved an extensive array of predominantly hard-wired sensors (strain gages, accelerometers, etc.) that are costly to place and maintain.

The current study is a part of a larger research program focusing on developing cost-effective, steel railway bridge structural health monitoring systems. As an initial step, a double-track steel railway bridge is used as a test bed to develop optimal sensor placement schemes and data-reduction techniques that can be used on bridges in similar structural systems. A summary of the ongoing work and initial findings are included in the poster. Initial research has included

1. Validation of a finite element (FE) model based on field tests;
2. Use of the validated FE model to develop a health-monitoring scheme based on large suite of sensitivity analyses;
3. Identification of potential data-driven and physics-based damage features;
4. Adoption of proper orthogonal modes (POMs) of simulated strain time histories as a damage feature; and
5. Developing an artificial neural network to identify damage from FE based POMs.

ROAD INFRASTRUCTURE ASSESSMENT WITH SMARTPHONES IN VEHICLES

Christoph Mertz and Jinhang Wang
Carnegie Mellon University

Fixing pavement problems when they first appear is more cost effective than waiting until a road fails. However, this requires that the roads be continuously monitored. Current methods consist of manual inspection, using specialized inspection vehicles, or waiting for citizen complaints. Manual inspection is tedious, often subjective, and takes a long time. Inspection by specialized vehicles gives accurate data, but it is expensive and is therefore done only once every few years and it is unaffordable for smaller townships. Citizen input is only useful for severe problems like big potholes. We have developed an inspection method that is based on smartphones. The smartphone is mounted on the windshield (Figure 1) of a vehicle and collects images, GPS, and other sensor data. This data-collection method is particularly inexpensive if vehicles are used that are part of a fleet that travels around on a regular basis—e.g., garbage trucks that drive past every house once a week. The data is then analyzed with computer vision and machine-learning algorithms to find cracks and other road damage. This road damage can be converted to a score and displayed on a GIS map (Figure 2). In addition to road damage the system can also detect and asses traffic signs.

FIGURE 1 Smartphone mounted on windshield of vehicle collects images, GPS, and other sensor data.

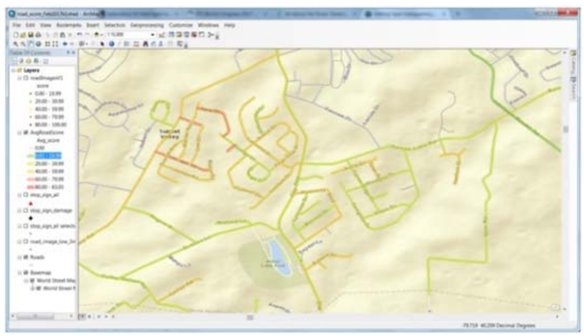

FIGURE 2 Road damage is converted to a score and displayed on a GIS map.

FIGURE 3 A map of stop signs detected in Pittsburgh and four individual signs with problems: defacement, occlusion by vegetation, and displacement.

Figure 3 shows a map of stop signs we detected in Pittsburgh and four individual signs with problems: defacement, occlusion by vegetation and displacement. Eventually, the plan is for the system to be able to detect and assess anything that is visible in the image: road markings, vegetation overgrowth, objects like fire hydrants, etc. The results of the assessment can then be presented to the user in Google Earth, GIS map, or any other common mapping application. Several pilot projects have been performed in and around Pittsburgh to test the system in the real world. The road assessment system has been commercialized (*1*).

References

1. RoadBotics (www.roadbotics.com). Disclosure: Daniel Linzell is cofounder of the company.

UTILIZING UNMANNED AIRCRAFT SYSTEMS FOR INFRASTRUCTURE MANAGEMENT

Michael O'Connell and Patrick Szary
Rutgers University

Introduction

The introduction includes a broad overview of the project and the potential of using unmanned aircraft systems (UAS) for infrastructure management activities.

Asset Identification

The poster provides a list of features associated with interchange assets including signage, pavement markings, medians, ramp terminal, surface conditions, and barrier islands, etc.

Equipment

The poster identifies equipment and software used in developing the images and models used in the study.

Flight Plan

The flight plan of the mission is provided, detailing the flight route, heights, locations, etc.

Flight Data

Examples of images and data collected via UAS of the interchange assets are presented, highlighting their current condition and status.

