Geotechnical Research Deployment

DETAILS

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Geotechnical Research Deployment

How Organizations Encourage Innovation: Lessons Learned

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Geotechnical Research Deployment

How Organizations Encourage Innovation: Lessons Learned

Presentations from the 93rd Annual Meeting
of the Transportation Research Board

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Preface

This e-circular was developed from presentations made during the 93rd Annual Meeting of the Transportation Research Board, in a session titled "Lessons Learned During Geotechnical Research Deployment: How Organizations Encourage Implementation." Mike Mooney of the Colorado School of Mines guided the session, which was cosponsored by the Standing Committee on Geotechnical Instrumentation and Modeling and the Standing Committee on Engineering Geology. This e-circular illustrates how transportation organizations are striving to implement innovative technologies, practices, and policies as they institutionalize performance standards. Federal law—the Moving Ahead for Progress in the 21st Century Act (MAP-21)—requires the implementation of performance standards to create more effective and efficient government, enhance stewardship of transportation infrastructure, and foster greater creativity and innovation to deliver a sustainable transportation system supporting prosperity and opportunity.

This is necessary because today's needs cannot be met with yesterday's technologies, practices, and policies. One of the reasons for the creation of state highway departments, now called state departments of transportation (DOTs), was to improve existing roads. Since then, the state DOTs' organizational structures and processes have optimized the design of new roads, including Interstates; construction management; and maintenance performance. The state DOTs are well-suited to apply existing standards efficiently, but generally are not well-suited to effectively implement new ideas with the urgency required today. Performance standards address this challenge and improve the ability to maintain public assets, which include roadways across the country. Better-performing roadways are expected to increase both public confidence in state DOT stewardship and the public's willingness to provide additional investment through increased taxes.

Performance standards demonstrate the new paradigm required by MAP-21 and are offered by neighborhoods across the country to gratefully honor the words of President Lincoln: "government of the people, by the people, for the people." Government must look for better ways to complete its fundamental mission to serve the people and their transportation needs. At the heart of this mission is the responsible stewardship of transportation infrastructure. By demonstrating a renewed good-faith effort to deploy innovative solutions, transportation organizations do their part to improve service delivery and to improve the condition of transportation infrastructure.

This e-circular shares lessons learned by public agencies during geotechnical research deployment and how these organizations positively enhance the implementation of new technologies and policies by encouraging a culture of innovation. The first paper, "Understanding Deployment Strategy from Research to Project Delivery," describes the importance of strategy and planning during the earliest stages of problem identification. The second paper, "Innovation at the Crossroads: Exploring the Intersection of Innovation Adoption and Specification Reform in Public Highway Construction," describes the people and some of their common tendencies. The third paper, "Enhancing the Culture of Innovation in a Department of Transportation," describes the importance of leadership combined with employee engagement. The final paper, "Implementing Dynamic Cone Penetrometer (DCP) and Lightweight Deflectometer in Indiana," provides an example of successful research deployment.

The content of the presentations are those of the individual authors and do not necessarily represent the views of standing committee, TRB, or the National Research Council.

—John Siekmeier, *Chair, Standing Committee on Geotechnical Instrumentation and Modeling*

Contents

Understanding Deployment Strategy from Research to Project Delivery

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Many famous football coaches will say that teaching a team to be successful and win requires developing and understanding a consistent and defined working process. The same is true for developing a culture of innovation and implementation of research results. The implementation of research generally does not just happen on its own. It takes a combined effort, beginning with the research team through the employees and practitioners to the executive level of an organization. Understanding the deployment strategy from the initiation of the research project to project delivery will greatly increase the smooth transition to implementation. The Louisiana Transportation Research Center (LTRC) uses multiple tools to define and guide its implementation process to increase the success of deploying research results into practice.

The LTRC is the Research, Technology Transfer and Education and Training Division of the Louisiana Department of Transportation and Development (LADOTD) and was formally created by the Louisiana State Legislature in 1986 to improve transportation systems in Louisiana. The center conducts short- and long-term research and provides technology assistance, engineering training and continuing education, technology transfer, and problem-solving services to LADOTD and others in the transportation community. LTRC conducts applied research through its in-house staff and external contracts with universities and the consultant community. The mission of the LTRC is to merge the resources of state government, universities, and the industry to identify, develop, and implement new technology to improve the state's transportation systems. Its research program is developed with the specific intent to move results into practice.

This paper will discuss how implementation of research results is incorporated into all phases of the research process from initiation to deployment.

RESEARCH PROJECT LIFE CYCLE

There are several phases in a research project management plan that begins with the generation of a research idea and hopefully ending with the successful deployment of the research findings. The LTRC project life cycle that generally defines the management of the research program includes the following phases:

- Development of a problem statement;
- Initiation of a research project;
- Conduct of the research; and
- Dissemination of research results.

Figure 1 provides a flow chart of the research project life cycle at LTRC. The research team and the research project managers are heavily engaged during this time, conducting the research tasks and performing management oversight. The Research Assessment and

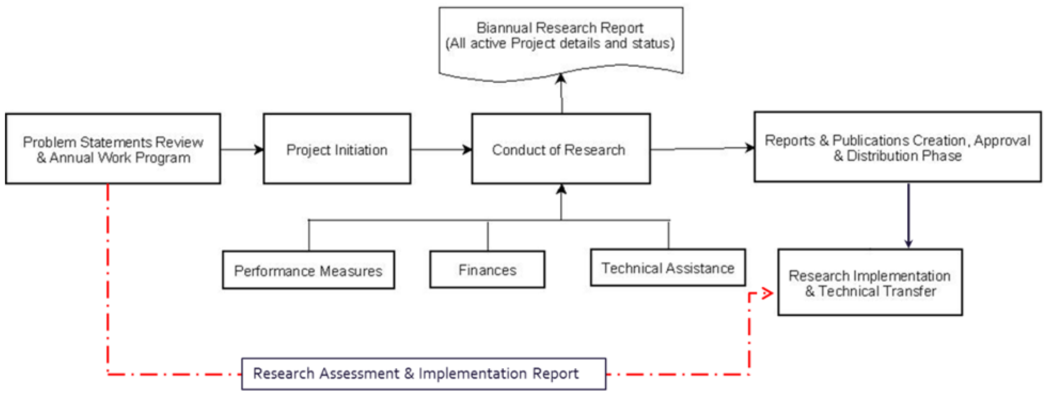


FIGURE 1 LTRC research project life cycle.

Implementation Report (RAIR), represented by the red line, is the formal linking of the beginning of the project work with the implementation or deployment expectations of the LADOTD.

OBSTACLES TO IMPLEMENTATION

In most cases, deployment of research results will not automatically occur with the publication of a research report. Without engaged thought and a targeted deployment strategy, the research report will often die on the shelf. There are many obstacles to implementation as depicted in Figure 2. The obstacles can be internal within LADOTD or external beyond the influence of the research team or practitioner. Identifying and understanding these obstacles at the beginning of the research project life cycle can greatly increase the chances of achieving a successful research project. Providing the research team with the knowledge of these obstacles may greatly influence the project work program and deliverables. Unfortunately, waiting until the research project is completed to understand these potential roadblocks will decrease the potential for successful deployment.

FIGURE 2 Obstacles to implementation.

PROBLEM IDENTIFICATION

A successful research project begins with the identification of a problem needing a solution, introduction of a new technology, or simply an evaluation of a new idea or concept. While LTRC accepts problem statements continuously, it conducts an advertised solicitation and prioritization of research problem statements every 2 years. The solicitation is open to LADOTD employees, industry, universities, and the general public. Problem statements are accepted on the LTRC website home page. A normal solicitation generally yields more than 100 problem statements to be considered. LTRC evaluates the statements received though a multilevel committee structure. The first level consists of a panel of technical experts in the topic area from LADOTD, FHWA, industry representatives, and university researchers. Typically there are approximately eight technical committees established based on problem statements received or LADOTD strategic needs. The committees will develop a prioritized recommendation of problem statements from those received through the open solicitation or developed by the committee itself. The top three or four problem statements are recommended to the LTRC Executive Research Advisory Committee, consisting of LADOTD executive management, for final prioritization of the LTRC research program. The ranking process for each problem statement is the same for both committee levels. Each statement is graded on two equal parts: (1) need for the research and (2) implementation potential of the research. The grades are multiplied together to reach a final grade for the ranking process. As LTRC's mission is primarily to conduct applied research for deployment, it is considered essential that the problem statements' ranking process include a discussion of implementation and obstacles to implementation when considering whether the project idea will be funded. Including this discussion in the ranking process minimizes the risk of proceeding with a project that has minimal chance of implementation success.

PROJECT INITIATION

Once a project is selected for funding, the project initiation will begin with the selection of the Project Review Committee (PRC) of technical experts and practitioners. Membership includes LADOTD, FHWA, industry representatives, and implementation champions (end users). LADOTD support personnel, such as information technology or legal, may also be included if this is an area that could be a potential roadblock to deployment. The PRC is responsible for scoping the project, proposal review, proposal selection, and development of a research implementation strategy.

The LTRC has employed an RAIR process to increase the chances of successful deployment of its research results. The process formally aligns the objective of a research project developed by the principal investigator with the expectations and implementation strategies of the end user. The RAIR process begins at the initiation of the research project and extends beyond the completion of the research work through deployment results. The process provides a better understanding of the deliverables and implementation products necessary for successful adoption of the research results into practice. The PRC will remain active beyond the end of the research project end date through the implementation process as defined in the RAIR.

CONDUCT OF RESEARCH

The Conduct of Research phase includes the development of the implementation strategy with the first draft of the RAIR. It is imperative that the implementation strategy be considered early in the project. The RAIR is first reviewed at the kick-off between the PRC and research team to achieve a clear understanding between the scope and deliverables of the research proposal and the anticipated deployment strategy needed for successful implementation.

IMPLEMENTATION STRATEGY

The RAIR consists of a series of topics and questions designed to provide guidance and insight to the PRC and research team for development of a successful implementation strategy. The following is the list of information to be provided by the PRC in the RAIR:

Project Number:
Project Title:
Principal Investigators:
PRC Committee Members:
LTRC Manager:
LTRC Implementation Engineer:

Objectives	[What are the objectives/deliverables/products of this research?]
Implementation Recommendations	[Provide the implementation recommendations as developed by the Project Review Committee.]
Potential Impact	[Describe potential impact of the recommendations in terms of cost, efficiency, safety, convenience, aesthetics, etc. Describe required changes to existing specifications, standards, procedures, etc.]
Target Audience	[Who will benefit from this research? List whom you want to reach, their primary interest, and your objective in reaching them.]
Strategies and Tactics	[Describe practical areas of application. List the activities required for implementation, including resource needs. Consider needs for training, multimedia, and marketing.]
Timeline	[Create a schedule for each discrete strategy or tactic.]
Implementation Responsibility	[Define roles and responsibilities of all personnel involved in the implementation effort. Identify who will be the decision-makers to implement results of the research.]
Evaluation	[Identify methods for evaluating the implementation effort. How will benefits be quantified or assessed?]

