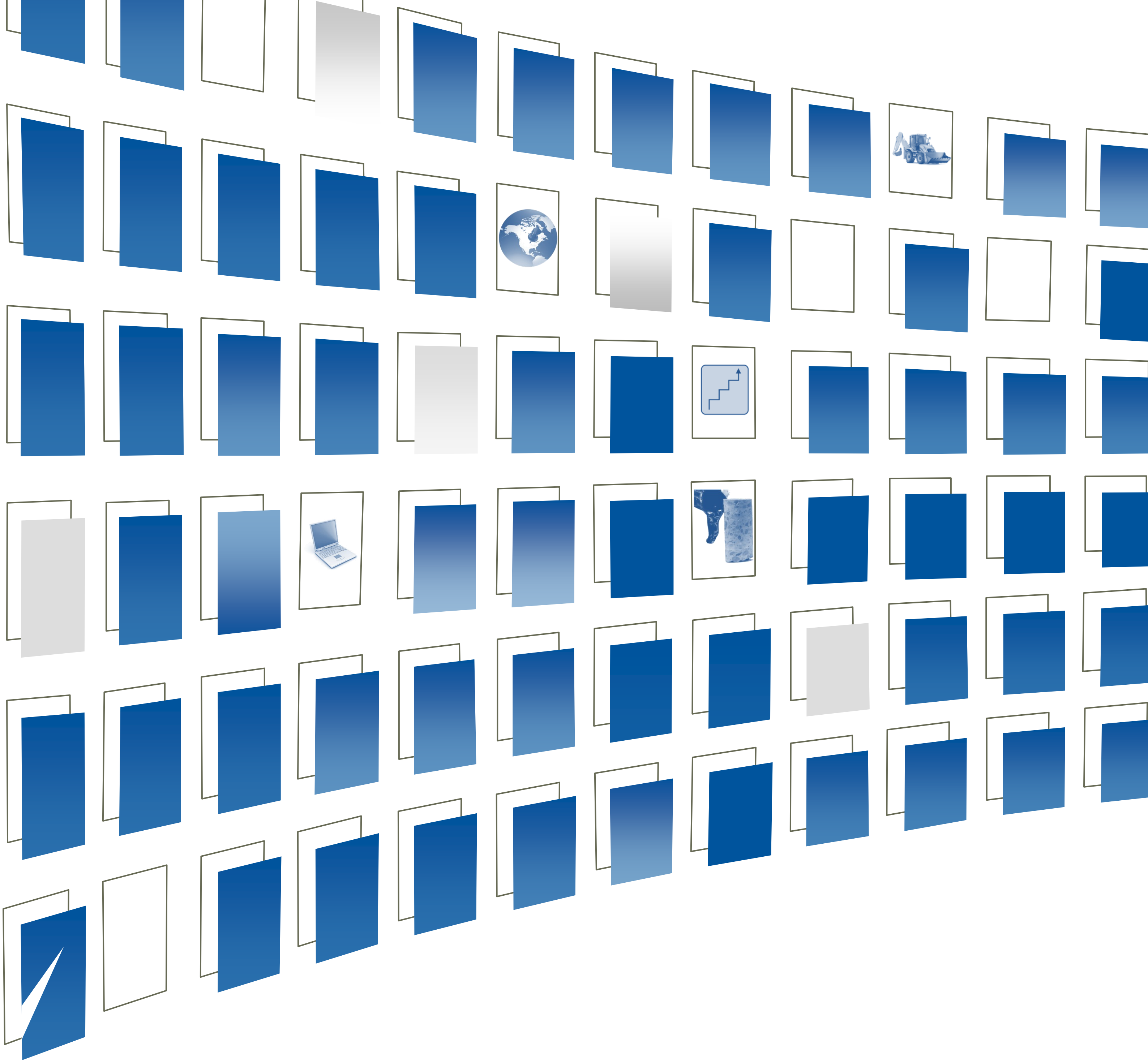

Improving Highway Project Delivery

Identifying Existing/Emerging Technologies in the Area of Intelligent Construction

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16. Abstract

This report presents the findings of a comprehensive literature search that was conducted to identify existing and emerging technologies in the area of Intelligent Construction of highways including but not limited to: systems, components, processes, and software. The technologies identified herein can provide benefits such as: increased production, increased efficiency, cost savings, real-time measurements/feedback, and improved quality and uniformity. During this task, the technologies identified were grouped by technology vendor/manufacturer type using the following categories: positioning systems, software and data management, construction equipment/machine automation, quality monitoring and materials testing, and improved construction practices and materials. A summary table for each technology category is included in the appendix.

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Introduction

Technology is the enabling force behind advancement in any industry, and highway construction is certainly no exception. The FHWA recognizes that there is a strong sense of urgency to deliver projects faster and implement the latest technology and innovation sooner. This is reinforced through new initiatives such as *Every Day Counts* (FHWA, Every Day Counts). **As quality demands increase and funds decrease, it is as important as ever to determine what innovative technologies are available and which can and should be implemented in the realm of Intelligent Construction.**

In September of 2009, FHWA held a *Stakeholder Meeting on Improving the Delivery of Highway Paving Projects* in Arlington, VA (FHWA, Meeting Minutes, 2010). The main objective of the meeting was to evaluate technologies and procedures to accelerate the delivery of highway paving projects. The corresponding implementation barriers for these technologies and possible solutions were discussed. The following items were identified as the most promising, and FHWA is concentrating research efforts to investigate them:

→*Increased Use of Full Lane Closures for Rehabilitation and Reconstruction*

→*Development of Improved Framework for Optimized Project Delivery*

→***Increased Use of Intelligent Construction Techniques***

The objective of this project and the focus of this interim report is on the last item, Increased Use of Intelligent Construction Techniques. This report summarizes the results of a literature review conducted to identify existing and emerging technologies in the area of Intelligent Construction of highway projects. The technologies and best practices presented herein are to be implemented during highway construction, beginning with the site layout/surveying to the finishing of the final pavement surface. Other engineering stages of paving projects such as planning, design, contracting, and procurement are out of the scope of this task.

The first step in this task was to review current, comprehensive research and technology reports on highway construction. These include the NCHRP Synthesis 372 (Hannon, 2007), NCHRP Synthesis 385 (Hannon et al., 2008), the NCHRP Report 626 (Von Quintus et al., 2009), the CP Road Map (Ferragut et al., 2005; CP Tech Center, 2008), and the Asphalt Road Map (NAPA et al., 2007). Next, proceedings and presentations were reviewed for the 2010 Construction Research Congress held in Banff, Alberta, Canada (ASCE, 2010), the Design to Dozer - Computer Controlled Heavy Equipment Demonstration held in Eugene, Oregon (Oregon DOT, 2010), and the 2nd International Conference on Transportation Construction Management in Orlando, Florida (ARTBA-TDF 2011). Finally, a web search was conducted using the TRB TRID database, and accessing highway construction equipment and control systems manufacturers' websites.

Objectives

The main objective of this effort is to identify existing and emerging technologies in the area of Intelligent Construction of highways including but not limited to: systems, components, processes, and software that can bring benefits such as: increased production, increased efficiency, cost savings, real-time measurements/feedback, and improved quality and uniformity. Ultimately, these benefits will contribute to the overall goals of FHWA (FHWA, Meeting Minutes, 2010): expedited construction, reduced construction impact on traffic, and improved quality.

The summary of technologies prepared under this effort is proposed to be used as a guide for discussion during the Intelligent Construction Systems and Technologies (ICST) Workshop planned for September 2011. Subject matter experts from FHWA, universities, paving associations, State DOTs, and vendors will be invited to this workshop. During this meeting the technologies FHWA should consider for field implementation will be identified and a long-term plan for guiding future improvements will be developed.

Scope

The summary of technologies presented in this report comprises intelligent technologies to be used from the beginning to the end of the construction of a highway project; that is, from surveying equipment to paving machinery to quality control / quality assurance devices.

Technologies deemed as "Intelligent Construction Systems" have the ability to collect information, analyze information, make, and execute an appropriate decision during construction. A notable example is stringless paving equipment for both flexible and rigid pavements. These systems utilize survey data and project design files (3D models), combined with non-contact/sensor guidance systems for automatic elevation/slope control and steering of the paving equipment.

Furthermore, this effort also considers components, processes, and software tools that "in conjunction with other supporting technologies, create a more efficient system of construction project delivery" (Hannon, 2007). For example, a technology such as ground penetrating radar (GPR) is categorized as "intelligent" because it can provide real-time, continous measurements to assess pavement quality in terms of thickness, density, or HMA segregation. When GPR technology is combined with the appropriate tools such as analysis sofware, the paving process can be monitored and adjusted in nearly real time rather than having to take remedial measures after paving has been completed.