Conclusions

The conclusion provides the findings of using a UAS for the inspection, inventorying, and monitoring of interchange assets. The poster includes recommendations for performing UAS flights near interchanges and challenges faced during in-flight operation.

Restoring Current System

AN ADVANCED UNDERSTANDING OF THE SOURCE OF THE CHEMICAL DAMAGE IN CONCRETE PAVEMENT EXPOSED TO SODIUM CHLORIDE DEICING SALT

Fadi Althoey and Yaghoob Farnam
Drexel University

PAT DALY BRIDGE DESIGN AND CONSTRUCTION WITH CONVENTIONAL AND FIBER-REINFORCED POLYMER MATERIALS: A CASE STUDY OF MATERIALS APPLICATION AND ACCELERATED CONSTRUCTION

Genda Chen
Missouri University of Science and Technology

Zhibin Lin
North Dakota State University

ENHANCING NONMOTORIZED MOBILITY WITHIN CONSTRUCTION ZONES

Abul Mazumder and Upul Attanayake
Western Michigan University

Managing motorized vehicles and providing safe routes for nonmotorized mobility due to construction work zones is becoming a challenge for urban, rural, and congested cities. Sometimes sidewalks, shoulders, bike lanes, or motorized vehicle lanes are taken to ensure space for equipment storage and management of construction activities. This leads to increased congestion, delay, and safety issues for different road users. In addition, implementation of construction work zones impair (1) access to local businesses, shops, recreation centers, bus stops, transit facilities, and schools, etc.; (2) mobility of a wide range of pedestrians of all ages and including people with hearing, visual, cognitive, and mobility disabilities; (3) cyclists; and (4) emergency crews. Emergency response teams need the quickest access route to a location or facility. Typically during construction work, highway or city officials provide temporary traffic control (TTC) management plans to manage motorized vehicles. TTC management plans include accommodating motorized vehicles within the construction zone with reduced speed limits and safety cautions or detouring via alternative routes. Detouring motorized vehicles increases the vehicle operating cost, value of time cost, crash rates, and environmental pollution due to burning more fuels.

Highway and city officials pay less attention to nonmotorized mobility. Due to lack of policies and guidelines, contractors are not required to provide facilities for managing nonmotorized mobility. This is common to almost all the construction zones. As a result,

contractors can close the sidewalk and streets completely without providing alternate routes within or around the construction zone and safety and accessibility of pedestrians are compromised as they are observed to come in contact with construction equipment and materials as they pass through the construction zone.

The safety and accessibility of pedestrians and cyclists can be improved if (*a*) the cities have policies for managing nonmotorized access, (*b*) engineers and planners have a framework to evaluate a site for developing alternatives and guidelines to accommodate nonmotorized traffic, and (*c*) contractors have access to means and methods of implementing the guidelines. Most construction activities in small cities are handled by contractors who do not have a large workforce to identify the latest technology for managing construction activities and providing facilities for nonmotorized mobility. Hence, the guidelines for managing nonmotorized access provided with a project award need to include a manual with technologies and infrastructure that the contractors can use to implement the guidelines.

The objective of this research was to develop a framework to illustrate the process that highway agencies, city officials, and contractors can follow and policies that can be implemented to plan access for nonmotorized traffic within and around construction work zones within the city environment. Current policies, guidelines, practices, and technologies were reviewed and revisions to the existing guidelines were developed so that highway agencies and city officials as well as the contractors have access to necessary tools to implement the guidelines for enhancing mobility within or around construction zones. This poster presents the outcome of this research.

PERFORMANCE OF ULTRA-HIGH PERFORMANCE CONCRETE AS CAST-IN-PLACE THIN-BONDED CONCRETE OVERLAY

Mahdi Valipour and Kamal Khayat
Missouri University of Science and Technology

COMPILATION OF ABC SOLUTIONS

David Garber
Florida International University

LABORATORY INVESTIGATION OF INTEGRAL ABUTMENT CONNECTION DETAILS FOR ABC PROJECTS

Travis Hosteng, Brent Phares, Behrouz Shafei, and Austin DeJong
Bridge Engineering Center, Iowa State University

Meeting the needs and demands of the traveling public with an aging infrastructure has led to significant developments in ABC projects which have been found to be critical elements to bridge designers and contractors in trying to meet those needs. Development of various ABC designs, techniques, and technologies have been fundamental to not just accelerating construction but also improving bridge sustainability and safety for both motorists and construction crews. At the same time, development and expanded use of integral abutments has led to improvement of bridge durability by eliminating the expansion joints. To date however, integral abutments have seen limited use in ABC projects despite widespread use in conventional bridge construction practices for decades. The development of an integral abutment design to pair with the ABC process has the potential to make bridges constructed using ABC techniques more efficient, economical, while also increasing service life by eliminating expansion joints; all benefits that conventional bridges with integral abutments have realized for decades.