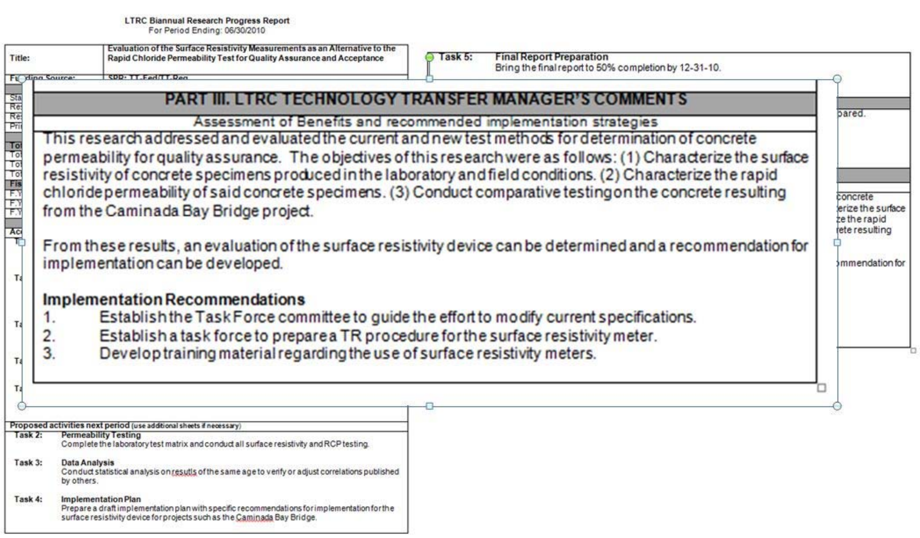
The RAIR development process begins with the assumption that the research will be successful and that the results of the research will be implementable. The report begins as a planning document to generate discussion on how the results of a successful project would be moved into standard practice. Who are the key decision makers? What deliverables or tools will be necessary? How will the benefits be defined? Not all components of the RAIR sections will be known at the beginning of a research project. The information is continually reviewed and updated at PRC meetings during the conduct of the research as the research outcome is more defined. The responsibility for development and updating and tracking of the RAIR document is with the LTRC project manager in cooperation with the PRC with input from the principal investigator. Besides the RAIR, other reporting tools such as the Biannual Reports, Implementation Summary Report, and performance measure tracking are also incorporated into the LTRC Manual of Research Procedures to increase the focus on deployment.

LTRC BIANNUAL PROGRESS REPORT

The LTRC Biannual Progress Report is submitted by the principal investigator to keep the PRC and project manager abreast of the status of the project. Included in the biannual report is a section labeled *Assessment of Benefits and Recommended Implementation Strategies* (Figure 3). This section is completed by the LTRC implementation engineer with input from the project manager. It is developed as a summary of the RAIR document. As the biannual report is submitted through a web-based LTRC project management system, the implementation assessment field is used as an implementation summary for the life of the implementation process from project imitation though determination of implementation outcome.

IMPLEMENTATION SUMMARY REPORT

Developing a culture of implementation within an organization takes effort and support from the executive level. Accountability of the research program is essential to maintaining and growing this support. LTRC has tracked its project implementation history for more than two decades in its Implementation Summary Report. The implementation assessment field in the biannual report provides the initial input for this report. The implementation summaries are updated for a



LTRC Biannual Research Progress Report
For Period Ending: 06/30/2010

Title: Evaluation of the Surface Resistivity Measurements as an Alternative to the Rapid Chloride Permeability Test for Quality Assurance and Acceptance

Task 5: Final Report Preparation
Bring the final report to 50% completion by 12-31-10.

PART III. LTRC TECHNOLOGY TRANSFER MANAGER'S COMMENTS

Assessment of Benefits and recommended implementation strategies

This research addressed and evaluated the current and new test methods for determination of concrete permeability for quality assurance. The objectives of this research were as follows: (1) Characterize the surface resistivity of concrete specimens produced in the laboratory and field conditions. (2) Characterize the rapid chloride permeability of said concrete specimens. (3) Conduct comparative testing on the concrete resulting from the Caminada Bay Bridge project.

From these results, an evaluation of the surface resistivity device can be determined and a recommendation for implementation can be developed.

Implementation Recommendations

1. Establish the Task Force committee to guide the effort to modify current specifications.
2. Establish a task force to prepare a TR procedure for the surface resistivity meter.
3. Develop training material regarding the use of surface resistivity meters.

Proposed activities next period (use additional sheets if necessary)

Task 2: Permeability Testing
Complete the laboratory test matrix and conduct all surface resistivity and RCP testing.

Task 3: Data Analysis
Conduct statistical analysis on resutls of the same age to verify or adjust correlations published by others.

Task 4: Implementation Plan
Prepare a draft implementation plan with specific recommendations for implementation for the surface resistivity device for projects such as the Caminada Bay Bridge.

FIGURE 3 LTRC Biannual Report: Assessment of benefits and recommended implementation strategies.

minimum of 5 years after the end date of the research project. The summary report is maintained for ease of review of its program and is presented annually to LADOTD leadership and the LTRC Policy Committee.

RESEARCH PERFORMANCE MEASURES

A culture of implementation needs to be encouraged in the philosophy and processes of an organization. Tracking research performance measures relays the importance of deployment to the both the employees of an organization and to the research team. LTRC categorizes its implementation status with five different classifications from project initiation through 5 years after the project's end date.

Project–Implementation in Progress

Projects are classified in this status code from the start date through a minimum of 5 years after the end date. Projects may be linked to phased projects or follow-up implementation projects may extend the 5-year minimum.

Implementation Recommended

Projects are classified in this status code upon a recommendation from the PRC that the results warrant deployment by LADOTD. Acceptance of a PRC recommendation to not make a change due to the research may also be considered an implementation success.

Implementation Complete

Projects are classified in this status code upon adoption of the results into practice by LADOTD. The outcome of the implementation has been documented in the Implementation Summary Report (i.e., specification change, process change, project application).

Not Implemented

Projects are classified in this status code when the project did not produce any implementable outcome. Projects not implemented in the 5-year implementation window will be closed as not implemented unless it is linked to a successive phased project or follow-up implementation project or activity.

No Implementation Expected

Projects are classified in this status code upon project initiation when the objective of the project clearly is accepted without an implementation outcome. These projects' objectives could include basic research, technical assistance, support projects to other tracked research projects, etc.

MARKET RESEARCH RESULTS

Communicating the value of its research projects will also enhance its implementation efforts. Decision-makers often do not have the time available to read lengthy research reports. Their interest is in the bottom-line effect of the implementation to the organization and transportation system. Will it make the department more efficient? Will it save lives? Will it save money? Demonstrating the benefits of implementation will significantly increase the chances of successful adoption of the deployment. Research organizations should also market its successful projects. LTRC utilizes brief technical summaries, newsletters, and implementation brochures to spread the word on innovation (Figure 4).

CONCLUSIONS

LTRC has a developed implementation process through its many years of serving LADOTD. Some of the lessons learned include:

- Understand that it's easy to identify research problem statements but not always easy to implement results.
- Engage practitioners (technical experts) for implementation expertise.
- Develop implementation strategy early:
  - Formalize an implementation strategy,
  - Identify obstacles, and
  - Provide implementation assistance.

FIGURE 4 LTRC technical summaries, newsletters, and brochures.

- Start early—it is difficult to go back and determine real data to quantify benefit.
- Market projects with quantifiable implementation benefits:
  - Use either quantitative or qualitative assessments or
  - Provide implementation analysis projections.

While LTRC has many research deployment strategies and procedures in place that have proved very successful, the center is continuously looking to improve the adaption of new technologies and processes to enhance the transportation systems. Following the LTRC process will not guarantee that every research project will be deployed. Identification of obstacles does not guarantee that they will be overcome. Understanding your research deployment strategy from initiation to project delivery, however, should greatly increase the chances of success.

Innovation at the Crossroads

Exploring the Intersection of Innovation Adoption and Specification Reform in Public Highway Construction

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The condition of the United States' highway system is deteriorating, with only 50% of roads in good condition, according to a recent report by AASHTO (*1*). The problem impacts not only state transportation budgets, but also individual motorists who spend on average $355 annually on vehicle maintenance resulting from poor road conditions (*1*). One of the primary avenues for relieving this problem is technology innovation to deliver faster, cheaper, and higher-quality road construction (*2*). However, the public road construction sector is inertially bound, being slow to seek and adopt innovative technologies (*3*).

This paper seeks to understand the innovation diffusion process in the highway construction sector in the context of a particular kind of policy innovation: specification reform. Oftentimes innovations are incongruent with current specifications, thereby requiring alteration of existing specifications prior to adoption. Using a case study approach, we follow the adoption of intelligent compaction (IC), a specific soil compaction quality assurance (QA) technology that requires specification reform in order to be implemented. With this research, we hope to characterize the following components of policy reform:

- Key players,
- Critical resources,
- Personality traits,
- Causal relationships and processes, and
- Pathways to innovation adoption.

To guide this analysis, we leverage Kingdon's theory of public policy agenda setting (*4*).

We begin with a description of IC, followed by a section explaining highway construction specifications and the organizational structure of this industry. Additionally, we detail the formal process by which specifications are changed. The third section reviews Kingdon's policy agenda setting theory in the context of highway construction specification reform. The fourth section discusses the methodology and analysis underlying this study. The final section discusses insights gained through the application of Kingdon's framework to the key people and processes that have played a part in the diffusion of IC.

INTELLIGENT COMPACTION

This paper focuses on the diffusion of IC, a technology used for monitoring soil compaction quality during soil compaction. Soil compaction (Figure 1) provides the mechanical stability for a roadway foundation. In current earthwork construction, soil compaction is typically specified in terms of target density and water content [per ASTM D698 (*6*)]. There are several technologies for evaluating soil compaction, such as the nuclear density gauge and sand cone, which measure density and water content at discrete locations on the roadway. These methodologies provide less than 0.1% spatial coverage of the constructed soil layer and require stoppage of construction activities that can lead to considerable delays (*7*).