Technology Categories

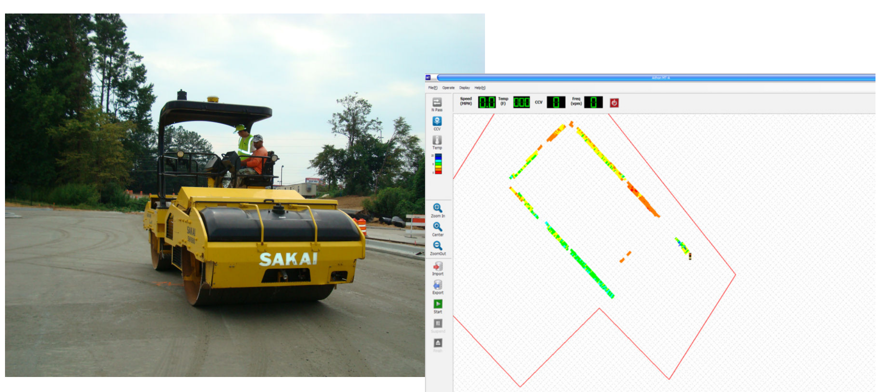
The literature search for Intelligent Construction Systems and Technologies began by considering the different aspects of a highway project. The main construction activities were summarized as shown in Table 1, and then potential intelligent technologies were initially identified.

Table 1. Summary of Highway Construction Activities and Sample Intelligent Technology

	SAMPLE INTELLIGENT TECHNOLOGY
Site Preparation/Layout	GPS
Bridge Work	Temporary Bridging
Subgrade/Base or Pavement Surface Preparation	Intelligent Compaction
Plant Operation	Automated Sampling Analysis
Steel Placement (PCC)	Independent Dowel Bar Inserter
Mix Transport	Automated Materials Tracking
Mix Placement	Stringless Paving
Compaction (HMA) or Finishing and Joints (PCC)	Intelligent Compaction
Quality Monitoring	Real-time Profilers

It was noted that several technologies are applicable to different stages of a highway construction project. For example, GPS equipment is now being utilized to enhance equipment used for site layout to machine control to quantity tracking and many points in between. Similarly, intelligent compaction (Figure 1) is being evaluated for use on subgrade/base materials and later in the paving process on HMA courses.

Figure 1. Intelligent Compaction Equipment (left) and Sample Data Display (right).



It is also proposed herein to consider a category that does not necessarily fit the "Intelligent Construction Systems and Technologies" definition but that offers significant opportunities to expedite construction and reduce construction impact on traffic: Improved Construction Practices and Materials. This category encompasses different stages, with Warm Mix Asphalt (WMA) as an example presented as one of the five initial "Accelerating Technologies/Innovations" in the *Every Day Counts* FHWA initiative (FHWA, Every Day Counts). The use of WMA has an impact in different paving stages: plant operation, mix transport, mix placement, and compaction, to ultimately accelerate project delivery and minimize traffic interruption.

Moreover, as explained by Singh (2009), a key aspect in engineering automation and Intelligent Technologies is data management and integration, not only during construction but throughout the life cycle of highway projects: planning, engineering, construction, and maintenance. For example, design files (3D models) can be used for project visualization and schedule optimization (emerging application) and later on are used for machine control (existing application); GPS, GIS, along with handheld computers are used for materials measurements and tracking during inspection (existing application) while later on this same information can be used for post-construction reviews and virtual as-builts (emerging application).

As the literature review progressed, the original classification by construction activities was replaced by the following categories, more likely following a technology vendor/ manufacturer type grouping:

 Positioning Systems

 Software and Data Management

 Construction Equipment/Machine Automation

 Quality Monitoring and Materials Testing

 Improved Construction Practices and Materials

Summary Table of Existing/Emerging Technologies

A summary table with all identified technologies as part of this effort was prepared to meet the objective of this Task and is included in Attachment A. For each technology category listed before, the items in Table 2 were noted.

Table 2. Description of "Summary Table of Existing/Emerging Technologies" (Attachment A)

COLUMN	SAMPLE INTELLIGENT TECHNOLOGY
1	Intelligent Systems and Technologies
2	Current Status of the Identified Technologies: Hypothetical, Emerging, or Existing
3	Applications/Stages where Intelligent Technologies Have Potential Use
4	General Description of the Intelligent Technology Along with Identified Examples, Such As Proprietary Systems, Software, or Case Studies
5	Where Applicable, the Traditional Method that this Intelligent Technology Complements or Replaces
6	Literature References
7	Known or Literature Reported Implementation Benefits
8	Known or Literature Reported Implementation Obstacles, Challenges, Barriers
9	Next Steps for Technology Development/Implementation
10	Ranking

The last four columns, Benefits, Obstacles, Next Steps for Technology Development/ Implementation and Ranking, are to be complemented/defined during the ICST Workshop. These four columns will be used to gather information on return-on-investment of technologies and ways to successfully implement them in the most economically beneficial manner. In addition, the overall content of the summary table is to be refined based on the feedback from the subject matter experts during the Workshop.

The following sections briefly describe the contents of the summary table (Attachment A).

Positioning Systems

GPS technology is being applied throughout the Intelligent Construction process, from layout to machine guidance (milling machine, slipform paver, and cure cart) to quantity tracking and many points in between. Relevant examples identified include:

→ Oregon DOT GPS implementation plan and efforts. (Singh, 2009)

→ A sample GPS guided paving tool. (Wiegand et al., 2010)

Note that this category is interlinked to most of the remaining Intelligent Construction categories. However, it is presented independently as well, because it is understood that it is complex enough to warrant separate evaluation.

Figure 2. Total Station at PCC Paving Site.

In addition, the main manufacturers of Positioning Systems such as Topcon, Leica, and Trimble are also offering the latest surveying systems, Robotic Total Stations and 3D Laser Scanners. Robotic Total Stations are used for surveying/mapping, but are also being used for machine guidance (Figure 2). Finally, another related and promising technology is Light Detection and Ranging (LiDAR) which is used to produce more accurate surveys and models. LiDAR can be used in construction to achieve better estimates (i.e. earthwork quantities) and reduce change orders.

Software and Data Management

3D/4D Modeling

This category involves the use of 3D and 4D modeling for highway project visualization and scheduling. Hannon (2007) explains how 3D models can be used in conjunction with the construction work progress schedule (4D) for project visualization. This application facilitates design change feedback, material fabrication/procurement, constructability reviews, communication of building methods/systems, quantity tracking, as-built documentation, public relations, and schedule optimization.

Similarly, in the area of structures, one of the most innovative emerging technologies is the use of Bridge Information Modeling (BrIM) to improve information transfer during the planning, design, fabrication, construction, operation, and maintenance stages of a bridge (FHWA, Integrated; Chen et al., 2009). Tools like the RM Bridge software from Bentley® allow for improved bridge constructability and smooth project delivery through the 2D/3D/4D simulation of bridge fabrication and construction (Bentley Website).

Figure 3. Use of 3D Model during Construction.

Data Management

Automated data management for improved process control and scheduling involves the use of GPS, GIS, handheld computers, tracking technologies such as Radio-Frequency Identification (RFID), and software. If development and implementation for the technologies in this category continues, it will fully enable data transfer between field and office, and more important during the life cycle of highway projects. NCHRP Synthesis 385 (Hannon et al., 2008) identified a number of "advanced processes" and best practices currently used by State DOTs, particularly 3D modeling, digital records, and GPS, that allow sharing information throughout all phases of the project delivery process. This concept, described as the creation of a Transportation Information Model is expected to allow State DOTs to accomplish synchronization and information sharing both internally and externally, and ultimately increase productivity and accuracy. Hannon et al. (2008) also list several barriers for implementation for such a model, including software interoperability, legal issues, and lack of understanding of the concept and its potential benefits.

Another important technology to accomplish the goal of information sharing is GIS, a tool that allows bringing data from multiple coordinate systems into one view (Kahler, 2011). Kahler (2011) explains how some of the technologies described above (i.e. handheld computers and GPS) can be used to collect and summarize field data and test results and then, with GIS technology these data can be viewed in the field, in real-time and in one place.

A relevant national group focusing on the standardization and best practices for handling intelligent engineering information is the AASHTO Joint Technical Committee on Electronic Engineering Data. The main references for this section include NCHRP Synthesis 372 (Hannon, 2007), NCHRP Synthesis 385 (Hannon et al., 2008), the "Engineering Automation Key Concepts" whitepaper by Singh (2009), 2010 Construction Research Congress proceedings (ASCE, 2010), and the "Beyond Asset Management" industry article (Cox, 2009).

In the area of utilities, the AASHTO Technology Implementation Group is promoting the use of "Utility Relocation Electronic Document Management Systems (UREDMS)", which are web-based applications to facilitate internal and external communication between DOTs, municipalities, and utility companies (AASHTO, 2011). These systems help expedite document submissions and retrieval, and report generation, which in turn streamline processes for permitting, and subsequent utility relocation. SHRP2 project R01(A) is also exploring innovations for locating and characterizing utilities, including other software and hardware available that take advantage of GPS and GIS technologies to increase quality and efficiency of storing, retrieving, and using utility records, with 3D information (SHRP2, Utilities). Another tool identified under SHRP2 R01 includes RFID to mark utilities permanently, by programming details related to underground utilities into the RFID tags, which later can be quickly discovered using a surface scan, as opposed to conventional methods that involve paper records and excavation (SHRP2, Utilities).

Construction Equipment/ Machine Automation

This category includes several new, vendor specific paving machines that offer improved quality of the final pavement, and construction cost and time savings as identified in Track 5 of the CP Road Map (Ferragut et al., 2005), and recent industry publications (Anderson, 2009; Guntert and Zimmerman, 2009). In addition, automated techniques to sample, monitor, and control HMA materials production are presented in this category, including a number of first generation devices as described by West (2006; 2005).