One potential design option uses grouted rebar couplers to develop the integral abutment connection. These couplers have been used in previous ABC projects to facilitate the rapid connection of prefabricated bridge elements (PBES construction), such as the Keg Creek Bridge. Phase I explored the use of the couplers for developing an integral connection in an accelerated bridge construction project. Further design and development of integral abutment connections using grouted couplers are warranted to access the constructability, strength, and durability of the grouted rebar coupler in these specific applications.

The focus of this project is to expand on previous work completed to further understand the constructability, strength, and durability characteristics of grouted couplers for use in ABC projects, specifically, integral abutments for ABC projects. In addition, a modified integral abutment detail developed by the Bridge Engineering Center at Iowa State University using short sections of H-pile encased in voids along with a third alternative using UHPC are proposed for evaluation. Testing and validating these design alternatives in a capacity directly related to ABC projects and integral abutments would ensure ABC integral abutments constructed using these technologies meet or exceed the requirements of their CIP counterparts. To accomplish this, the following aspects of ABC coupled integral abutment connection will be evaluated through laboratory testing: (1) constructability of both the individual components and implementing the design into the ABC process(es), i.e., PBES, slide-in construction, etc.; (2) strength as compared to CIP counterpart; and (3) durability of the connection.

SELF-SUSTAINED ROADWAY THROUGH INNOVATIVE ENERGY HARVESTING SOLUTIONS

Abbas Jasim and Hao Wang
Rutgers University

TOWARDS SIMULATION-AIDED PREDICTIVE DEMOLITION PLANNING

Seung Jae Lee
Florida International University

RETROFITTING DAMAGED BRIDGE ELEMENTS USING THIN ULTRA HIGH PERFORMANCE SHELL ELEMENTS

Alireza Valikhani and Azadeh Jaberi Jahromi
Florida International University

Rapid Repair and Keeping Things Moving

CORROSION OF POST-TENSIONED TENDONS WITH DEFICIENT GROUT

Samanbar Permeh, K.K. Krishna Vigneshwaran, and Kinsley Lau
Florida International University

Ivan Lasa
Florida Department of Transportation

Corrosion failure of post-tension tendons with prepackaged thixotropic grout was documented in Florida bridges in 2001. The accelerated corrosion was largely associated with the localized presence of segregated grout. Initial analysis of deficient grout in Florida post-tensioned bridges where severe corrosion developed indicated enhanced sulfate ion concentration, high pore water pH, enhanced moisture content, and low chloride content. The corrosion was not consistent with the conventional causes of steel corrosion such as bleed water accumulation in grout void spaces, chloride contamination, and pore water carbonation. Furthermore, there were separate cases of bridges with similar prepackaged thixotropic grout materials but containing significant chloride contamination (*1*, *2*). Chloride limits for prestressed concrete provided by the American Concrete Institute (ACI) are either 0.06% water-soluble chloride by weight of cement or 0.08% acid-soluble chloride by weight of cement (*3*, *4*). However, reported results from research on these prepackaged grouts indicated chloride threshold limits as low as 0.2% (*1*). It is noted that the proposed limits did not directly consider the effect of grout deficiencies with enhance sulfate concentration such as that observed in the recent tendon failures in Florida.