The specification of soil compaction is not entirely straightforward, due to the complex nature of soil. Highway design engineers specify foundations in terms of "stiffness." Soil stiffness reflects the resistance to vertical deflection under a given load or stress, and is measured in units of stress or force over deflection. Stiffness development through compaction is particularly important to ensure the mechanical stability of highway subgrade materials, as they are subject to repetitive traffic loading (*8*). Due to soil's mechanical complexity, there is a multitude of ways to define its stiffness, only a few of which are used in pavement design (e.g., resilient or elastic modulus). A modulus value, however, is notoriously challenging to quantify in the field. The use of density and water content to evaluate compaction assumes a phenomenological correlation between these parameters and modulus. The relationship between modulus and density–water content is not fully understood, leaving an unresolved discrepancy between design parameters, construction specifications, and operational performance.

IC presents one of the first opportunities to quantify the in-situ stiffness of a soil. IC is a

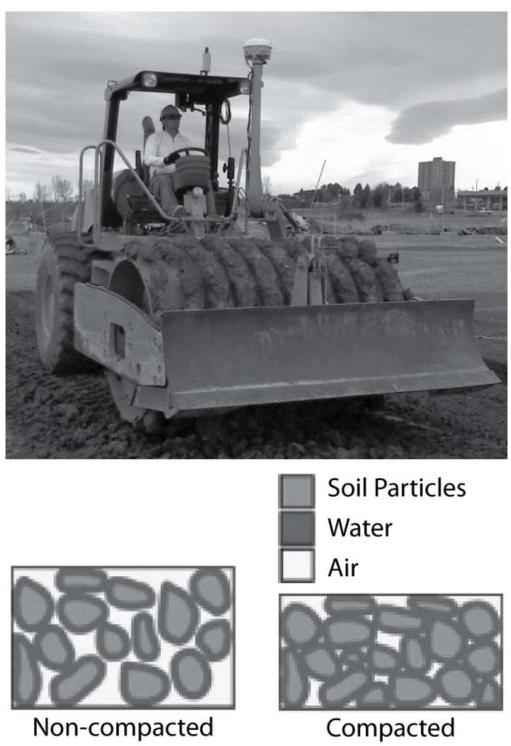

FIGURE 1 Example of a roller compactor used on highway projects (*5*).

machine-integrated soil compaction evaluation method that reports in real time during construction. IC vastly improves coverage of soil testing [i.e., from <0.1% to virtually 100% (*9*)] ensuring a more-comprehensive performance evaluation. Furthermore, IC provides real-time measurements, eliminating the delays associated with conventional spot testing techniques.

Many IC systems, including those for vibratory compaction, are correlated to the stiffness of the soil, which is more congruent with mechanistic design characteristics. One problem is that the stiffness measurements provided by these systems are not standardized between manufacturers. Each IC manufacturer has a proprietary stiffness measurement value that does not replicate any widely used stiffness parameter (*10*). This lack of standardization requires site specific calibration of IC and complicates the provision of standardized specifications for IC (*10*). In effect, technology innovation (i.e., IC) requires policy innovation (i.e., a standard for stiffness measurement values that cross technological platforms). IC for vibratory compaction thus represents both a change in process and measurement quantity of a QA program specification.

Such dramatic procedural change can encounter significant resistance with respect to an institutional status quo. A NCHRP study (*11*) on the culture within the highway construction sector reported that institutional inertia poses a considerable barrier to innovation. This report goes on to say that several factors such as risk, economy, and quality can serve to either enhance or inhibit such a process conversion.

HIGHWAY CONSTRUCTION SPECIFICATIONS

Specifications are the primary method used by highway construction project owners to ensure that the desired level of quality of construction is achieved. Simultaneously, specifications can be barriers to innovation because of their rigidity. Here we define specifications in the context of highway construction projects and the process by which they can be changed, e.g., to allow for the adoption of an innovation. We also discuss the key players in the highway construction industry that help shape these policies.

Construction specifications provide the basis for performance evaluation, and serve as a crucial link between a construction project owner [state departments of transportation (DOT)] and construction contractor. They are coincident to all infrastructure projects, typically involving the development of a QA program (*12*). Through QA programs, materials, products, and workmanship are ensured to meet specifications by providing evidence and documentation for both acceptance and archival purposes (*12*). Statewide manuals outline specifications that dictate almost every aspect of a project from the types of soils and concrete mixes used, to the spacing of rebar in bridges, to the degree of compaction of each layer of a roadway, etc.

Certain innovations, such as IC are incompatible with current statewide construction specifications and require specification reform for implementation. New specifications are introduced in two phases: project specific pilot or special specifications and statewide specifications. Special specifications are a way to trial a new form of specification while limiting the risk of failure to a single project. These specifications may even be introduced as shadow specifications that are implemented in addition to existing specifications to further limit risk. Multiple special specifications may be created within a single state for a given innovation until a document general and successful enough emerges that can be adopted for statewide specification reform. Statewide specification revision differs in frequency from state to state, ranging from 1 year to 10 years. Both special and statewide specifications must be approved via a specification review committee, composed of high-level officials including chief engineers and division heads.

In addition to the specification review committee, proposed changes are reviewed by several external parties. In the case of special specifications, the construction contractor on the project is a key player in shaping the new policy. Supplementary funding for highways is often provided by the FHWA, giving them the power to review specification changes. Each state has local chapters of the Associated General Contractors (AGC) of America that represent the interests of the contractors in a given state. The AGC is consulted to ensure that new specifications are not too onerous on contractors. Other parties may play various roles on a case-by-case basis, such as academic consultants, private financial investors, etc.

The state DOTs are the most important players in specification reform, often initiating reform as well as passing new policies. Therefore, it is critical to understand the state DOTs' decentralized organizational structure. State DOT organization is similar across the United States, with only minor variations from state to state. The DOTs geographically split their state into several districts that are run by district offices. These offices manage the majority of roadway construction projects, with the exception of special projects (e.g., large or complicated projects) that are managed by the central office. The central office handles specifications, research, and funding distribution. The district offices receive funding from the central office, and generally follow the technical guidance from the central office, but have a certain degree of latitude in the execution of their projects. As we will demonstrate, this operational independence turns out to be an important feature when considering the diffusion of innovation.

To our knowledge, IC has yet to pass statewide specifications in any state, but special specifications for IC exist in at least 10 states (*13–15*). As a result, this research focuses mostly on the passage of special specifications, the crucial first step for any emerging technology in highway construction.

KINGDON'S THEORY OF PUBLIC POLICY MAKING

Scholars and other external observers have sought to understand the manner by which public policy manifests change [e.g., (*16*)]. John Kingdon presents a formalized theoretical framework in an attempt to characterize policy reform activities (*4*). Kingdon begins by identifying the plethora of topics associated with a given domain, which individually may or may not be paid serious attention. Of particular interest is the narrowing process by which specific issues and initiatives become selected to a decision agenda from what could otherwise be described as an infinite realm of possibilities. Kingdon's theory of public policy-making establishes a framework that enables us to understand and identify the motivations and drivers behind setting the decision agenda within a given institution.

Kingdon's theoretical framework describes public policy agenda setting as a confluence of three streams (*17*):

- Problem: defining a situation such that it is deemed a problem requiring attention;
- Policy: developing technically and practically viable solutions; and
- Political: a prevailing political environment conducive to changing the domain in question.

Kingdon's *stream* analogy exemplifies the dynamism associated with each of the three components of policy formulation. These processes develop and evolve coincidentally rather than according to a formal or linear progression, as borrowed from the garbage can model of Cohen et al. (*17–18*). Policy reform results from streaming confluence under a window of opportunity opened by both specific causality as well as probabilistic serendipity (*16*).

Kingdon conceptualizes the interaction of three streams in the context of decision agenda setting and policy-making at the federal level. Scholars have suggested that Kingdon's framework may, however, apply more generally to all policy environments. Kingdon's analysis approach has been applied to policy environments such as state legislative bodies and federal scientific–bureaucratic institutions (*19–20*). In nearly all cases, authors have ultimately identified theoretical limitations with respect to specific application outside Kingdon's original lens.

METHODOLOGY

We conducted interviews in order to investigate causal relationships and key players in the policy reform and innovation diffusion process. Interviewees included members from several state DOTs, comprising employees from central and district offices, FHWA officials, construction contractors, and QC–QA contractors. The position of interviewees ranged from project managers to research engineers to materials engineers. Participants were initially selected by cold calling individuals connected to intelligent compaction by technical reports. Additional participants were identified in a snowball fashion, whereby interviewees were asked to suggest other candidates from their professional network. The process was considered complete once we had collected data from participants at all affiliations deemed important by the interviewees. Additionally, at this point, conclusions drawn from interview materials tended to converge.

Interviews were conducted face to face and over the phone, typically lasting about an hour. A predetermined set of questions formed the basis for about half of this time period, with the remainder of the interview being a free-form discussion allowing participants to direct the conversation into rich areas. All interviews were recorded for analysis purposes and coded using Dedoose (see www.dedoose.com). Dedoose is an online qualitative data analysis tool. We used this tool to facilitate the organization and quantification of interview results.

Analysis

This research identifies the importance of personal character among key players, with respect to both problem definition and innovative championship. Second, regulation with state and federal DOTs is a highly technical policy-making environment, which has some implications on the role of bureaucrats in decision making. Finally, we address the prevailing path by which IC policy is ultimately raised to the decision agenda.

Personal Character

One participant stated, "Personalities, one word...," when asked to comment on DOT climates that may foster or hinder innovation. Personalities determine how one defines a problem; in this case whether current spot-testing techniques and incongruence between design and assessment parameters is a problem or not. In the case study on IC, there is hardly a clear distinction between this being a "situation" and a "problem." An individual's innovation proclivity impacts this distinction, and therefore the likelihood they will contribute to developing the problem stream. In the case of IC, this personal characteristic can even serve as a more critical decision making factor than exposure to technical and visual evidence of performance improvements. In fact, one participant indicated that often personal character can outweigh technical research and field validation of IC with disinterest and lack of acceptance. At the very least, one's innovation proclivity impacts the way they interpret policy alternatives and problems, not to mention what values they base their decisions upon.