Modern equipment for bridge installation is also available, such as above-deck driven carrier systems, wheel carriers, and self-propelled modular transporters (SPMTs), that allow for rapid installation of bridges and bridge segments (SHRP2, Bridges). Similarly, the National Institute of Standards and Technology continues development of remotely operated cranes to assemble highway bridges (Goodwin, 1997).

Machine Automation: Guidance/Control

3D models and GPS are essential for construction machine automation. GPS technology along with 3D site plans are used for machine control and guidance of bulldozers used for subgrade grading, eliminating the need for survey stakes, and at the same time


Figure 4. Stringless PCC Paving.

increasing accuracy and productivity while lowering operating costs (Caterpillar).

Similarly, GPS technology, 3D models, and GIS are used for automated PCC and HMA paving technology. Multiple equipment manufacturers are marketing stringless PCC slipform pavers (Figure 4). This technology is included as part of Track 3, High-Speed Nondestructive Testing and Intelligent Construction Systems, which is one of the priority tracks in the CP Road Map (CP Tech Center, 2008). As for HMA automated paving technologies, Anderson (2010) provides an update on the latest screed, grade, and slope control systems.

The AASHTO Technology Implementation Group (TIG) has designated Automated Machine Guidance (AMG) as a Focus Technology. In addition, there is a relevant undergoing project in this area that should be noted, NCHRP 10-77, "Use of Automated Machine Guidance (AMG) within the Transportation Industry".

Quality Monitoring and Materials Testing

With State DOTs' budget constraints and downsizing, this category presents an excellent opportunity to assure construction quality with less intensive and direct inspection. A number of technologies were identified to make the Quality Control/Quality Assurance process more efficient. The list covers technologies to evaluate the different pavement layers, subgrade/base, HMA, and PCC, and assess characteristics such as uniformity, thickness, density, stiffness, smoothness, and air voids. The majority of the devices provide benefits such as improved accuracy, non-destructive, continuous, and real-time measurements, which in turn make possible the construction of more uniform and long lasting pavements. The main references for this category include the CP Road Map (Ferragut et al., 2005), the Asphalt Road Map (NAPA et al., 2007) (Figure 5), and NCHRP Report 626 (Von Quintus et al., 2009).

Similar initiatives to the CP Roadmap and Asphalt Roadmap are currently looking at the use of innovative quality control tools and nondestructive testing for other areas of highway construction.

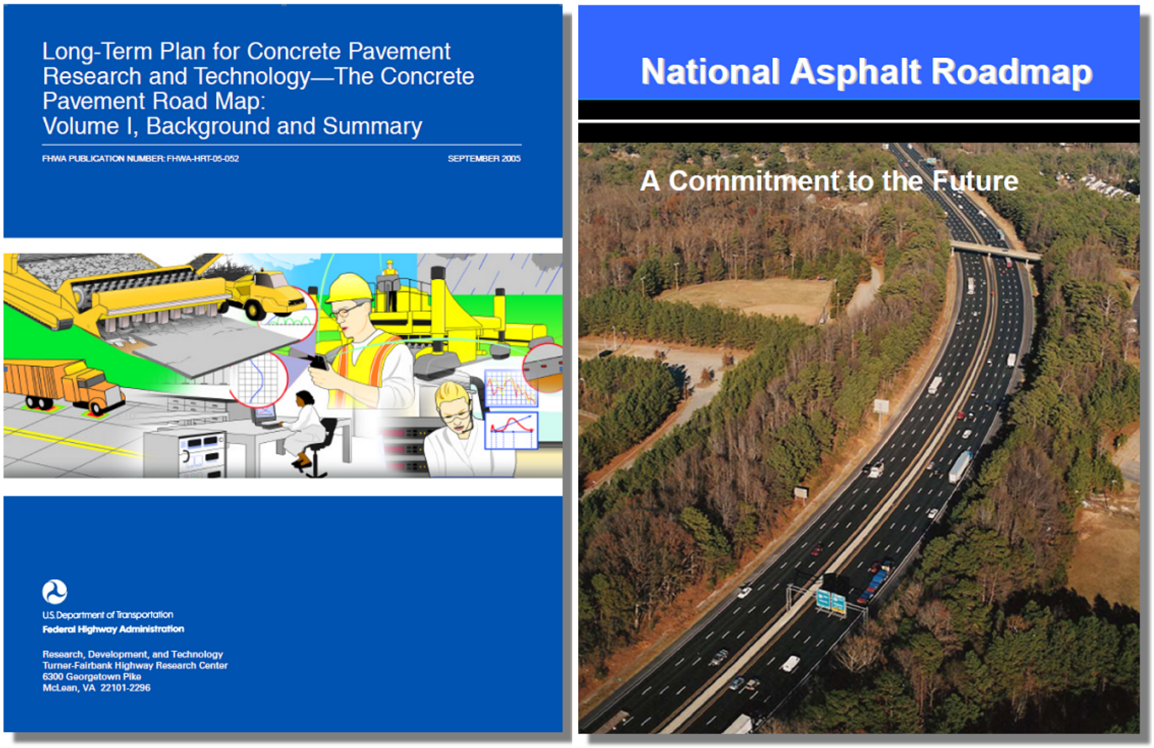
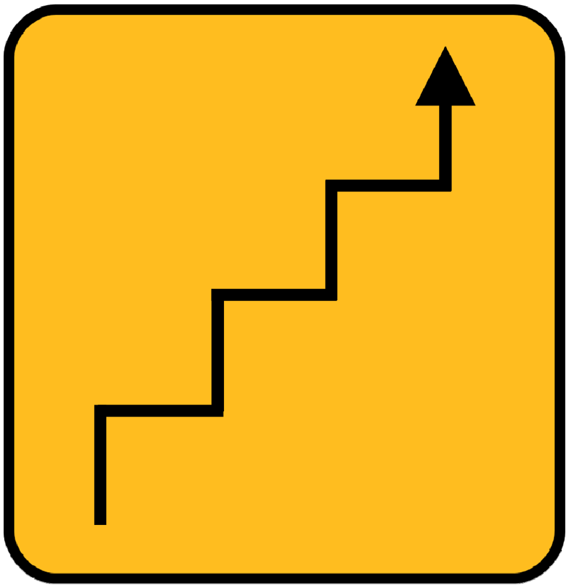


Figure 5. Concrete and Asphalt Pavements Road Maps.

For example, the SHRP2 Renewal program is evaluating products that can produce rapid inspection of new construction such as: high-speed ground-penetrating radar, real-time smoothness measurements of Portland cement concrete pavements, infrared technologies, the use of continuing deflection testing devices, tools for mapping voids, debondings, and moisture behind or within tunnel linings, and the use of field spectroscopy devices (Wimsatt et al., 2009).

Other emerging NDT techniques that show promise in improving quality and speed of construction include thermal integrity testing for drilled shafts through infrared thermal mapping, soil resistivity profiling, and acoustic emission.



Improved Construction Practices and Materials

This category offers significant opportunities to expedite construction and reduce construction impact on traffic. For example, best practices and materials such as precast pavements, roller compacted concrete (RCC), warm mix asphalt (WMA), self-consolidating concrete, high performance concrete/steel, recycled materials, and geosynthetics are presented as alternatives to provide cost and time savings during construction (Figure 6).

Figure 6. Use of Geosynthetic Separator layer (left) and Precast Pavement (right).

In the area of erosion control, new products such as flexible growth medium and bonded fiber matrix, and recycled materials are being used to reestablish vegetation during and after construction (Willnerd, 2007; Barkley, 2004). These products are proving to be more effective compared to traditional mulching and rolled mats/blankets, especially under poor soil, drought, and steep/rough slope conditions.

Developments in bridge construction include the use of even more prefabricated bridge elements for Accelerated Bridge Construction (ABC), such as precast post-tensioned concrete deck panels, precast pre-stressed concrete girders, and precast pier caps and abutment footings (Iowa DOT Website). Temporary bridging is a technology used to minimize impacts on the environment while expediting project delivery and cost (NCHRP, 2008). In some cases, ABC and temporary bridging may not impact the timeframes for design and overall construction significantly, but allow reducing lane/road closures to days or even hours.

Innovative techniques to rehabilitate corrugated steel pipe culverts include cured-in-place pipe (CIPP) lining and a sliplining system using high-density polyethylene pipe (HDPEP) liners. In 2009, as part of the FHWA Highways for LIFE program, the Montana DOT demonstrated the use of both trenchless technologies, CIPP and HDPEP (Ardani et al., 2009). For this demonstration it was reported that no lane closures were required and traffic was not impacted at all. Similarly, the Texas DOT recently conducted a successful demonstration of HDPEP (Trenchless Technology, 2011). In addition to reducing or eliminating traffic delays and lane closures, these technologies offer safety improvements for the workers and traveling public, and easy installation.

Several techniques are also available to expedite embankment construction under unfavorable ground conditions with the use of innovative ground improvement methods, the use of geotechnical materials and systems for accelerated widening and expansion of existing roadways, recycling of on-site material in new construction, and the use of geosynthetics and soil stabilization. SHRP2 is currently developing guidelines and procedures for the utilization of these techniques (SHRP2, Geotechnical).

Other technologies identified include the use of modern foundation systems to allow rapid embankment construction in urban or challenging environments. For example, during the reconstruction of an interstate project in an urban environment with problem soils, different embankment/foundation systems were evaluated including mechanically stabilized earth (MSE) walls and expanded polystyrene (EPS) geofoam (Farnsworth et al., 2008). EPS geofoam is a lightweight, rigid foam plastic that is significantly lighter than most soils and lightweight fill materials (FHWA, EPS, 2006). Installation is easy and quick, and where right-of-way is limited, EPS geofoam can be used to construct vertically and it can be finished to look like a wall.