The objective of the research was to analyze the characteristics of deficient grout associated with steel corrosion and identify the role of sulfates ions on corrosion initiation of steel in cementitious materials and alkaline solutions, combined effect of sulfate content with low chloride content and recommendation for practical threshold limits. Testing on identifying role of sulfate in alkaline solution (12.5 <pH <12.3) showed destabilization of passive film growth resulting in severe corrosion in pre-mixed >4,000 ppm sodium sulfate solution at circuit potential condition. Laboratory testing created with various adverse condition including expired or pre-exposed grout, excess mix water, and different level of sulfate–chloride concentration showed that formation of deficient grout can be promoted by enhanced moisture presence. High sulfate concentrations (>0.01 $g_{sulfate}/g_{powder}$) can be accumulated in deficient part of samples without external sulfate sources. Corrosion developed in all samples with deficient grout and high sulfate concentration including grout materials with low-level additions of chlorides when combined with as low as 2,000-ppm sodium sulfate in its mix water. Additions of 0.08% and 0.2% chloride by cement in itself did not initiate corrosion. The enhanced sulfate addition apparently had effect to initiate corrosion in presence of low-level chlorides. The finding would suggest that assessment of corrosion susceptibility of deficient grout by chloride content alone would not be sufficient as sulfate ion presence and grout characteristics are also important. Practical limits accounting for expected grout pore water conditions may be proposed. Active corrosion conditions developed where sulfate levels exceeded ~0.0007 $g_{sulfate}/g_{powder}$. Test results

suggested an upper limit of $[SO_4^{-2}]/[OH^-]$ =0.15 for typical grout pH environments.

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SEISMIC PERFORMANCE OF SIMPLE FOR DEAD LOAD AND CONTINUOUS FOR LIVE-LOAD STEEL-BRIDGE SYSTEM

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PERFORMANCE OF FIBER-REINFORCED SELF-CONSOLIDATING CONCRETE FOR REPAIR OF FLEXURAL STRUCTURAL ELEMENTS

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APPLICATION OF NANOPARTICLE-ENRICHED EPOXY PRIMER TO ENHANCE DURABILITY OF HIGHWAY STEEL BRIDGES

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The three-coat paint systems incorporating a zinc-rich primer, epoxy midcoat, and urethane topcoat layer has been widely used for highway steel infrastructure. Review of bridge performance records in Florida showed cases of early coating degradation within 15 years and repair requirements by ~25 years of service life. Durable novel coating systems are of interest to meet the bridge service life as well as to reduce maintenance cost. The purpose of this study was to evaluate a coating containing carbon nanoparticles with the zinc rich primer (NPE-ZRP). The nanoparticles were promoted as providing better electrical continuity of the zinc pigment for enhanced cathodic protection. To evaluate the coating performance for steel infrastructure application, NPE-ZRP samples were exposed to outdoor marine conditions, salt–fog environment, as well as immersion in chloride solution. Test parameters included introduction of

local coating defects to evaluate the corrosion development near the defect site. A conventional three coat system was evaluated as a reference to assess the influence of nanoparticles.

It was apparent that the mechanism for corrosion protection provided by NPE-ZRP is similar to conventional ZRP. NPE-ZRP provides barrier-like protection when the coating is intact. In solution immersion tests, generally noble open-circuit potentials (OCP) and low corrosion currents developed for defect-free samples. When the steel substrate was exposed, the zinc pigments were initially in active conditions but quickly trend to more passive-like conditions indicating that zinc activity may be reduced after early consumption. In lab testing, steel corrosion developed after the initial period of high zinc activity. Similar findings for outdoor and salt–fog samples were made but with greater severity of corrosion for salt–fog samples. By the end of testing, all tested samples generally showed good corrosion protection where minimal rust accumulated after its initial development. That would indicate zinc activity and some level of beneficial cathodic polarization. The benefits of the inclusion of the nanoparticles in ZRP coated steel in chloride solution immersion tests could not easily be ascertained but some level of enhanced conductivity can be inferred as generally limited steel corrosion developed at defect sites even though high anodic currents were measured and consumption of zinc pigments adjacent to the defect was apparent. This high current was measured after the apparent shift in potential to passive-like conditions and in part accounts for the steel corrosion activity. The OCP trends to more passive values could be related in part to the coating composition, permeability of the coating and top coat, tendency for zinc to trend towards passive-like conditions, and change in local chemistry within defect sites. Also at different levels of potentio-static polarization, NPE-ZRP coating showed marginally higher anodic and cathodic activity than ZRP. Further assessment of the effect of nanoparticles on the throwing power, conductivity and mechanical performance of dispersed zinc pigments and also the impact of adverse exposure before coating application on the long-term durability of NPE-ZRP coating is in progress.