What makes an individual tolerant of innovation and risk? To answer this, we can leverage the large body of literature concerning innovation in combination with our study results. None of the participants was an explicitly, self-proclaimed hindrance to innovation. However, we only considered innovators to be those that could give concrete examples of where they had championed innovation, which amounted to 55% of participates. Study found a positive correlation between level of education and proclivity towards innovation, with 100% of participants with graduate degrees having specific examples of supporting an innovation. This concept concurs with prevailing literature, which suggests that individuals with an advanced structural organization of knowledge are better innovators (*21*). We did not find any correlation between age and innovation, further supporting claims that innovation tendency is independent of age (*21*). In interviews, supporters of innovation were often described as leveraging sizeable professional networks, which agrees with research that shows a statistically significant correlation between one's personal network and diffusion of innovations in housing construction regulation (*22*). Interviewees particularly emphasized the role of professional networks in providing exposure to a variety of ideas and demonstrations, and commanding a degree of credibility contributing to the capacity to spread ideas.

Most important to understanding ideological stances, we look at motivation. An individual's stance on innovation and risk can be motivated either intrinsically or extrinsically. A study surveying eight DOTs found that the institutional incentives for innovation consisted solely of recognition (*23*). Incentives that were mentioned included recognition in newsletters and notoriety from technical conferences. Study participants reported that these extrinsic incentives do not drive policy entrepreneurs. Participants resoundingly attributed personal character—that is, intrinsic motivation—as the dominant catalyst for policy change. Kingdon identifies three categories of incentives pursuant of the entrepreneur: personal interest, values promotion, and pure enjoyment of the game (*4*). The innovators identified in this study had no personal gain from the success of IC and did not appear to be "policy groupies" (*4*, p. 123), thus suggesting them to be motivated by values promotion. Interviewees described champions of innovation as risking their short-term performance goals and professional reputations. One participant said of innovating, "you're swimming up Niagara Falls, and your reputation is on the line." Yet, these individuals are the key to driving innovation.

DOT Regulatory Environment

The structure of the DOT has specific implications on agenda. The DOT regulatory environment is referred to here as a scientific bureaucracy (*20*). So-called scientific bureaucracies are said to privilege scientific research as the basis for bureaucratic policy output, as opposed to, for example, values-based decision making (*20*). This study in particular considers two focal points characteristic of DOT regulatory institutions. Firstly, we look at ideological affiliation, not in the context of political persuasion as with Kingdon's theory, but with respect to innovation proclivity. Secondly, we look at the balance of power between bureaucrats and political appointees.

Proclivity to innovation and risk taking is the most relevant ideological affiliation to this case study, as opposed to political party as discussed by Kingdon (*4*). At no point was political affiliation mentioned by participants, either to identify themselves or others. Yet a wide variety of terms were used to describe innovation proclivity characteristics, such as "forward thinker" and "innovation minded" versus "uninterested in new things" and "stick-in-the-mud." Individuals in the transportation construction network contribute to or impede the progress of a policy change related to IC according to their innovation proclivity.

The dominance, or lack thereof, of this ideology can vary highly from state to state, and within different networks in the same DOT. Changes in the political makeup of a particular network depend mainly on turnover of positions. Some participants felt that long term shifts in political makeup were occurring due to promotion criteria and practices. While this phenomenon seems possible, studying these changes was beyond the scope of this study, and would be worth further consideration.

Kingdon stresses the role of political appointees in defining the political environment, suggesting the existence of a top-down power structure: "the appointees, not the career civil servants, are the movers and shakers" (*4*, p. 30). Our findings, however, indicate that this model for federal policy agenda setting differs considerably from state transportation construction policy agenda setting. None of the study participants indicated the influence of the politically appointed DOT directors to be a significant factor in IC adoption, or innovation in general. DOT regulatory reform appears to occur outside the influence of appointed positions and in fact, civil servants tend to operate as policy entrepreneurs.

This agenda setting structure is perhaps due to the highly technical nature of infrastructure construction. Specialists, in the form of civil servants, are disposed with more agenda-setting power than appointees. Yet some DOTs are clearly the front runners in use of IC, suggesting the presence of unique conditions that foster innovation at these DOTs. Identifying the institutional positions within which these entrepreneurs act is the first step in understanding a political environment.

We propose a method for identifying a DOT's ideological distribution through a classification system based upon participant interview. The manner in which a political environment becomes conducive to policy change involves strategic, albeit serendipitous, positioning of four key roles presented in Figure 2. First, there are "policy explorers" that manifest problem awareness and demonstrate technical feasibility, often having to battle institutional inertia. Interviews revealed these individuals to exist as DOT research engineers, DOT district engineers, and construction contractors. For an innovation to proceed to the next level, explorers must make a successful hand off to "policy pioneers." Pioneers are individuals willing to expend political leverage, energy, and resources to implement a new technology, such as IC, on DOT projects. This entails passing a special specification for the project, requiring political influence that can typically only be exerted by a DOT District Engineer or a contractor. Special specification passage generally requires an iterative interchange between the various key roles.

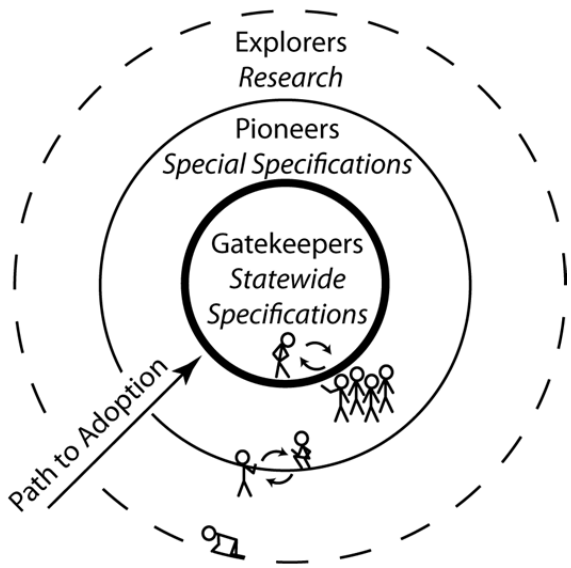

FIGURE 2 Depiction of three of the four roles required for innovation adoption in highway construction: explorers research potential innovations; pioneers apply promising innovations on projects through special specifications; and gatekeepers determine if an innovation is suitable for statewide use. The fourth role, leaders, helps to coordinate and motivate the interactions of the other roles.

Upon successful implementation of the innovation via the special specification, it can be considered for full adoption by the gatekeepers, who often sit on a specification review committee. These committees vary in composition between states, but often include chief engineers and division engineers. Gatekeepers also include certain outside organizations, including funding agencies (e.g., FHWA) and professional organizations (e.g., AGC) that can block the passage of a specification. Finally, there must be leaders willing to endorse an unaccepted technology via a vast political network. Leaders are critical in coordinating and motivating the hand-off between the aforementioned levels. This power anecdotally resides in high ranking management positions. When there is ideological alignment of individuals in exploring, pioneering, gatekeeping, and leadership roles, the political stream is ripe for innovation-based policy agenda setting.

CONCLUSION

U.S. DOTs face a tough road ahead with constricting budgets and deteriorating highway conditions. Technological innovation is one means to alleviate this pressure, but the highway construction industry is slow at adopting new innovations. In this paper, we have sought to understand this innovation adoption process through a case study on IC, and with the aid of Kingdon’s theory of agenda setting. Our intention was to provide insights into DOT policy reformation processes that we hope the industry will find useful in streamlining adoption of future innovations.

First, perhaps the most critical factor driving innovation adoption is the personal character of the people involved; their risk tolerance and perseverance are what give an innovation a chance at adoption. Coincident with the literature, personal character is duly noted as one of the primary motivators for policy entrepreneurs. Additionally, this research identifies the importance that personal character plays in a more general sense, that is, with respect to an innate tendency of personnel in this industry to either accept or reject innovation. Given the role personal character plays in facilitating innovation adoption, DOTs may wish to consider the impact that their hiring and promotion processes have on their desired level of innovation.

Second, the highly technical nature of DOT policy-making differentiates it from other highly politicized environments. This technical policy environment results in a need to redefine ideological affiliations as a proclivity towards innovation, rather than political affiliation. Further, it is clear that it is the career civil servants that need to be the "movers and shakers" for specification reform, rather than the political appointees. We define four roles that policy entrepreneurs fulfill in the DOT technology adoption process: the policy explorers, policy pioneers, gatekeepers, and leaders. Alignment of these individuals within a professional network creates a pathway to innovation adoption. The identification of these roles may assist innovation-minded leaders in structuring initiatives to promote technology adoption.

It is the authors' hope that these contributions will provide tools that help manage innovation adoption in the highway construction industry.

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Enhancing the Culture of Innovation in a Department of Transportation

John Siekmeier
Minnesota Department of Transportation

Effective innovation deployment is important because delay during implementation can have adverse consequences that include wasted labor, wasted energy, and wasted material resources. Enhancing the culture of innovation combined with clear performance standards at Minnesota DOT will improve our ability to maintain roadways and other transportation assets across Minnesota. Better performing roadways are expected to increase the public's confidence in our stewardship and increase the public's willingness to provide additional transportation investment through increased taxes.

Minnesota DOT's organizational culture significantly influences the deployment of innovative technologies, practices, and policies. A well-functioning organization, in ways similar to America's tradition of success, encourages exploration, rewards pioneering, and welcomes a diversity of employees as the organization embraces greater effectiveness. By demonstrating a renewed good faith effort to deploy innovative solutions, Minnesota DOT does its part to improve service delivery and enhance performance.

Employees throughout Minnesota DOT continue to strive to better serve the people of Minnesota. This shared employee commitment is demonstrated by the "big ideas" offered to Minnesota DOT leadership in the *Innovation Culture Assessment Report*. Positive change is underway because as a leader noted many years ago "the people insisted on changes and they were made." When fully implemented, these changes will enhance government effectiveness and guarantee accountability for the people's investments for decades to come.

AGREEING ON POSTIVE OUTCOMES

At the beginning of the journey toward more effective innovation deployment it is helpful to agree on the positive outcomes that are likely to result from successful deployment. During the construction of road foundations it is expected that enhanced process control will produce the following positive outcomes:

1. Empowering the equipment operator and the construction inspector with better information while construction is occurring so that process improvement occurs immediately.
2. Improving road foundation quality and uniformity by increasing performance-based measurements, optimizing compaction in deficient areas, and prudent utilization of materials.
3. Creating a much more complete record of the as-constructed pavement foundation in order to enhance continuous learning resulting in better performing pavements in the future.

To succeed in effective innovation deployment, it will likely be necessary to overcome a variety of challenges that can impede effective innovation deployment. These challenges may include organizational inertia, failure to recognize existing opportunities for innovation, impaired organizational structures, and a complacent organizational culture. Other reasons for poor roadway condition include deferred maintenance, less than optimal project selection, misplaced financial incentives, reduced construction inspection, and inadequate investment. It is necessary to overcome these challenges and establish a culture of innovation because we can't meet today's needs with yesterday's technologies and policies. Positive change will be driven by authentic leaders with the help of empowered and resilient employees.