Part of the FHWA Every Day Counts Initiative, Geosynthetic Reinforced Soil (GRS) is recommended for bridge embankment construction (Adams et al., 2011). GRS consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. It has evolved into the GRS Integrated Bridge System for small, single-span structures that includes a reinforced soil foundation, a GRS abutment, and GRS integrated approach (Adams et al., 2011)

There are several efforts in the area of traffic management in work zones to provide advance warning, site identification, and driver guidance to improve work zone safety and facilitate traffic control. One of the most innovative technologies being used is the application of Intelligent Transportation Systems (ITS) to dynamically respond to changing traffic conditions with the use of Variable Message Signing (VMS), portable traffic detectors and cameras, and Reinforcement Learning through micro simulation (Transport Canada Website). Another innovation is the Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) software program to obtain the best estimate of the length of freeway that can be rehabilitated or reconstructed within the project constraints (construction windows, lane closure tactics, pavement materials, pavement structure, mix design, and contractor resources) (Caltrans Website). Lastly, there is ongoing research on traffic control technologies such as mobile barriers systems which have potential to increase productivity and increase safety (Oregon DOT Website).

Development and Implementation Plan

Columns 8 and 9 in the summary table (Attachment A) list the known and literature reported benefits and obstacles for each potential technology identified during the research phase. The key benefits are improved accuracy and efficiency over traditional methods, which are tied to the FHWA overall goals for expedited construction, reduced construction impact on traffic, and improved quality.

Current obstacles for implementation are more diverse, ranging from lack of specifications, general ignorance of the potential benefits, the end-users' lack of technical skills, lack of funding, to agency procedural issues. In addition, some technologies were classified as emerging, meaning that they still need to undergo extensive calibration and validation with diverse materials and field conditions. Mechanisms to overcome these barriers typically include workshops, model specifications, lead agency (FHWA, AASHTO) endorsement, and further studies to highlight the benefits to highway contractors and owner agencies/DOTs.

The goal for the ICST Workshop is to discuss the summary table gathered during this effort (Attachment A) to:

→ Identify additional/missing relevant technologies for each category.

→ Refine the Benefits and Obstacles defined in Columns 7 and 8 based on the attendees' expert feedback.

→ Populate the last two columns in the table, Next Steps for Technology Development/Implementation and Ranking.

With these, a framework can be developed where public agencies, contractors, equipment manufacturers, etc. will work together to move the most promising technologies forward.

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ATTACHMENT A: Summary of Existing-Emerging Intelligent Construction Technologies

Existing / Emerging Technologies in the Area of Intelligent Construction: Positioning Systems

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	RANKING
Global Positioning Systems (GPS) and other related technologies	Existing	Surveying, Machine Guidance and Testing/Inspection Records	**General:** GPS technology, in some cases augmented with robotic total stations to improve vertical accuracy, is being applied throughout the intelligent construction process, from layout to machine guidance (milling machine, slipform paver and cure cart) to quantity tracking and many points in between. **Example:** Enhanced use of GPS, the Oregon DOT Geometronics Unit is in the process of developing a statewide GPS reference station network known as the Oregon Real Time GPS network, which consists of strategically located GPS Continuously Operating Reference Stations (CORS) that provide real-time kinematic (RTK) correctors via cellular phone and/or radio broadcast. It facilitates the use of GPS for construction surveyors, inspectors, and machine guidance and control systems, at a significantly reduced cost, providing accurate, reliable, and repeatable positioning on the construction coordinate system.	Traditional surveying with stakes and stations	Engineering Automation-Key Concepts for a 25 Year Time Horizon, Singh, 8 March, 2009	• Decreases time and cost of surveying • Improved project workflow • Improved pavement smoothness • Less errors • Fewer access constraints to the contractor and the traveling public	• Lack of standards • Current specifications do not require that digital files be provided to the contractor • Limited guidance and expertise at DOTs • Cost		
Robotic Total Stations	Existing	Surveying, Machine Guidance	**General:** Used to shoot points and elevations for developing site information to generate CAD/electronic files. Also used to direct excavators and concrete placing equipment that require 3D contours.	Traditional surveying with stakes and stations	"Testing and Performance Evaluation of Fixed Terrestrial 3D Laser Scanning Systems for Highway Applications", Hiremagalur et al., TRB 2009 Meeting CD-ROM (2009)	• Increased productivity			
GPS Guided Dowel Bar Inserter	Hypothetical	PCC Paving	**General**: Dowel bar placement could be digitally located and coordinated with GPS equipment.						
GPS Guided Joint Sawing Equipment	Existing	PCC (Overlays) Paving	**Example**: Research to ensure that the longitudinal joints in the overlay match underlying joints in the existing pavement. A saw was equipped with a GPS unit. The data from the original longitudinal joint survey was loaded into the GPS unit on the saw. A screen mounted on the saw allowed the contractor to visualize the location of the saw blade in relation to the existing longitudinal joint line and make adjustments as necessary. **Conclusions:** A conventional saw can be outfitted with a GPS receiver, allowing the operator to saw a joint in the overlay that is within 1 inch horizontally from the existing joint in the underlying pavement. Concrete cores verified that this method is more precise than measuring the centerline offset from paving hubs.	Measuring the centerline offset from paving hubs, which are often destroyed during construction	"Improving Concrete Overlay Construction" Wiegand et al. March 2010/Executive Summary June 2010	• More accurate method to match joints • Prevention of reflective cracking and extended overlay design life	• First generation device • Contractor, DOTs unawareness • Lack of specifications		
3D Laser Scanners	Existing	Construction Layout (Grading, Bridge and Highway)	**General:** Scanners measure thousands of data points per second and generate a very detailed "point cloud" data set. **Examples:** Systems such as Leica ScanStation, Optech ILRIS-3D and Trimble GX.	Field control surveying	"Testing and Performance Evaluation of Fixed Terrestrial 3D Laser Scanning Systems for Highway Applications", Hiremagalur et al., TRB 2009 Meeting CD-ROM (2009)	• Increased productivity	• Performance (accuracy and detection range) vary with distance, object reflectivity, and angle of incidence • Lack of standard specifications		

Existing / Emerging Technologies in the Area of Intelligent Construction: Positioning Systems									
INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	RANKING
Light Detection and Ranging (LiDAR)	Existing	Mapping	**General:** Three different systems: Static/Fixed Terrestrial (3D Scanning), Mobile Terrestrial and Airborne LiDAR. Airborne type can map same features as traditional photogrammetry, cost effective for wide area projects, and provides a higher density "3D point" measurement.More accurate models to estimate earthwork quantities and reduce change orders.	Field control surveying and aerial photography	Advancements, MoDOT Research Bulletin, January 2011, http://library.modot.mo.gov/RDT/reports/LiDAR/ADV-LiDAR.pdf	• Improved worker safety, data quality • Time savings for data collection	• High amount of data reduction and processing		

Existing / Emerging Technologies in the Area of Intelligent Construction: Software and Data Management

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
3D/4D Design/Modeling	Emerging/Existing	Scheduling, Staging Plans, Machine Automation, As-builts	**General:** 4D design places 'time' tags to certain design elements providing the ability to determine and convey construction staging. Think of it as a project schedule built into the design. Slide the time scale to the date of interest to see the construction completed to that point in time. **General:** Consists of 3D digital project plans with the additional integration of construction work progress schedule (time). The simulated visualization is used to see the facility's evovlement with construction to aid with: Design change feedback, Material fabrication/procurement, Constructability reviews, Communication of building methods/systems, Quantity tracking, As-built documentation, Public relations, Schedule optimization. **General:** "Increase scheduling efficiency by incorporating the findings of modern cognitive theories that suggest human brain interacts more effectively with 3D virtual worlds than long lists of project activities and textual content."		• Engineering Automation-Key Concepts for a 25 Year Time Horizon, Singh, 8 March, 2009 • NCHRP Synthesis 372 - Emerging Technologies for Construction Delivery • "Visually Scheduling Construction Projects" - Saeed Karshenas, and Anamika Sharma; Construction Research Congress 2010. Innovation for Reshaping Construction Practice (2010)	• True 3D design enables detection of conflicts in design elements • Determines element clearance and sight distances • Produces materials lists and quantities • Facilitates construction machine automation • Produces engineered visualization	• Cost increase during design stage • Not a requirement under current standards, specifications • File format issues/compatibility between 3D/4D design software and related applications		
Modeling/Processes for Integrated Design and Construction Highway Bridges	Emerging	Bridges	**General:** Use of 3D Bridge Information Modeling to improve information transfer during the planning, design, fabrication, construction, operation and maintenance stages of a bridge.	2D plans, with manual transcriptions which are time-consuming and costly	• NCHRP 108 - Accelerating the Design of Bridges with 3D Bridge Information Modeling • "Framework for Extending TransXML for Steel Bridge Construction", Nagarajan and Chen (TRB 2011) • "Integrated Bridge Project Delivery & Life Cycle Management". http://www.fhwa.dot.gov/bridge/integrated/flyer.pdf	• Better quality, time and cost savings	• Need standardization for electronic information transfer • Means to integrate computer-aided design (CAD), computer-aided engineering (CAE), and computer-integrated manufacturing (CIM) are needed, i.e.: bridge industry Extensible Markup Language (XML) specification		
Software or Web-Based Programs	Existing	Asset Management Systems/"Telematics"	**Example:** Asset management systems that help determine how fast a paver needs to lay down mix, how much material a batch plant must produce per hour, decipher when trucks should deliver more HMA and learn what rollers are needed and when to reduce bumps and get the smoothest surface possible. Also used for fuel managing and equipment maintenance scheduling.		• "Beyond Asset Management" by Barbara Cox, Better Roads, April 2009 • http://www.mindsinc.ca/		• Heavy equipment manufacturers need to pursue a universal telematics data format, so users could pull machine data directly from third party servers and integration		