INVESTIGATION OF MACRO-DEFECT FREE CONCRETE FOR ACCELERATED BRIDGE CONSTRUCTION, INCLUDING ROBOTIC CONSTRUCTION

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A major construction equipment manufacturer has developed several formulations of a "Cemposit," a variation of macro-defect free concrete. This material is unlike cement-based materials currently available, and is much more closely related to various types of rubber, although with vastly different properties than rubber. Cemposit properties of interest include: high strength (comparable to UHPC), rapid early strength, extremely low permeability, and the ability to be extruded to fit specific project needs. The goal of this project was to assess important material characteristics and to develop conceptual uses for the material with a specific focus on accelerated or robotic bridge construction. This research summarizes the material test results seen for the developed macro-defect free concrete, as well as highlights potential applications for use in ABC projects.

After many different formulations of Cemposit, with varying additives aimed to improve attractive material properties, a suite of material tests was performed by Iowa State University. These tests included freeze–thaw, compressive, and split-tensile tests. Varying material layer orientations were molded to determine any effect on the test results. Compressive and split-tensile test results revealed that the material has significantly higher strength than that of traditional concrete. Though variability was present in the test results, the strength consistently exceeded traditional concrete material properties. The material was also subjected to 300 rounds of freeze–thaw cycles to assess the durability of the material. The durability factor, or the average relative dynamic modulus of elasticity after 300 cycles, was found to be significantly lower than that of traditional concrete, signaling that the durability of the material is not as high as desired.

This project incorporates the theme of deploying innovative materials to maximize the value of new transportation assets in a cost-effective manner. This research was sponsored by the ABC–UTC.

USING ELASTIC LAYER THEORY TO INVESTIGATE USE OF EXISTING PAVEMENT AND OTHER LOCAL MATERIALS FOR OPTIMIZING CONCRETE PAVEMENT STRUCTURES

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Critical stress–strain analysis is a design and analysis method that examines the critical elements in the entire pavement structure, layer by layer. Each layer can be optimized in terms of material properties and thickness to handle the maximum vehicle loading. By varying moduli and thicknesses of layers the designer can understand how these properties affect the resulting critical stresses and strains. Lower stresses and strains result in better performance. The weaknesses and strengths of each analysis method are noted.

Benefits: Why Consider Critical Stress–Strain Analysis?

- Elastic layered theory allows for the proper evaluation of the concrete slab compared to the supporting layers. Proper evaluation is critical since the concrete layer is the most costly. Current concrete designs generally keep stresses below 20% of design strength; therefore failure would normally be initiated in the supporting pavement layers. The Portland Cement Association design method allows (allowed) stresses at 45% of design strength for unlimited loadings of the concrete.
- Critical stress–strain analysis allows for evaluation of the suitability of locally available materials for the supporting layers.
- Critical stress–strain analysis allows for evaluation of existing pavements due to the impact of overloads and permitted vehicles.
- Critical stress–strain analysis allows for the proper evaluation of overlays (asphalt or concrete) on existing pavement and to properly incorporate the existing pavement. Commonly used methods many times result in thinner asphalt overlays than concrete.
- Critical stress–strain analysis allows for the evaluation of local materials and the use of full-depth reclamation (FDR).

- Critical stress–strain analysis allows for the evaluation of the effect of construction vehicle loads on the layers during staged construction.

Continuously Reinforced Concrete Over an Existing Pavement

Graphs comparing elastic layered theory, with 3-D FE and Winkler for various loads and subgrade moduli.

Continuously Reinforced Concrete Over Full-Depth Reclamation

Graphs comparing elastic layered theory with 3-D FE and Winkler analysis for various loads, subgrade moduli, and FDR thickness.

Findings

The continuously reinforced concrete pavement structure can be optimized for both stresses and strains using the elastic layer theory method and the 3-D FE method to maximize the performance and to minimize cost. For jointed concrete pavement, currently only 3-D FE method should be used.