One specific challenge today is that many departments of transportation are implementing a new pavement design method in order to optimize financial effectiveness and improve pavement performance. This new design method requires new inputs for the pavement foundation materials. However the quality assurance testing required during construction is not yet utilizing readily available tools, which would provide the quantitative measurements needed during design. This type of inefficiency between the design and construction silos of an organization is an example of what the new federal Moving Ahead for Progress in the 21st Century Act (MAP-21) performance requirements were created to mitigate.

MAP-21 requires performance-based measures to be implemented by the state DOTs and many agree that it would enhance organizational effectiveness if performance-based predictive (lead) measures were used in addition to consequential (lag) measures. Verification of design parameters during construction is an example of implementing a predictive measure such that performance expectations are achieved. Other performance measures are included in the appendix of this paper as examples, which demonstrate the new paradigm required by MAP-21. These measures are suggestions offered by the people of communities across our country to gratefully honor the words of President Lincoln: "government of the people, by the people, for the people." Earlier in 1863, President Lincoln had established the beginnings of today's National Academies, which continually delivers research products that are expected to be deployed by government agencies.

ORGANIZATIONAL INERTIA

Many organizations have a tendency to resist change, which may be verbalized as "that's how we do it here" or "we've always done it that way." These are common barriers to innovation and quality improvement. Inertia may also exist even when our established practices are flawed. For example, Ralph Proctor's original QA method for soil compaction, which was successfully implemented during the 1930s and 1940s, was a performance-based strength test. However, our established practice today is not what Ralph Proctor and his staff were doing successfully 80 years ago. Proctor's inspection staff used "firm blows" to compact soil specimens by swinging a hammer, not just dropping a hammer as is done today. Today's typical procedure results in less compaction and lower soil strength than was achieved on Proctor's construction sites during the 1930s and 1940s. After many years of successful construction deployment, Proctor summarized his methods in several publications during 1945 and 1948: "Methods for hand compaction, such as dropping various weight tampers from different heights and mechanical tampers, were tried and discarded. No use is made of the actual peak dry weight. The measure of soil compaction used is the indicated saturation penetration resistance."

In spite of Proctor's very sincere efforts to correct the technical record, our typical construction testing practice today prescribes what Proctor clearly recommended against. "Dropping various weight tampers from different heights" and using the "peak dry weight" to assess compaction. Compounding this irrational situation today is that we have vast computing power and existing instrument technology that Proctor could not have conceived of 80 years ago. Yet he and his inspection staff were building successful projects and using performance-based testing methods, which we are struggling to deploy today.

OPPORTUNITIES FOR INNOVATION DEPLOYMENT

Opportunities for greater innovation deployment currently exist. It is unclear, however, why these opportunities are not better recognized in spite of easy access to existing specifications and other publications, supplemented by internet-based webinars provided by multiple professional organizations. For example, several recent publications by the National Cooperative Highway Research Program (NCHRP) include:

1. *Synthesis 456: Non-Nuclear Methods for Compaction Control*;
2. *Synthesis 445: Practices for Unbound Aggregate Pavement Layers*; and
3. NCHRP Project 10-84: Modulus-Based Construction Specification for Compaction of Earthwork and Unbound Aggregate.

In addition, recent publications by the Strategic Highway Research Program (SHRP 2) include:

1. Project R07: Performance Specifications for Rapid Highway Renewal and
2. Project R02: Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform.

Existing ASTM standards include:

1. D 6951-03: Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications;
2. E 2583-07: Standard Test Method for Measuring Deflections with a Light Weight Deflectometer; and
3. E 2835-11: Standard Test Method for Measuring Deflections Using a Portable Impulse Plate Load Test Device.

Draft AASHTO standards proposed by others include:

1. Standard Specification for Modulus-Based Quality Management of Earthwork and Unbound Aggregates, proposed NCHRP 10-84; and
2. Performance Specifications for Earthwork/Pavement Foundation, proposed SHRP2 R07.

Other opportunities are provided to state DOTs through participation in the FHWA Transportation Pooled Fund (TPF) Program. The TPF Program currently includes TPF-5(285): Standardizing Light Weight Deflectometer Measurements for Quality Assurance and Modulus Determination where 10 states are cooperating to enhance lightweight deflectometer deployment. The TPF Program also includes TPF-5(233): Technology Transfer Intelligent Compaction

Consortium where 11 states are collaborating to implement IC technologies in order to improve pavement performance.

Finally, construction equipment manufacturers are deploying new equipment, which quantifies compaction while construction is occurring so that corrective actions can occur immediately thus reducing waste and eliminating future costs. Similarly, testing equipment manufacturers are also deploying new testing devices, which are performance based and therefore better able to measure the critical properties effecting pavement performance.

STRUCTURAL CHALLENGES

The organizational structure of many DOTs creates challenges for innovation deployment. Generally, there is a need to strengthen horizontal linkage across silos, and lessen the negative effects of vertical hierarchy and a feudalistic management model. Creating successful horizontal linkages and greater representation across silos enhances innovation deployment by improving communication and the ability for follow-up action (Figure 1). This improves participation by district and central office staff as well as participation by maintenance, construction, and design staff. It is good to recall that maintenance staff are responsible for the long-term stewardship of our transportation assets and therefore must participate fully during design and construction conversations in order to enhance the effectiveness of future projects.

Supportive actions are currently under way at the Minnesota DOT to mitigate some of the known obstacles. These supportive actions include:

1. Identify a single departmentwide strategic priority to focus our efforts on "enhancing financial effectiveness."
2. Establish a Materials Advisory Committee to better listen to our customers and encourage fact-based asset management.

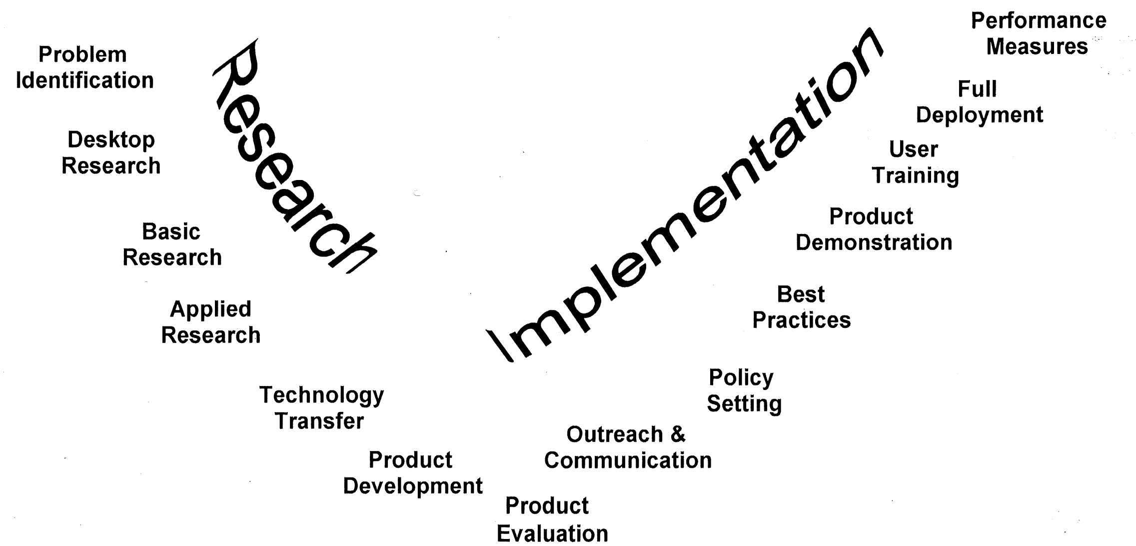

FIGURE 1 Strengthen horizontal linkage across silos and lessen negative effects of hierarchy.

3. Continue to engage with the construction industry, share ideas, and deploy innovative solutions in partnership.
4. Improve transparency and measurement of transportation asset condition so that the public can better communicate their commitment to transportation investment as a necessity for safe travel, economic well-being, and livable communities.
5. Provide employee access to the Leadership Development Program and requiring greater participant accountability.
6. Encourage teamwork through Employee Resource Groups and Technical Work Groups, which increase creativity and the courage to take action. These employee-led teams are enhancing the culture of innovation because they understand that there is no "I" in team and no place for indifference, intimidation, or ignorance. These teams value engagement, empathy, and education and are grateful to everyone that chooses authentic participation.
7. Enhance cooperation between the employees and management through regularly scheduled meet and confer meetings supplemented by additional communication.
8. Create supportive tools available to all employees such as the Decision Support Tool and Executive Briefing Tool, which facilitate communication, fairness, and agreement. These tools are used to document relevant information while making important, strategic, and controversial decisions.

Developing and implementing an effective culture of innovation includes familiarizing oneself with the following definitions, which describe the terms in Figure 1.

1. Problem Identification is likely the most important step because this requires recognition of a need. This also requires acknowledgement that failure to act is not acceptable for good stewards of public assets.
2. Research means a systematic controlled inquiry involving analytical and experimental activities, which primarily seeks to increase the understanding of underlying phenomena. Research can be desktop, basic, or applied.
3. Desktop Research involves collecting, analyzing, and synthesizing existing information. It can be the basis of further research or can lead directly to implementation.
4. Basic Research means the study of phenomena whose specific application has not been identified. The primary purpose of this kind of research is to increase knowledge.
5. Applied Research is the study of a specific need in connection with the functional characteristics of a system. The primary purpose is to answer a question or solve a problem.
6. Implementation is the process of putting the results of research into practical use in order to realize a measurable return on investment.
7. Technology Transfer is the conveyance of research results to entities capable of using the results to produce operational products and also providing ongoing support during deployment.
8. Product Development means the translation of research results into prototype materials, devices, techniques, enabling technologies, and procedures for the practical solution of a problem.
9. Product Evaluation is the testing of a new product or procedure to determine its ability to perform in an operational environment.
10. Outreach and Communication are processes for sharing information about a new product or procedure with specific audiences using targeted messages.

11. Policy Setting is requesting that management adopt a new product or procedure based on benefit, cost, and other relevant information. This process leads to decisions about the resources required for full deployment.

12. Best Practices is a program to identify, prioritize, and allocate resources for deployment.

13. Product Demonstration is showcasing a new product or procedure in an operational environment for the purpose of informing decision makers and potential users about its capabilities and limitations.