Existing / Emerging Technologies in the Area of Intelligent Construction: Software and Data Management

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
Handheld Computers	Existing	Inspection Records	Daily construction activity records, time and project material tracking. **General:** These devices should be GPS enabled to provide an inspector accurate real-time positions on the project coordinate system. The device should contain project design elements to allow the inspector to validate the positions of items being constructed. Inspectors would also use these devices for managing their construction records, daily progress reports, material certification and testing, and access to specifications and standard drawings. These devices should be capable of wireless communication for email, online meetings, transmittal of engineering data, and access to DOT servers.	Paper trail	• NCHRP Synthesis 372 - Emerging Technologies for Construction Delivery • Engineering Automation-Key Concepts for a 25 Year Time Horizon, Singh, 8 March 2009	• More accurate records • Construction time/cost savings • Design-Construction-Maintenance data integration	• End-user lack of knowledge/training • Not a requirement under current specifications, standards	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	
Radio-Frequency Identification (RFID); Barcodes	Emerging/Existing	Automated Materials/Data Tracking	**General:** RFID allows for automated tracking of materials and data. Coupled with other sensors, RFID can be used to track variability of materials such as moisture, temperature, etc. **General:** RFID tags have been used extensively for product inventory, tracking, identification and payment. This and other related technology could be utilized in construction material delivery, certification and payment. Since the RFID tags are passive (not requiring any internal power), their use could be further exploited in managing assets once installed. **Example:** Tracking samples based on barcodes. **Example:** Low cost RFID tags affixed to the fleet for tracking jobsite activity. The tagged vehicles report to "read points" that capture the activity of plants and pavers and other machinery. **Case Study:** Large scale field trials were conducted on two sites in Texas and Toronto using an integrated system of RFID tags, global positioning system (GPS) technology, map software, and handheld computing to automatically track materials in the projects' respective lay down yards. It was concluded that automated materials tracking has the potential to improve construction productivity, cost, and schedule performance.		• NCHRP Synthesis 372 - Emerging Technologies for Construction Delivery • Engineering Automation-Key Concepts for a 25 Year Time Horizon, Singh, 8 March 2009 • "Beyond Asset Management" by Barbara Cox, Better Roads, April 2009 • http://www.mindsinc.ca/ • "Automated Materials Tracking and Locating: Impact Modeling and Estimation". Construction Research Congress 2010, Innovation for Reshaping Construction Practice - Proceedings of the 2010 Construction Research Congress. May 8-10, 2010, Banff, Alberta, Canada	• Low cost technology • Time/cost savings • Construction - Maintenance data integration			
Real-time Data Integration and Visualization	Emerging/Existing	Real-time Data Integration and Visualization	**General:** Once remote sensing and intelligent data processing technology are applied to supplement manual data recording, very few data visualization tools in construction exist that allow visualizing dynamic resource data in a field-realistic virtual reality environment and are at the same time able to perform this task in or near real-time. Technology to assist in real-time data visualization and situational awareness can have a significant impact on stakeholders' successful and safe completion of construction projects.		• "Real-Time Data Collection and Visualization Technology in Construction". Tao Cheng and Jochen Teizer. Construction Research Congress 2010, Innovation for Reshaping Construction Practice - Proceedings of the 2010 Construction Research Congress. May 8-10, 2010, Banff, Alberta, Canada				

Existing / Emerging Technologies in the Area of Intelligent Construction: Software and Data Management

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
Transportation Information Model/Bridge Information Modeling	Hypothetical	Transportation Information Model/Building Information Modeling	**General:** Processes, best practices for sharing of information throughout all phases of the project delivery process		• NCHRP Synthesis 385 - Information Technology for Efficient Project Delivery	• Synchronization and information sharing • Increased accuracy, less errors	• Software interoperability • Legal issues • Lack of understanding		
Geographic Information Systems (GIS)	Existing	Construction Quality Data Management	**General:** Can bring multiple coordinate systems into one view. Inspection, Sampling and Testing, Quantities and Pay Items can all be summarized in one place, in real-time, and categorized by producer/inspector, etc.	Text-based, separate, manual forms stored in the office	• "GIS-Based Construction Quality Management", Danny Kahler, 2nd Int. Conference on Transportation Construction Management, Feb 8-10, 2011	• Graphics-based • Data is available in field • Handheld collectors • Integrated measurements • Delay immediate • Off the shelf • Infinite copies	• Equipment/software requirements for field personnel • File format standardization is needed		
Utility Relocation Electronic Document Management Systems (UREDMS) and other utility-related software and hardware	Existing	Utility coordination	**General:** Web-based methods of facilitating internal and external communications (DOTs, municipalities & utility companies) as projects are planned and constructed. Used to expedite document submissions, retrieval, and report generation, which in turn streamline the process for permitting, and subsequent utility relocation. Ongoing SHRP2 R01(A): Project to support development of software and hardware that take advantage of GPS and GIS technologies to increase quality and efficiency of storing, retrieving, and using utility records, with 3D information. Also, investigating data collection and use in a multi-utility environment. Ultimate goal is to have comprehensive utility records for all utilities in the ROW.	Paper trail, 2D utility plans and markups	• AASHTO TIG. http://tig.transportation.org/Pages/UtilityRelocationElectronicDocumentManagementSystem.aspx • SHRP2 Project Brief R01 (March 2009): "Encouraging Innovation in Locating and Characterizing Underground Utilities" • SHRP 2 R01(A): Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data	• Time/cost savings • Improved data storage			
Radio-Frequency Identification (RFID)	Emerging	Utility Locating and Characterizing	**General:** RFID to mark utilities permanently, by programming details related to underground utilities into the RFID tags, which later can be quickly discovered using a surface scan.	Paper records and excavation	SHRP2 Project Brief R01 (March 2009): "Encouraging Innovation in Locating and Characterizing Underground Utilities"				

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
High Efficiency Mixers	Existing	Concrete Batching and Mixing Equipment	**Example:** High efficiency mixers which allow the concrete mixture to reach uniformity after 15, 30 seconds, etc. of mixing time, compared to the standard of 60 seconds.	Standard mixing time typically 60 seconds	• CP Road Map (Track 5), Guntert & Zimmerman Const. Div., Inc. Ron Guntert	• Improvement in mix uniformity • Construction time & cost savings	• Vendor specific/ proprietary product that may not be widely available • Lack of specifications by State DOT at this point	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	
Mobile Concrete Batching & Mixing Plants	Existing	Concrete Batching and Mixing Equipment	**Example:** Mobile batch plants designed to cut mobilization costs and reduce the number of concrete plants owned. Few pieces of equipment make up the plants and are designed with smaller features/dimensions to facilitate transport and work in confined areas.		• CP Road Map (Track 5), Guntert & Zimmerman Const. Div., Inc. Ron Guntert	• Construction time & cost savings	• Vendor specific/ proprietary product that may not be widely available • Lack of specifications by State DOT at this point	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	
Automated Plant Operations (APO) - General	Emerging/Existing	Automated Plant Operations	**General:** Automated techniques to sample, monitor and control materials production. **Examples Below:** Evaluation study of different devices by NCAT; sponsored by the AL DOT and FHWA.	1) The asphalt binder content and aggregate gradation (to determine that the mixture meets the JMF) 2) The volumetrics of the compacted plant-produced mixture 3) The temperature of the HMA 4) The moisture content in the HMA	• Asphalt Road Map (2.5.04) • FHWA "Improving Delivery of Paving Projects" Stakeholder Meeting, September 2009 • "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006)	• Time/cost savings		• Endorsement/Encouragement for its use	