ALTERNATIVE ACCELERATED BRIDGE CONSTRUCTION CONNECTIONS USING ULTRA-HIGH-PERFORMANCE CONCRETE

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ACHIEVING POST-EARTHQUAKE OPERATIONAL PERFORMANCE IN EXISTING HIGHWAY BRIDGES WITH DUCTILE FUSE RETROFIT

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DEVELOPMENT AND DEPLOYMENT OF CONCRETE PAVEMENT PERFORMANC-RELATED SPECIFICATIONS

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Managing the Assets

BUILDING SPATIOTEMPORAL MODELS FOR PAVEMENT SURFACE DETERIORATION

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Forecasting pavement deterioration is a critical element in the pavement management process which facilitates the ability to develop future investment strategies. Among the variables that govern the deterioration mechanism, surface distresses (cracking and patching) are the main characteristics that describe the serviceability of the pavement. The current study presents the findings for analyzing pavement sections monitored as a part of the long-term pavement performance database. The first aspect of the study is to construct spatiotemporal analysis of the pavement performance. It was found that spatiotemporal models can provide greater insights into the deterioration dynamics, and how localized features can propagate spatially over time to form larger defected areas. Furthermore, transfer functions have been used to describe intervention models. These models can describe the impact of maintenance activities and possibly catastrophic events on the pavement performance. These models will allow transportation agencies to forecast the impact of maintenance alternatives on the pavement performance.

UNSOLICITED PROPOSALS IN TRANSPORTATION INFRASTRUCTURE DELIVERY IN THE UNITED STATES: CURRENT STATE AND BEST PRACTICES

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The American Society of Civil Engineers (ASCE) estimates the country's infrastructure funding needs by 2020 to be about $3.6 trillion. In ASCE's 2017 report card, roads and transit infrastructure systems had D and D– grades which emphasize the urgent need for increased investment for maintenance and expansion of existing assets. PPPs have been touted as one of the ways to meet the nation's infrastructure funding gaps. According to the National Conference of State Legislatures, the number of states with PPP-enabling legislation increased from 29 to 33 between 2010 and 2015. This is an indication of the growing willingness of states to leverage private-sector expertise and resources to provide much needed public infrastructure. Interestingly, not all the state PPP laws have provisions for unsolicited proposals from private-sector entities. The acceptance of unsolicited proposals encourages innovative project delivery ideas from the private sector but in most cases they can be difficult for public agencies to manage. Challenges include constrained resources for reviewing proposals and a lack of competition and transparency in the procurement process. This research focuses on a comprehensive assessment of current acceptance and review processes for unsolicited proposals for transportation infrastructure delivery across states. Based on this assessment, best practices will be outlined to ensure sustained partnerships between the public and private sector.

MAKING THE CASE FOR FUNDING HIGHWAY PRESERVATION FIRST

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This poster has a simple message: take care of existing assets. It focused on roads, but the same principles apply to bridges and other types of transportation assets. When funding is limited it is tempting to defer preservation work; when funding is higher there is pressure to spend it on the worst roads. But the need to protect investments an agency has made never takes a vacation.

Recognizing the importance of this message, in 2016 Maine DOT convened a Roads Report team, consisting of engineers from all of the major bureaus: 12 members in all. The group analyzed 11 years of pavement condition and construction spending data. Discussing this in light of design, construction, and maintenance experience, the conclusions were clear.

- Keeping good roads good is the most cost-effective way to extend the life of the built network. This is accomplished with light treatments (crack–fog seal through thin hot-mix asphalt overlays, including ultra-thin bonded overlays).
- Our heavier treatments were not lasting as long as expected, and certainly not long enough to offset their much higher cost.
- At least a few of our built roads have been neglected to the point that they now would require expensive rehabilitation. In 2017 and 2018 we will begin to quantify the extent of this problem.
- Roads needing rehabilitation, or those that never have been built to a modern standard, can be kept serviceable by relatively low-cost holding actions.

Based on all of the above we determined that preserving what still is preservable is the top priority. It is not good stewardship to rehabilitate or reconstruct short sections at high cost if this means that longer-built sections will lapse into needing rehabilitation (because no funds were left to preserve them).

The funding policy recommended by the Roads Report is as follows:

- Fully fund preservation needs, before funding anything else.
- Do not fund rehabilitation or reconstruction work until the higher-priority needs are fully funded. These other needs include:
  - Cost-effective maintenance paving and plant-mixed recycled-asphalt pavement for the lowest-priority state roads;
  - Replacement of large culverts nearing end-of-life; and
  - Safety and spot improvements.

The Roads Report was released at the end of 2016. This poster describes the reaction to the report’s recommendations from industry and state lawmakers. The authors believe that other agencies would find value in the practical details of how Maine DOT went about developing and implementing the Roads Report.