14. User Training is an educational program that matches the specific needs of various groups to enhance effective deployment.

15. Full Deployment is the point at which research results are put to use in an operational environment to the extent practical.

16. Performance Measures are metrics that allow progress toward an outcome to be quantified and these are critically important during effective innovation deployment.

ORGANIZATIONAL CULTURE

The organizational culture and worldview of the employees significantly influence innovation deployment. Therefore it is crucially important to respect all people and seek common ground. It is also important to recognize that individual employees may act as explorers, pioneers, or settlers as they perform their job functions. A well-functioning organization, in ways similar to America's tradition of success, encourages exploration, rewards pioneering, and welcomes a diversity of employees as the organization embraces greater effectiveness and sustainable resource utilization.

In spite of the challenges described earlier, there is much common ground between employees throughout the organization. Most agree that it is appropriate and necessary that government strive to reduce waste, preserve assets, encourage innovation, and conserve our world's limited economic and natural resources. This shared employee commitment is demonstrated by the following "big ideas" offered to Minnesota DOT leadership in the Innovation Culture Assessment Report.

Positive change is underway because as a leader noted many years ago: "The people insisted on changes and they were made." It's also good to remember the wisdom of others who understand that good leaders need to really listen and mean it when they say "Tell me something I don't know and that I'm not going to like." Big ideas one through nine focus on how to create, sustain, and implement innovative technologies, practices, and policies throughout Minnesota DOT. Big ideas 10 through 14 are intended to create paradigm shifts that enhance Minnesota DOT effectiveness.

MINNESOTA DOT's BIG IDEAS

1. Make Innovation Visible

Challenge

Minnesota DOT is a large organization with many moving parts. Innovative ideas and activities are underway, but not well-distributed across the organization.

Opportunities

- Market innovation;
- Celebrate innovation;
- Endorse innovation;
- Create an innovation "brand" to message and promote innovation excellence;
- Make innovation integral to employee performance reviews;
- Celebrate successes and failures;
- Celebrate individuals, teams, offices, and districts; and
- Showcase innovation so it is visible everywhere and available for everyone to see.

2. Make Innovation Possible

Challenge

Minnesota DOT is a diverse organization with many talents, tools, and assets. Minnesota DOT has an opportunity to make innovation possible by leveraging time, dollars, and other resources.

Opportunities

- Create white space for innovation by allowing time to work on new ideas.
- Create an innovation bazaar where employees have the opportunity to show other Minnesota DOT employees from across the department what innovations are underway.
- Provide funding with minimal bureaucracy to work on innovative ideas.
- Provide financial compensation to districts when deployed research does not perform well.
- Identify and deploy innovation champions that display a passion to serve and are empowered to work across silos to implement innovative ideas aligned with the strategic direction.
- Allow funding to be rolled over from one biennium to the next so that implementation of innovation concepts can continue.
- Identify what does not need to continue and reduce "too much work on the plate."

3. The District Is the Customer

Challenge

Minnesota DOT is both a centralized and decentralized organization. Embracing “The District is the Customer” concept will positively influence innovative technologies, practices, and policies and their adoption.

Opportunities

- Create shared visions;
- Create shared outcomes;
- Create collaborative environments;
- Create demand for innovative solutions;
- Allow flexibility to create both project-based and function-based teams; and
- Develop “relationship managers.”

[NOTE: (*a*) The districts are the customers and integral to adopting innovation. (*b*) The technical offices should offer to lead as needed. (*c*) The central office needs to listen, understand, anticipate, and communicate.]

4. Share, Share, Share

Challenge

Minnesota DOT has a diverse workforce with multiple offices and unique operating structures. This creates many challenges for effective communication and sharing ideas. These challenges are expected to grow in difficulty in the future unless new strategies are developed and deployed.

Opportunities

- Leverage social media opportunities (Facebook, Twitter, Wikis, YouTube, and more).
- Share best practices formally and informally.
- Showcase new ideas and technologies.
- Enhance online forums and encourage posting of innovative ideas.
- Listen to constituents, customers, and suppliers.
- Create webinars to share ideas and innovations.

5. Challenge Lock-Ins

Challenge

One of the greatest barriers to innovation at Minnesota DOT relates to “Lock-Ins.” Lock-Ins are behaviors, structural processes, and cost elements allowed to exist without clear benefit. Lock-Ins inhibit innovation and are barriers to becoming a nimble organization. Lock-Ins include:

- Processes and procedures that once worked, but are now a deterrent.
- Bureaucratic obstacles during funding of innovative activities.
- Poorly aligned employee strengths with job duties.
- Attitudes that inhibit innovation.
- Consensus decision making that is inconsistent with engineering best practice.
- Existing rules and institutional inertia, which perpetuate "that's how we do it here."
- Project lock-in once a project is designed or defined in a request for proposal.
- Project lock-in once a project is funded.

Opportunity

Establish processes that identify, challenge, and eliminate lock-ins and other barriers.

6. Create Learning Environments

Challenge

Minnesota DOT is an organization with many diverse functions requiring expertise and experience. Due to the multifaceted nature of Minnesota DOT, the potential for knowledge loss is immense.

Opportunities

- Create learning environments where knowledge and experience can lead to a more responsive and nimble organization.
- Conduct project debriefs following every major project and some minor projects.
- Create a list of innovative ideas following each project.
- Develop communities of practice for project managers to share lessons learned.
- Share best practices and innovative ideas.
- Develop processes and formats for sharing ideas.
- Encourage strong department leaders to stay in their current position.
- Create, maintain, and enhance technical expert offices.
- Leverage the knowledge of contractors through greater participation and partnership.

7. New Office Strategy

Challenge

Minnesota DOT is able to test new ideas, processes, and procedures by creating new offices. This holds many benefits since it carries over few processes from an existing office and creates leadership opportunities for motivated employees. The downside of creating new offices is that unintended consequences will likely occur such as increased organizational complexity and redundancy.

Opportunities

Two strategies should exist when a new office is proposed (creation and consolidation):

1. Office creation. What are the goals for the new office? Who will lead it? What will it look like? What are the desired outcomes? By when?
2. Office Consolidation. If a new office is successful and achieves the desired outcomes, what happens? Does it remain as a standalone office or is the new team consolidated back into an existing office? What is the timeline for this to occur? Who is responsible for combining offices?

8. Design Thinking

Challenge

Several projects have followed the design–build contracting process with success. This process is referred to as "design–thinking" in the innovation community. Design–thinking is a creative problem solving approach where innovation is best thought of as a system of overlapping spaces rather than a sequence of orderly steps.

Opportunities

- Utilize design–thinking to alter the structure and processes of offices.
- Utilize design–thinking to identify Lock-Ins and create sensible alternatives.
- Utilize design–thinking to better connect with stakeholders.
- Utilize design–thinking to optimize office space and resource utilization.
- Utilize design–build contracting processes in other areas where design–thinking creates benefit.
- Utilize consultants and university professors to provide additional design–thinking opportunities.

9. Institutionalize Innovation

Challenge

As a government entity, Minnesota DOT's sincere efforts to enhance its culture of innovation can be easily sidetracked when a change of administration occurs. These changes are a distraction and provide a reason to not fully invest in, and commit to, innovation. Innovation should not be viewed as a cost, but rather as an investment that will enhance future prosperity and opportunity.

Opportunities

- Strive to create a culture of innovation that is resilient during political changes.
- Demonstrate that innovation provides a competitive advantage for the state.
- Publicize how innovation produces a positive return on investment for the state.
- Publicize and market innovative technologies, practices, and policies.

- Institutionalize innovation as an everyday occurrence.

10 Through 14

Big ideas 10 through 14, below, have been offered to Minnesota DOT leadership from employees with the expectation that these ideas will create paradigm shifts that enhance Minnesota DOT effectiveness for decades to come.

10. Project managers could choose to significantly alter past practice to improve how the work gets done.
11. Implement best-value processes that leverage contractor expertise and participation to identify what works well, what does not, and how to best enhance effectiveness.
12. Redesign Minnesota DOT from the ground up to create an organizational structure optimized to deliver the outcomes expected by the people of Minnesota. Fully consider which offices and positions should be retained and enhanced.
13. Buy out employees who create barriers to greater effectiveness and consider early retirement incentives. Implement the wisdom of President Lincoln: "I want it said of me by those who knew me best that I always plucked a thistle and planted a flower where I thought a flower would grow."
14. Assign leadership development coaches to leaders across the organization in order to leverage leadership instruction, learning, and new skill deployment.

LESSONS LEARNED

The hard work continues because it's the right thing to do. We are working better together and listening to our customers in order to prioritize our work and commit the resources required to be more effective. It is also becoming acceptable for employees to act boldly as management invites others to be part of the solution and take action. We understand that change is not easy.

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APPENDIX

These example performance measures for surface transportation sustainability are offered by the people from neighborhoods and communities across our country to gratefully honor the words of President Lincoln "government of the people, by the people, for the people."

Performance Measures That Assure Freedom to Move for All

- People moved within the trunk highway right of way (count).
- Business products moved within the trunk highway right of way (dollars).
- Fatalities and injuries for each travel mode (per mile traveled and total count).
- Level of traffic stress for each travel mode (per mile traveled).
- Condition induced vehicle damage and insurance for each travel mode (dollars).
- Travel time reliability personal vehicles, business vehicles, and transit (minutes per mile).
- Ride quality personal vehicles, business vehicles, and transit (rating per mile).
- Incident and crash management deployed (miles).
- Intelligent transportation system technologies deployed (miles).
- Remaining service life pavement (years per mile).
- Structurally deficient bridges (count).
- Intersection average daily traffic for each travel mode (count).
- Intersection fatalities and injuries for each travel mode (count).
- Intersection safety and maintenance level of service for each travel mode (count).
- Intersection person delay for each travel mode (seconds).
- Sidewalk (miles), Americans with Disabilities Act (ADA)–compliant sidewalk

(miles).

- Sidewalk ramps (count), ADA-compliant ramps (count).
- Sidewalk safety and maintenance level of service (miles); ramps (count).
- Sidewalk remaining service life (years per mile); ramps (count).
- Bikeway on-highway protected lane (widths and miles).
- Bikeway on-highway marked lane (widths and miles).
- Bikeway off-highway (widths and miles).
- Bikeway ride quality (miles).
- Bikeway safety and maintenance level of service (miles).
- Bikeway remaining service life (years per mile).
- Intermodal connections completed (count).