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
APO - Automated Belt Samplers	Emerging/Existing	Automated Plant Operations	**Belt Samplers** : To obtain samples of aggregate or RAP from moving conveyor belts; when activated, an open box rapidly sweeps transversely across the belt, closely following the contour of the belt so that all of the material in the cross section is removed. The speed of the sweep is very fast to obtain an even cross section of material and minimize the potential influence on the plant's belt scales. Technology has been used by other industries, i.e. mining industry, for several decades, so this technology is mature and the equipment is robust enough for the HMA industry.		• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• More frequent, continuous, and more accurate sampling for improved quality of the final pavement course	• Not a requirement in current specifications, standards • Initial equipment and training costs	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs • Automated belt samplers are manufactured by several companies and their costs range from $10,000 to $15,000 installed. Some conveyors may require additional support or frame modification	
APO - Automated Moisture Content of Aggregates and Reclaimed Asphalt Pavement (RAP)	Emerging/Existing	Automated Plant Operations	**Microwave Moisture Probes:** Inserted into the stream of material traveling on the belt. Instantaneously senses the microwave energy absorbed by the material, which is proportional to the moisture content of that material. Technology has been used in several other manufacturing applications, including the ready-mix concrete industry. However, due to mix production scheduling issues, the instruments were not recalibrated for each mix. Therefore, the moisture content results obtained with the microwave probes show a consistent offset from the measured moisture contents determined with laboratory tests. This problem can be corrected by establishing and following a calibration process for each mix.		• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• Moisture probes were easy to set up and operate • More frequent, continuous, and more accurate testing for improved quality of the final pavement course	• Unique calibration factors are necessary for each material, so each mix requires a different calibration, which is a time-consuming process		
APO - Automated Gradation Devices	Emerging/Existing	Automated Plant Operations	**Automated Sieves/Gradation Devices:** Similar to laboratory sieving equipment and was equipped with six standard sieve screens; other sieve screens can be used. Overall, the automated gradation device provided results similar to the laboratory dry gradation test results on the same samples. **Automated Imaging/Gradation Devices:** Not evaluated during NCAT study, but as with the automated gradation sieving devices, a sample of the aggregate is removed from the belt using a belt sweeper and drops into the imaging unit. Inside the device, the aggregate sample is fed onto a belt where special cameras and lighting capture 3D images of the particles. Rapid imaging analysis reports particle size distribution and particle shape information. The shape and size data is transmitted wirelessly or by Ethernet cable to a PC for data storage. At the present, separate units are necessary to capture the range of particle sizes of interest in HMA quality control.		• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• More frequent, continuous, and more accurate testing for improved quality of the final pavement course	• Not a requirement in current specifications, standards • Initial equipment and training costs		

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
APO - In-line Binder Viscometers	Emerging/Existing	Automated Plant Operations	**In-line Viscometer** : Installed in the asphalt supply line from the plant's tanks to the point of mixing in the drum used to indicate if the correct binder grade (e.g., PG 67-22 or PG 76-22) is being used in the mix being produced. Uses a magnetically excited vibrating rod in the flow of the asphalt binder. The dampening effect of the asphalt on the vibrating rod is proportional to the viscosity of the asphalt. To compensate for the effect of temperature on the viscosity of asphalt, the instrument also measures the temperature of the binder and a PLC interface corrects the viscosity to a standard reference temperature. The measurements of the in-line viscometer were successful in differentiating the unmodified PG 67-22 binders from the polymer-modified PG 76-22. In-line viscometers are used in other industries to monitor and control chemical mixing processes and to optimize fuel viscosities for large combustion engines and burners.		• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• Rapid viscosity check provided by this instrument appears to provide excellent process control information	• First generation device, more testing and development is needed	• More testing is needed to evaluate other grades and sources of asphalt	
APO - Robotic Truck Samplers	Emerging/Existing	Automated Plant Operations	**Robotic Mix Sampler:** For retrieving HMA samples from haul trucks, also was evaluated on this project and compared with two other sampling methods: sampling by a technician using a shovel, and sampling behind the paver using a template. The robotic truck sampler consisted of a large steel frame with a hydraulically operated telescoping arm and sampling probe. Due to mechanical problems with the robotic sampler, only one mix was sampled with this device. The test results indicate that the samples obtained with the robotic truck sampler were more similar to samples of HMA taken just behind the spreader. Compared with samples taken with a shovel from a sampling stand, the mix samples taken with the robotic device were coarser and had lower asphalt contents. The difference in results between these two sampling methods is likely due to some segregation during sampling with the shovel from the top of the load.	Shovel, template sampling from truck	• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• More frequent, accurate sampling for improved quality of final pavement course • The robotic sampler was able to penetrate deep into the load to obtain mix samples, which was believed to provide a less segregated and more representative sample of the mixtures	• More testing and development needed to overcome technical problems observed during NCAT study		

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

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APO - In-line Binder Viscometers	Emerging/Existing	Automated Plant Operations	**In-line Viscometer:** Installed in the asphalt supply line from the plant's tanks to the point of mixing in the drum used to indicate if the correct binder grade (e.g., PG 67-22 or PG 76-22) is being used in the mix being produced. Uses a magnetically excited vibrating rod in the flow of the asphalt binder. The dampening effect of the asphalt on the vibrating rod is proportional to the viscosity of the asphalt. To compensate for the effect of temperature on the viscosity of asphalt, the instrument also measures the temperature of the binder and a PLC interface corrects the viscosity to a standard reference temperature. The measurements of the in-line viscometer were successful in differentiating the unmodified PG 67-22 binders from the polymer-modified PG 76-22. In-line viscometers are used in other industries to monitor and control chemical mixing processes and to optimize fuel viscosities for large combustion engines and burners.		• "Seizing Control", R.West, Roads & Bridges, Vol. 44 No. 2 (February 2006) • "Development of Rapid QC Procedures for Evaluation of HMA Properties During Production", R.C. West, NCAT Report 05-01, January 2005	• Rapid viscosity check provided by this instrument appears to provide excellent process control information	• First generation device, more testing and development is needed	• More testing is needed to evaluate other grades and sources of asphalt	
90-degree Steering	Existing	Slipform Paving Equipment	**Example:** Pavers with side forms that allow you to back up over previous pours. Traditional pavers without 90-degree steering require maneuvering the machine out and away from the slab, and a much larger section of concrete is often left to hand pour.	Leave outs for hand pouring, poor smoothness	• ConstructionEquipment.com, "Slipform-Paver Makers Quick to Respond", Mike Anderson, January 2010 • Guntert & Zimmerman Construction Profiles Fall 2009: Hawkins Construction New Telescopic End Sections pg. 6	• Time/cost savings • Improved quality final PCC	• Vendor specific/proprietary product that may not be widely available • Lack of specifications by State DOT at this point	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	
Telescopic End Sections	Existing	Slipform Paving Equipment	**Example** : Telescopic end sections that allow the contractor to perform paving width changes in shortened amount of time and with fewer personnel. Latest equipment promises improved smoothness.		• ConstructionEquipment.com, "Slipform-Paver Makers Quick to Respond", Mike Anderson, January 2010 • Guntert & Zimmerman Construction Profiles Fall 2009: Hawkins Construction New Telescopic End Sections pg. 6	• Time/cost savings • Provide ~6 ft of quick width change, allowing the ability to change pave widths in a matter of hours with fewer personnel while it used to take days • On new pavers or retrofit	• Vendor specific/proprietary product that may not be widely available • Lack of specifications by State DOT at this point	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	
Narrow-Width Paving Equipment	Existing	Slipform Paving Equipment	**General:** Available to address restricted work zones.						

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

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Minimum Clearance	Existing	Slipform Paving Equipment	**General:** Reduced clearance allows for minimal traffic disruption in full lane closure rehabilitation projects.		• Guntert & Zimmerman Construction Profiles Fall 2009: Hawkins Construction New Telescopic End Sections pg. 6 • Gomaco	• Work in more restricted areas, especially under traffic			
Above-deck Driven Carrier Systems, Launched Temporary Truss Bridges, Wheel Carriers, Self-propelled Modular Transporters (SPMTs)	Existing	Modern Equipment for Bridge Installation	**Description:** Using modern construction equipment-such as above-deck driven carrier systems, launched temporary truss bridges, wheel carriers, and self-propelled modular transporters (SPMTs)-to rapidly install bridges and bridge segments. **Case Study:** SHRP 2 will conduct a field demonstration of ABC techniques in spring 2011. SHRP 2 is working in conjunction with the Iowa Department of Transportation to incorporate innovative bridge elements into a bridge located at US 6 over Keg Creek in Pottawattamie County, Iowa.	Traditional construction practices-such as erecting beams and framework, tying deck reinforcing steel, placing deck concrete, and allowing concrete to cure-are time-consuming and disruptive to traffic.	• Tomorrow's Bridges: A Renewal Project Brief Summarizing Bridge Research in SHRP2 (April 2011)	• These techniques make it possible to move large, prefabricated bridge elements or even major bridge systems • Road closures may be limited to days or even hours using accelerated bridge construction (ABC) techniques			

Existing / Emerging Technologies in the Area of Intelligent Construction: Construction Equipment/Machine Automation