RAIL FATIGUE LIFE FORECASTING USING BIG DATA ANALYSIS TECHNIQUES

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Railroad represents one of the largest infrastructure costs for railway systems and is often the largest single maintenance-of-way expense item. Rail fatigue is one of the primary causes of rail failure, occurring in all modes of rail transit, from heavy axle load freight to rail transit. The current approach to forecasting the fatigue life of rail is a cumulative defect analysis using Weibull equations, which allows for the determination of the rate of defect growth and prediction of defect rates based on cumulative traffic levels (million gross tons of traffic). While the Weibull equations have been effective in projecting the growth rate of rail defects, they are insensitive to such key parameters as axle load, speed, curvature, and rail maintenance activities such as rail grinding. As such, traditional Weibull forecasts are based on the assumption of homogeneous conditions throughout the entire analysis period and specified location. This has been a very limiting assumption.

With the availability of large volumes of data, it is now possible to extend the Weibull analysis, using new big data analysis techniques, to allow for more-accurate and effective forecasting of rail life. This research activity makes use of a large volume of rail defect data, representing approximately 100,000 rail defects taken from over 11,000 mi of railroad track over a period of almost 10 years. The goal is to extend and possibly replace the existing Weibull forecasting models to overcome many of the deficiencies of the current model and to allow for more accurate rail life forecasting. To date, over 60 papers were reviewed based on their possible applications to the improvement of the Weibull function, big data analysis, forecasting, and failure mechanics in other fields. Of these papers, approximately 10 showed some potential use in the advancement of this project, in addition to approximately five general reference papers that covered the history, basics, and use of techniques involved.

Initial analyses were performed using the machine learning process *k*–nearest neighbors (KNN). KNN was chosen as it is a basic big data function, and has the potential for picking up and predicting on smaller segments of data, such as half-mile sections of track. However, these KNN applications, while interesting, did not show an improvement in forecasting capability.

The project is ongoing, using several approaches identified in the literature search to include an alternate fatigue forecasting models, the hazard function approach (Stoyan, 2012) which appears to offer potential application to this data set. Another potential application is to combine big data methodologies with the existing Weibull function, to provide predictions on Weibull parameters, while still using the existing two-parameter or expanded three-parameter Weibull function. It is expected that the updated rail forecasting equations will be able to better predict the rate of rail defect development, allowing more accurate management of the expensive rail replacement process.

Appendixes

APPENDIX A

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APPENDIX B

List of Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ABC	accelerated bridge construction
AMP	asset management plan
ARRA	American Recovery and Reinvestment Act
ASCE	American Society of Civil Engineering
ASTM	American Society for Testing and Materials
BASt	Federal Highway Research Institut (Germany)
CAC	Calcium Aluminate Cement
CaOxy	Calcium Oxychlrides
CIPR	cold-in-place recycling
DOT	department of transportation
FDR	full-depth reclamation
FE	Finite Element
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
HIPR	hot-in-place recycling
IoT	Internet of Things
ITS	intelligent transportation systems
KNN	*k*–nearest neighbor
LCCA	life-cycle cost analysis
LCA	life-cycle assessment
LWS	lightweight sand
LRFD	Load and Resistance Factor Design
MDBF	mean distance between failures
NBI	National Bridge Inventory
NCHRP	National Cooperative Highway Research Program
NDE	nondestructive evaluation
NHS	National Highway System
NPE-ZRP	carbon nanoparticles with zinc rich primer
OCP	open-circuit potentials
PAVER	Pavement Management Software
PBES	Prefabricated Bridge Elements
PEM	performance-engineered concrete mixtures
POM	proper orthogonal modes
PPP	public–private partnerships
PRS	performance-related specifications
PTC	positive train control
QA	quality assurance
QC	quality control
SEPTA	Southeastern Pennsylvania Transportation
SGR	state of good repair

SHRP2	Strategic Highway Research Program 2
SRA	shrinkage reducing admixture
TAMP	Transportation Asset Management Plan
TOD	transit-oriented development
TRB	Transportation Research Board
TTC	temporary traffic control
UAS	unmanned aircraft systems
UHPC	ultra-high-performance concrete
UTC	University Transportation Center

TRB

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