Performance Measures That Promote the General Welfare and Establish Justice for All

- Household transportation cost for each travel mode (dollars per year).
- Access to employment for each travel mode (count).
- Access to education for each travel mode (count).
- Access to health care for each travel mode (count).
- Access to recreation for each travel mode (count).
- Access to crossings of trunk highway right of way (per mile).
- Local main street compliant with complete street statute (miles).
- Public health outcomes for each travel mode (count).
- Equitable distribution of impacts for each travel mode (dollars).
- Equitable distribution of energy consumption for each travel mode (kW-h).
- Equitable distribution of material consumption for each travel mode (tons).
- Equitable distribution of hiring opportunities for each travel mode (jobs).

Performance Measures That Secure the Blessings of Liberty for Tomorrow

- Reduce financial liability resulting from poor infrastructure condition (bond interest rate).
- Reduce pollutants produced within trunk highway right-of-way (tons).
- Reduce greenhouse gases produced within trunk highway right-of-way (tons).
- Reduce energy consumption within trunk highway right-of-way (kW-h).
- Reduce material consumption within trunk highway right-of-way (tons).
- Enhance utilization of land currently served by transportation infrastructure (acres).
- Enhance utilization of land currently served by utility infrastructure (acres).
- Restore working lands such as agricultural and forest lands (acres).
- Restore recreational lands such as parks, trails, and open space (acres).
- Restore natural lands, waters, wetlands, and wilderness (acres).
- Restore cultural and historic lands (acres).

Implementing Dynamic Cone Penetrometer and Lightweight Deflectometer in Indiana

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Indiana DOT has been using density and moisture control for compaction control in embankment construction for many years. During this time, there has been disconnect between design and construction because embankment design is based on strength, whereas compaction control during construction measures density and moisture content. Indiana DOT and Purdue University Joint Transportation Research Program (JTRP) recommended the use of the dynamic cone penetrometer (DCP) and lightweight deflectometer (LWD) as alternative means of embankment and subgrade compaction control. Indiana DOT implemented research recommendations by constructing several pilot projects and revising recommendations as necessary. The revised recommendations were then used as more than 20 million cubic yards of soil and several million tons of aggregates were compacted with DCP and LWD measurements used for compaction control. This paper summarizes the implementation of DCP and LWD and the phasing out of nuclear density gauges, thus narrowing the gap between design and construction by measuring strength and stiffness in the field.

Indiana DOT requires compaction control based on density and moisture testing for soils in accordance with Section 203 of the Standard Specifications (*1*). Embankment material is required to be compacted to 95% of the maximum dry density with a moisture content that is controlled between –2 to +1 of the optimum moisture content. The moisture content for silt dominated soils is required to be within –3 percentage points of the optimum moisture content. Moisture for granular or nonplastic soil is required to be several points below the optimum moisture content. Maximum dry density and optimum moisture content is determined in accordance with AASHTO T 99 using method A for soils and method C for granular materials. The embankment loose lift may not exceed 8 in. (*1*).

There are often problems when the measured density using the nuclear gauge or sand cone method is compared with the density measured using the standard proctor test. The proctor test is measured in the laboratory using a small representative sample of the fill material. Scattered results between field and laboratory methods often result in disagreements between project personnel. Variation problems arise because of the following factors:

1. Differences in soils between the borrow pit and soil used for the embankment;
2. Time delay effects on the density and moisture of chemically modified soils;
3. Different compaction techniques between field and laboratory tests;
4. Different mixing processes between field and laboratory tests;
5. Nonuniform soil layers; and
6. Contractor methods of excavation of borrow soils.

All of these factors can cause problems during construction when teamwork, quality, and meeting deadlines are essential for successful and timely completion of a project. Reduced time spent on a project by a better connection with design parameters such as strength or stiffness during construction and with resilient modulus during design is critical. The compaction control measuring devices should be simple, easy to understand, robust, and precise enough to promote confidence with which Indiana DOT and contractor both can understand during embankment compaction. The strength and modulus measurements during compaction would help designers to understand material response during construction and help in cost effective future design.

Indiana DOT and the Purdue University JTRP have been studying various types of compaction testing equipment for several years and have published several research studies (*2–4*) which selected the DCP and the LWD as the test devices. DCP measures strength and can be related to California bearing ratio, gradation, modulus, and compaction uniformity whereas LWD measures the deflection and can be related to modulus. Indiana DOT DCP blow counts are related to minimum 95% of standard proctor. Moisture control plays an important role in maintaining adequate compaction. However, we are monitoring and calibrating DCP and LWD criteria by revising specifications based on feedback from construction, and Purdue University is further refining these criteria by performing additional research. These two types of testing equipment are simple, take only a few minutes to perform, and are easily understood by Indiana DOT and contractors.

DYNAMIC CONE PENETROMETER

DCP equipment (Figure 1) consists of an 8-kg hammer allowed to free fall a distance of 570 mm to drive a 16-mm steel drive rod with a 20 mm diameter and 60° conical tip below the testing surface. The conical tip may be either disposable or replaceable. An Indiana Test Method (ITM) has been developed for the use of the DCP.

The JTRP study recommended the use of the DCP for soil and the LWD for aggregates. The DCP research grouped the soils into several categories such as clayey, silty, and granular soils. Indiana DOT DCP blow counts were determined by performing a sieve analyses, ASTM D1140, Atterberg limits, AASHTO T 89 and T 90, and the standard proctor, AASHTO T 99. The DCP blow counts determined are shown below.

Silty or clay soils (clayey behavior PI >8):

$$N_{\text{DCP 0–6 in.}} = 17^{[-0.07(\text{PI})\ (\%\ \text{passing No. 40})/100]}$$

Silty, sandy, and granular soils:

$$N_{\text{DCP 0–12 in.}} = 4(\ln C_u) + 2.6$$

where

PI = plasticity index,
C_u = coefficient of uniformity,
$N_{\text{DCP 0–6 in.}}$ = blow counts for 0 to 6 in., and
$N_{\text{DCP 0–12 in.}}$ = blow counts for 0 to 12 in.

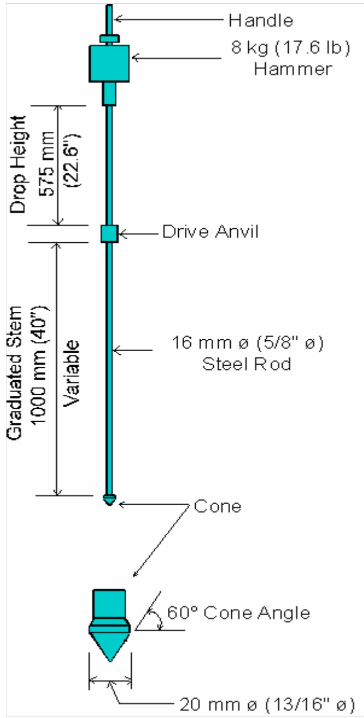

FIGURE 1 DCP.

District Testing Engineers and Geotechnical Engineers prepared a testing protocol to perform sieve analyses, Atterberg Limits, standard proctor, and the loss on ignition to characterize the soils (Figure 2).

The following laboratory tests are required:

- Sieve Analysis..................AASHTO T-88, T-89,/or ASTM D-1140
- Atterberg Limits .... AASHTO T-90
- Moisture –Density .... AASHTO T-99
- Loss on Ignition...............AASHTO T-267 (when required)
- Ca/Mg Carbonate............ ITM-507 (when required)

A representative soils sample (25 lbs) from project limit or borrow pit:

FIGURE 2 DCP lab testing for DCP blow counts.

The soils were grouped into clayey, silty, sandy, and nonplastic granular soil types (*5*). Blow counts were obtained from the designated formulas for each soil considering the soil behavior, density, plasticity, and uniformity. During 2011–2013, more than 20 million cubic yards of soils were used to construct numerous embankments at various locations in Indiana. From these projects, a relationship was found between soil plasticity and the maximum dry density (Table 1).

Soils were classified based on density (*5*). Identification of soil type and the use of the equation were very difficult; therefore, the soils were grouped based on plasticity or behavior which relates to the maximum dry density. The project personnel follow the blow count criteria given by the District Testing Engineer and verify the blow count and optimum moisture content by performing the One-Point Proctor when required (Figure 3).

TABLE 1 DCP Criteria for Compaction

Plastic Index , Max. Dry Density VS DCP blows Relation

S.No	Textural Classification	Plastic Index	Max. Dry Density pcf	DCP criteria for 6 in. lift	DCP criteria for 12 in. thick (2 lift of 6 in.) (95 % Compaction)	DCP Criteria for 0 to 12 in. thick (100% Compaction)
A	**Clay Soils**					
	Clay Soils	greater than 20	less than 105 pcf	7		
	Clay Soils	8 to 20	105 to 112 pcf	8		
B	**Silty Soils**					
	Silty Soils	4 to 8	113 to 116 pcf		10	
	Silty Soils	less than 4	117 to 120 pcf		12	
C	**Sandy Soils**					
	Sandy Soils	less than 8	121 to 125 pcf		12	
	Sandy Soils	less than 4	greater than 125 pcf		13	
D	**Granular Soils**					
	Structure Backfill					
	Structure backfill # 30				7	10
	Structure backfill # 4				9	12
	Structure backfill # 1/2 in.				11	14
	Structure backfill # 1 in.				18	–

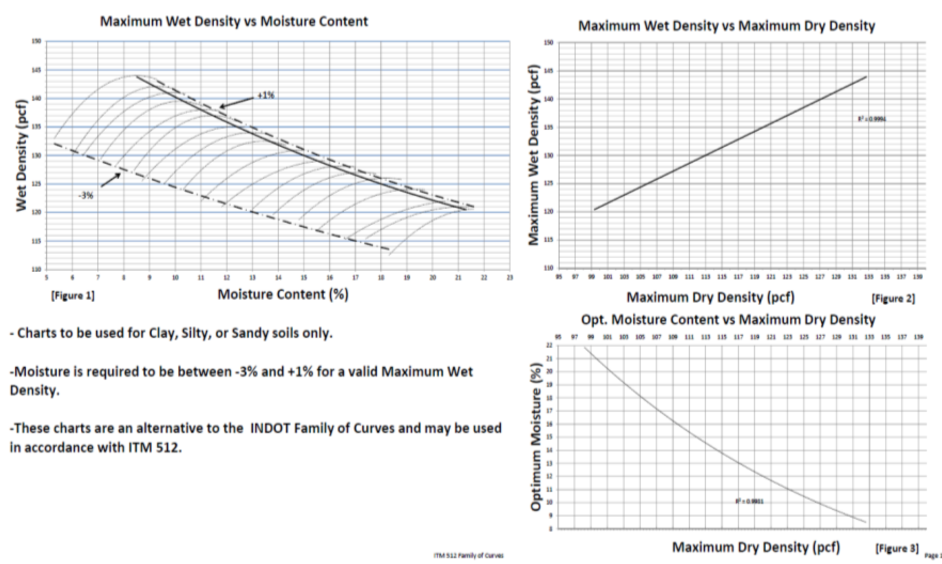

FIGURE 3 Indiana DOT family of curves.