INTELLIGENT TECHNOLOGY	STATUS: Hypothetical, Emerging, Existing	APPLICATION	DESCRIPTION: General Concept, Specific Example such as a Proprietary System or Software, Case Study (descriptions below in some cases extracted verbatim from references on the right)	TRADITIONAL METHOD	REFERENCES	BENEFITS	OBSTACLES	NEXT STEPS FOR TECHNOLOGY DEVELOPMENT/IMPLEMENTATION	Ranking
3D Design	Emerging/ Existing	Grading, Paving	**General:** Facilitates construction machine automation, i.e. Control Grading, Stringless Pavers, etc. **Example:** Ongoing NCHRP effort (10-77-Use of Automated Machine Guidance (AMG) within the Transportation Industry). **Description:** AMG links sophisticated design software with construction equipment to direct the operation of the machinery with a high level of precision, improving the speed and accuracy of the transportation construction process. **Research Objectives:** To develop guidelines for use of AMG technology for state transportation agency construction projects. The guidelines should (1) include technical procurement specifications for AMG technology; (2) provide guidance on the use of such technology in construction projects; and (3) address the implementation of AMG technology into construction techniques (including the provision of electronic files and models to support the AMG process).		• Engineering Automation - Key Concepts for a 25 Year Time Horizon, Singh, 8 March 2009 • 3D Design for Machine Control Grading, Tom Metcalf: Oregon DOT "Design to Dozer - Computer Controlled Heavy Equipment" • NCHRP 10-77: Use of Automated Machine Guidance (AMG) within the Transportation Industry. http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2504 • Presentation by J. Hannon at TCM-2: Status of NCHRP Project 10-77, 9 February 2011	• Reduced construction cost and improved quality • Improved worker safety, time and cost savings for both agencies and contractors • Improved the overall quality and efficiency	• More difficult & time consuming which means more design time and cost • Contractors don't use InRoads or other design software; they deal with different proprietary software for machine guidance and need to convert the 3D design models for the machines to read • In summary: Lack of standards, digital files not available to contractors, differences between different equipment manufacturers		
Stringless Concrete Paving Technology and Equipment	Emerging/ Existing	Slipform Paving	**General:** Developing stringless paving technologies commonly begins with collecting survey data and building a database, such as the Geographic Information System (GIS). Computer-aided design and modeling for the pavement system follows. A noncontact guidance system then ties the paving surface to the 3D GIS and guides the movements of all paving equipment during construction. Noncontact sensors can be either GPS- or laser-based, evaluation has shown GPS superior. **Case Study:** To evaluate use of stringless paving using a combination of global positioning and laser technologies. The evaluation was conducted on two paving projects in Washington County, Iowa (Summer 2003). The research team from ISU monitored the guidance and elevation conformance to the original design. Combination of physical depth checks, surface location and elevation surveys, concrete yield checks, and physical survey of the control stakes and stringline elevations.	Physical guidance such as stringlines, stakes	• CP Road Map (Track 3), ISU/CP Tech • "Stringless Portland Cement Concrete Paving", Cable et al. CP Tech Center, 2004	• Improved efficiency (time/cost savings) by saving the labor it takes to go out and put up stringline and have surveyors doing staking • Improved quality (eliminate common pavement smoothness issues, such as chord effects, sag effects, and random survey)			
Stringless Asphalt Paving Technology and Equipment; "Advanced Screed Control for Asphalt Pavers"	Emerging/ Existing	Asphalt Paving	**General:** Technology that allows HMA paving without reference surface or stringlines (also for milling machines). It typically uses computerized project design files and sensor technology for automatic elevation and slope control.	Physical guidance such as stringlines, stakes	• "Machine Control for Pavers", Mike Anderson, Better Roads - Highway Contractor, Volume 80, No. 8 (August 2010)	• Time/cost savings due to effort required to set and adjust stringlines • Eliminates trucks moving on and off site to navigate around stringlines			

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Automated Machine Positioning	Emerging/ Existing	Earthwork, Grading and Compaction Equipment	**Case Study & Example:** Study to measure the productivity increase using an Automated Machine Positioning System. Two identical roads were built, one using the "Conventional Way" with stakes on the ground and the other was the "New Way" using a Machine Control system. The production study consisted in measuring the time for all different operations, the number of passes, buckets or truckloads, fuel consumption and accuracies to compare the two methods. Analysis demonstrated that productivity and unit cost improvements result from a reduction in surveying support, increase in operational efficiency for earthmoving, and decrease in number of passes. Overall time for building the road was 3½ days vs. 1½ with AccuGrade; increase in overall job site productivity of 101%. **Example:** Caterpillar, AccuGrade™ Grade Control System. "Is factory integrated, sensor-independent, and features a suite of products which includes cross slope, sonic, laser, GPS, and ATS technology. By combining digital design data, in-cab operator guidance features, and automatic blade controls, the AccuGrade Grade Control System enhances grading accuracy and eliminates the need for survey stakes." **Example:** Trimble Machine Control, GCS900 "Line of machine control systems for scrapers, excavators, dozers, graders, compactors, trimmers, etc." "The GCS900 Grade Control System is an earthmoving grade control system that puts design surfaces, grades and alignments inside the cab. The system uses GPS, GPS and laser, or construction total station technology to accurately position the blade or bucket in real time, reducing material overages and improving the contractor's productivity and profitability."	Traditional construction staking and machine operator control; traditional stakes or grade checkers	• CAT website (CAT Machine Control AccuGrade system page) http://www.cat.com/technology/earth-moving-solutions/accugrade-grade-control-system • "Trimble GCS900 Grade Control System 3D Automatic Control", http://www.trimble.com/gcs900.shtml	• Higher and more consistent accuracy • Time/cost savings • Ability for moving material accurately, quickly, and safely the first time	• Existing specifications • Lack of verification studies • QA/QC procedures • Proprietary system? • Lack of specifications? • Cost?		

Existing / Emerging Technologies in the Area of Intelligent Construction: Quality Monitoring and Materials Testing

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Rheology Testing	Emerging?	PCC Workability	**General:** To determine workability of mixtures needed for slipform paving. There is a need to develop a simple field test for measuring how much a paving mixture will move when vibrated (viscosity) and whether it will be prone to edge slump (yield stress). **Check on the status of research in this area, to see if there are promising methods/procedures.**	Slump Test	• CP Road Map (Track 1)				
Intelligent Compaction, GPR, Infrared Tomography, Acoustic Emissions	Emerging/Existing	Compaction of HMA, Base, Soil	**General:** Rollers with IC technology for soils/aggregate (single drum) and asphalt pavement (tandem drum) compaction. A non-destructive method for density measurement. Feedback is used by compactor operators to control roller patterns to achieve the desired air void content level. This information needs to be in a form that the laydown machine operator can use to adjust the process.	Nuclear Density Gauge	• TPF-5(128) • NCHRP Report 626 • Iowa DOT/ISU 2008, 2009 Workshops • Asphalt Road Map: Project Statement 5.06 Non-Destructive Evaluation for Process Control and QC/QA • Minnesota DOT Specs	• More uniform material density • Reducing the number of passes needed to obtain specification density • QC/QA tool that allows visual record of material stiffness values at 100% of the roadway locations in real-time • Proof rolling (mapping) to identify soft spots • Monitor asphalt surface temperature (to keep up with the paver)	• US DOTs lack knowledge and experience • Equipment not widely available in the US • No standard calibration parameters exist for the different manufacturers • Studies of correlations with existing measurements on different materials are needed • Training for contractors and State DOTs is needed QC/QA procedures		
Air Void Analyzer (AVA)	Existing	PCC Air Void Systems	**Example:** The air void analyzer is a device intended to provide on-site evaluation of the air void system in fresh concrete. Work is being conducted by a number of researchers to evaluate the device and to develop guidelines on its use. The findings of these researchers need to be gathered and interpreted, and a formal method statement needs to be developed for submission to AASHTO and ASTM.	Pressure method (ASTM C 231 or AASHTO T 152) or the volumetric method (ASTM C 173 or AASHTO T 196)	• CP Road Map (Track 1) • ACPA R&T Update 4.05: Air Content in Concrete Pavements (2003)				
Temperature and Maturity Meters	Existing	PCC Field Temperature and Moisture	**General:** Monitoring temperatures of concrete pavements at early ages can help prevent cracking, estimate strength, and determine optimal time for surface texturing, joint sawing/cutting, and opening to traffic.	Strength testing of laboratory or field-cured specimens					
Real-time Test Methods for Thickness Verification	Emerging?	PCC Pavement Thickness	**General:** Real-time test methods as alternates to the current practice for thickness verification: cores and measuring their length with calipers. **Example:** Laser scanning and eddy current sensors. **Example:** Magnetic Imaging Tomography to determine the thickness of freshly placed concrete. This technique may be used for process testing and for acceptance testing during construction of new concrete pavements. The technique is applicable only to plain (non-reinforced) concrete pavements.	Coring, i.e. every hour, every 500 ft	• CP Road Map (Track 3) • Scanning Lasers for Real-Time Pavement Thickness Measurement, Iowa DOT & ISU • Determination of Concrete Pavement Thickness Using the Magnetic Imaging Tomography Technique (FHWA-HIF-09-023), September 2009	• Cost reduction • Non-destructive • Continuous & real-time measurements			

Existing / Emerging Technologies in the Area of Intelligent Construction: Quality Monitoring and Materials Testing