The Office of Geotechnical Services and Materials Management oversee the DCP criteria for consistency. Indiana DOT field personnel are familiar with performing the One-Point Proctor Test at the project in accordance with ITM 512 (*6*). Upon determination of the target DCP blow count for a specific soil, QA tests are performed with the DCP in accordance with ITM 509, the moisture content in accordance with ITM 506, and the maximum dry density and optimum moisture content in accordance with ITM 512. Testing is performed in accordance with Figure 4.

The frequency of acceptance testing using the DCP is one test for each 1,400 yd^3. One moisture test is required each day. A recurring special provision (*7*) was developed for the use of the DCP. Stiffness relates to design modulus and improved compaction may reduce the pavement thickness. Indiana DOT has owned DCPs and LWDs since 2013 (Table 2). The use of the majority of Indiana DOT nuclear gauges were discontinued in 2013.

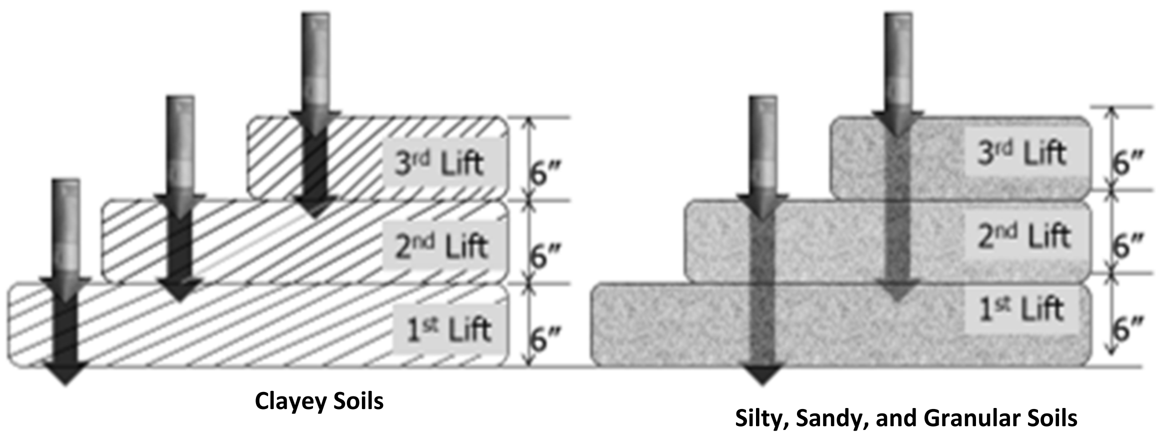

FIGURE 4 DCP testing of cohesive and granular soils.

TABLE 2 Indiana DOT Inventory of LWD and DCP Testing Equipment

LWD (ZORN) & DCP (KESSLER)		
District	**Total No's of LWD available**	**Total No's of DCP available**
CRAWFORDSVILLE	8	10
FORT WAYNE	8	17
GREENFIELD	11	30
LA PORTE	10	25
SEYMOUR	8	13
VINCENNES	13	20
Office of Geotechnical Services	2	2
Total	**60**	**117**

LIGHTWEIGHT DEFLECTOMETER

The LWD is a nondestructive testing instrument that simulates the effect of a moving load by dropping a 10-kg weight from a height of about 70 cm on the subgrade (Figure 5).

This test device generates a load of 7.07 kN by dropping a weight onto a plate placed on a test layer. The force is transmitted to a 30-cm diameter loading plate and the deflection is measured with the accelerometer. This deflection is then converted into the resilient modulus of the soil. The 30-cm diameter plate is used to measure the coefficient of subgrade reaction from bearing pressure-settlement curves at the same position as the falling weight deflectometer (FWD) to compare the results of the LWD test with those of the plate bearing test. Indiana DOT's Office of Pavement Engineering has been using resilient modulus as one of the input parameters in pavement design. LWD modulus determination helps designer to compare with laboratory modulus. LWD testing was initiated by Indiana DOT research and has been evaluated with other compaction devices in several research projects (*3*, *4*). The LWD was found to be an effective testing tool. The LWD improves the precision, reduces testing time, is easily understood, and requires minimum exposure to traffic. The test device also requires minimal training, no nuclear licensing, and relates to actual roller passes.

The Indiana DOT Office of Materials Management initiated discussion concerning the use of the LWD with Minnesota DOT based on their extensive experience with this test device. In 2011, Indiana DOT developed a unique special provision to use the LWD in compaction control of aggregates and chemically modified soils and developed ITM 508 for using the LWD. The unique special provision includes requirements that a maximum allowable deflection be determined with successive roller passes on a test section allowing a difference in deflection of 0.02 mm between two successive passes. The minimum passes are established at five passes of the roller. An alternate to the test section procedure is allowed that requires 10 LWD tests to be performed after achieving 100% density. The maximum allowable deflection for the particular material was the average of the 10 LWD tests and this value was used as the requirement for the

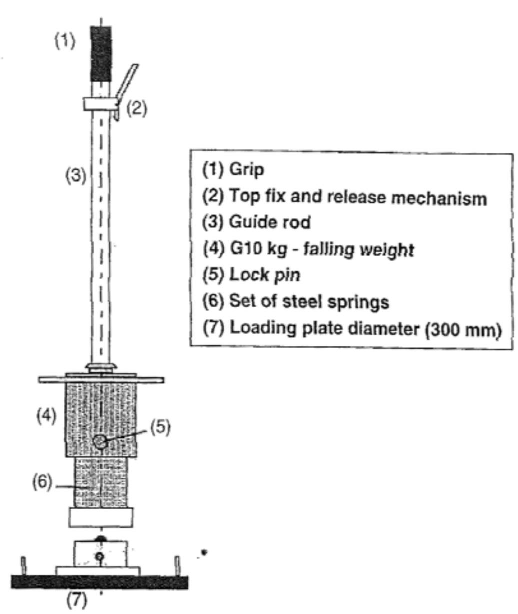

FIGURE 5 LWD.

project. Many projects were constructed during 2011, 2012, and 2013, and data from the test sections was collected. The testing frequency was based on Table 3.

After evaluation of numerous projects using the LWD, the unique special provision was revised to include a maximum allowable deflection for lime-modified, cement-modified, and aggregates over lime- and cement-modified soils (Table 4).

A test section is required for all other materials to establish the maximum deflection criteria. Indiana DOT District Testing also performs repeatability tests on the LWD prior to the start of the construction season.

DEVELOPMENT OF DOCUMENTS AND TRAINING PROGRAM

Indiana DOT Office of Materials Management, Office of Geotechnical Services, and District Testing developed numerous documents for soils and aggregate laboratory testing to assist construction inspectors and contractors in understanding the new techniques and procedures for soil and aggregate compaction. Several presentations were given throughout the state including the Road School at Purdue University in 2012, 2013, and 2014. These presentations are available at the JTRP website. These presentations emphasized the need for fewer air voids, appropriate moisture content, and adequate stiffness of embankment, subgrade, and subbase materials. These parameters can be achieved with adequate roller passes. Clay and silty soils can be effectively compacted by sheep foot rollers and nonplastic granular soils can be compacted by vibratory rollers. Following documents are available at the Office of Materials Management website (http://intranet.indot.state.in.us/materialtests/index.asp):

- ITM No. 508-12T: Field Determination of Deflection Using Lightweight Deflectometer;
- ITM No 509: Field Determination of Strength Using Dynamic Cone Penetrometer;
- LWD Field Testing Procedures Indiana DOT Office of Materials Management and Office of Geotechnical Engineering; and
- Light Weight Deflectometer TD, 409 LWD.

TABLE 3 LWD Acceptance Testing Criteria

Chemically modified soils	One test per 1,400 yd^3 for two-lane road
Chemically modified soils shall be proofrolled	
Aggregates over chemically modified soils	One test for 800 tons
Moisture test	One moisture test per day

TABLE 4 Maximum Allowable Deflection

Material Type	Maximum Allowable Deflection (mm)
Lime-modified soil	0.30
Cement-modified soil	0.27
Aggregates over lime-modified soil	0.30
Aggregates over cement-modified soil	0.27

- Dynamic Cone Penetrometer TD–409 DCP;
- Field Testing of Soils and Aggregates;
- Light Weight Deflectometer testing, Unique Special Provisions; and
- Dynamic Cone Penetration Recurring Special Provisions.

FUTURE WORK

Clayey soils are required to be compacted between minus 2% and plus 2% of the optimum moisture content. This range of moisture content may result in variability in the required DCP blow count for this type of soil. A study has been initiated to understand the DCP blow count variability from the dry side of optimum moisture content to the wet side of optimum moisture content for the clayey soils. Results would help in predicting the blow counts for these soils during construction.

Currently specifications require granular soils to be compacted in 6-in. lifts and tested after completing 12 in. Contractors have expressed concern that if a lift fails and the bottom lift needs additional compaction, delays in the contract would result. We have requested Purdue University to include this problem in the current research project using the DCP on soil compaction. We have also initiated the use of the DCP test prior to placing retaining wall footing, as proof rolling the soil for this application is not possible due to site conditions.

The LWD is likely to be used more often with other materials. The use of the DCP and LWD will provide additional compaction data which will give designers confidence in establishing higher strength and resilient modulus values for embankments and pavements.

CONCLUSION

The DCP and LWD tests are easy to perform can be performed in a few minutes, and the results are related to the laboratory tests. DCP blow counts developed from the laboratory tests and blow counts achieved during construction are looked into for improving the specifications. Similarly LWD modulus from test sections and modulus from construction are monitored to improve the specifications. Discussions with project personnel, contractors, and their input help in improving the specifications. We believe the continuous dialogue with researchers, implementers, and contractors made possible for Indiana DOT to move from density to strength–modulus. It is very important for all the players to understand the issues. Compaction data should be improving the design requirements. There are no licensing or safety issues with the equipment. Since DCP blow counts and LWD modulus are sensitive to moisture content, a passing test has to be within proper moisture range. Hence moisture variability decreases whereas uniformity in compaction increases. The DCP and LWD data collection is simple and requires few steps, leading to time savings and fewer errors with documentation.

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