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Real-time Test Methods for Thickness Verification	Existing	HMA Pavement Thickness	**General:** Real-time test methods as alternates to the current practice for thickness verification: cores and measure their length with calipers. **Example:** GPR, Ultrasonic Impact Echo, SPA, SASW, Magnetic Tomography.	Depth checks	• NCHRP Report 626 • Asphalt Road Map. Project Statement 5.05 Real-time Process Control for Laydown and Compaction	• Improved accuracy • Cost savings • Non-destructive • Continuous & real-time measurements			
Magnetic Tomography Devices: MIT-SCAN-2 and MIT-SCAN-2F	Emerging?	PCCP Dowel/Tie Bar Alignment	**General:** Allows for paver adjustment and misalignment correction during construction by detecting dowel and tie bar misalignment behind the paver.	Visual inspection	• CP Road Map (Track 3) • FHWA CPTP Task 7 Field Trials of Concrete Pavement Product and Process Technology, Magnetic Tomography for Dowel Bar Location	• Better joint and overall pavement performance			
SmartCure System	Existing	PCC Curing Effectiveness	**Example:** Measuring components (namely weather station, GPS, and infrared temperature sensor) connected to a laptop computer operating a Windows® based software program. Possesses the ability of providing real-time monitoring of the curing process in the field and warning the user when there is a risk for damage to the pavement structure. Recommendations are made for curing materials and procedures as a function of the current conditions.	Laboratory test methods for evaluating the effectiveness of curing compound	Proposal & CP Road Map (Track 3)	• Better ensures adequate development of concrete properties, and minimizes damage to the pavement because of inadequate curing			
Reflective Ultrasonic Technique		PCC Early Age Strength	**General:** Using ultrasonic wave reflection (UWR) as a nondestructive testing method to measure the shear wave reflection loss at an interface between the hydrating cement paste and a buffer material. The wave reflection technique can be used to monitor the viscoelastic properties of cement pastes at very early ages and it also reflects the accumulation of the solid particles in the microstructure of the cement paste.		• CP Road Map (Track 3) • "Ultrasonic Technique for the In-Situ Monitoring of the Setting, Hardening, and Strength Gain of Concrete", Northwestern University http://www.iti.northwestern.edu/publications/utc/tea-21/FR-1-6-Shah.pdf				
Real-time Profilers	Emerging/Existing	Smoothness	**General:** Measurements of pavement profile in real-time for detecting surface irregularities during paving operations.		• SHRP2 R06(E)	• Improve process control and allow for equipment and operations adjustments to correct surface irregularities while the concrete is still plastic, resulting in higher quality, lower cost, and faster construction	• Lack of knowledge • End-user technical skills • Confusion, QC tool not for ride quality specification	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	

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GPR and Non-Nuclear Gauges	Hypothetical?	HMA: Air Voids, Voids in Mineral Aggregate and % Voids Filled with Asphalt	**General:** Use of GPR and non-nuclear gauges to measure air voids in the field.	Laboratory testing on compacted samples of HMA material; nuclear gauge measurements in the field	• Asphalt Road Map: Project Statement 4.14 Field versus Laboratory Volumetric and Mechanical Properties • NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction	• GPR offers full lane coverage • Non-destructive • Non-radioactive	• This application of GPR testing needs to be proven in the field before it will be used by public agencies • Interpretation of data needs to become more readily available on a commercial basis		
Non-Nuclear Devices to Test for Base and Soil In-Place Density	Emerging/Existing	In-place Density	**General** : Status of non-nuclear devices to replace Nuclear Density Gauge. **Examples:** GPR, Non-Nuclear Gauges, Pavement Quality Indicator (PQI, Trans-Tech Systems) and PaveTracker (Troxler Electronic Laboratories) **Case Study:** The authors conclude that electromagnetic gauges can be affected by several variables including: aggregate type, binder content, nominal maximum aggregate size, traffic level, presence of moisture, number of roller passes, etc. Need to be calibrated on a test strip on a project/mix basis. Also concluded that "both devices generally agreed with the findings from the standard core method".	Nuclear Density Gauge; coring (destructive) and lab density measurements (time consuming & costly)	• NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction • "Implementation of Electro-Magnetic Gauge Readings for Assessing Hot Mix Asphalt Quality", Andrea N. Kvasnak, and R. Christopher Williams, Proceedings of the Fifty-Second Annual Conference of the Canadian Technical Asphalt Association (CTAA) 2007	• Rapid • Non-destructive • Non-radioactive • Easy to use	• Lack of knowledge • Not included in current State DOT specifications • More research needed?		
Non-Nuclear Devices to Test for Base and Soil In-Place Density	Emerging/Existing	Base and Soil In-place Density	**General** : Status of non-nuclear devices to replace Nuclear Density Gauge. **Examples:** GPR, Non-Nuclear Gauges, Pavement Quality Indicator (PQI, Trans-Tech Systems) and PaveTracker (Troxler Electronic Laboratories)	Nuclear Density Gauge	• NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction				
Infrared Thermography; High-Speed GPR	Emerging/Existing	HMA Segregation	**General:** Method to detect segregation in HMA during paving (real time). Uses infrared imaging to detect variation in temperature (temperature segregation) during paving operations. **Example:** System mounted on the rear of a paver and uses a sensor beam to produce a thermal profile of the project, that is used to detect segregation in real time. The standard screed-mounted beam has 12 infrared sensors, and is scalable up to 24 sensors/24 ft width.	Visual inspection	• Asphalt Road Map: Project Statement 5.13 Segregation Control • NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction • SHRP2 R06(C): "Using Both Infrared and High-Speed Ground Penetrating Radar for Uniformity Measurements on New HMA Layers" • "Machine Control for Pavers", Mike Anderson, Better Roads - Highway Contractor, Volume 80, No. 8 (August 2010)	• Improved quality • Time/cost savings if less removal/replacement • Continuous & real-time measurements	• Initial cost/investment • End-user lack of knowledge/expertise	• Endorsement/Encouragement for its use • Studies to highlight the benefits to contractors and/or DOTs	

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PSPA, SASW; FWD, LWD, IC	Existing	HMA Stiffness/Modulus	**General:** Use of NDT to supplement traditional HMA acceptance testing. In addition, layer moduli is a key material property in M-E pavement design, and it is now needed to consider these measurements in the field.		• VA DOT • NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction				
DCP; DSPA, SPA, SASW; FWD, LWD; Geogauge; IC	Existing	Base and Soil Stiffness/Modulus	**General:** Use of NDT to supplement traditional HMA acceptance testing. In addition, layer moduli is a key material property in M-E pavement design, and it is now needed to consider these measurements in the field.		• VA DOT • NCHRP Report 626 – NDT Technology for Quality Assurance of HMA Pavement Construction				
Rapid Field Tests Laboratory Test	Emerging/Existing	Soil Sulfate Content	**General**: TTI/TxDOT identified two rapid field tests to identify sulfates-rich (swelling) soils, which may present problems when treated with traditional calcium-based stabilizers. **Examples:** Conductivity Test and Colorimeter Test equipment to run parallel with it.		• "Laboratory and Field Procedures for Measuring the Sulfate Content of Texas Soils", Harris et al., TTI 2002	• Allow to identify in the field sulfate swell problems which are frequently localized • Provide information on both the total sulfate content and the grain size distribution • Low cost < $1000 per kit			
Webcams	Emerging?	Remote Site Monitoring	**General:** Construction engineers, inspectors and administrators should be able to monitor certain construction activities by remote means. Web cameras facilitate monitoring and recording construction work progress; contract compliance, worksite conditions, actual construction schedules, as-built information and safety compliance.		• Engineering Automation-Key Concepts for a 25 Year Time Horizon, Singh, 8 March 2009 • NCHRP Synthesis 372 - Emerging Technologies for Construction Delivery	• Improved quality • Time/cost savings with improved productivity due to reinforced inspection/monitoring	• Cost		
Thermal Integrity Testing	Emerging?	Drilled Shafts QA	**General:** Infrared thermal detection method to assess the presence or absence of intact concrete both inside and outside the shaft reinforcement cage. The heat generation from curing concrete is used to scan constructed shafts for defects. Study consisted of 1) field temperature measurements of mass concrete structures with specific interest in drilled shafts, and 2) numerical modeling to verify the anticipated temperature response within a drilled shaft or mass concrete structure.	Cross Hole Sonic Logging (CSL) Limitations: Inability to assess integrity outside the access tubes Results are often inconclusive	• "Thermal Integrity Testing of Drilled Shafts" Mullins et al., 2007 • Univ. of South Florida/FDOT	• Physical dimension and location of anomalies may be predicted			
Soil Resistivity Profiling	Existing/Emerging	Embankments QA	**General:** Continuous testing to detect soil strata changes, voids and areas of excessive moisture. Resistivity testing of new alignments has been implemented by Minnesota and Florida DOTs, and they are enthusiastic about the benefits of this technology.	Soil borings	• SHRP2 Report S2-R06-RW: "A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection", Wimsatt et al., 2009	• Continuous coverage to detect isolated problem areas			

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Field Spectroscopy	Existing/Emerging	Materials QA	**General:** Potential for quality assurance testing of cements, paints, thermoplastics, epoxies and emulsions. **Description** : Field guns that contain predefined chemical spectra of the material under test.	Laboratory testing	• SHRP2 Report S2-R06-RW: "A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection", Wimsatt et al., 2009 • SHRP2 Project R06(B)	• Low cost equipment for faster, accurate testing in the field, requiring a small sample			
Acoustic Emission	Emerging?	PCC QA	**General:** Technology developed for detection of debonding of bridge deck from the girders, delaminations, wire breaks in cable strays, and crack growth in structural members. Texas, Illinois and Oregon DOT have tried the technology and results are promising.		• SHRP2 Report S2-R06-RW: "A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection", Wimsatt et al., 2009	• Low cost and adaptable software applications			
Multi-Sensor Platforms for Utility Locating	Emerging	Utility Locating	**SHRP2 R01(B):** Project to support development of combinations of new and/or existing sensor technologies and analysis software must offer significant advances in terms of utility detection and position (horizontal and vertical) from the ground surface across a wide range of soil types and site conditions.	Use of different instruments and techniques to identify different utilities at a project	• SHRP2 R01(B). http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2674	• Time/cost savings			

Existing / Emerging Technologies in the Area of Intelligent Construction: Improved Construction Practices and Materials

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Precast Pavements	Existing	PCC Bridge Approaches, Rapid Full Depth Repairs	**General:** The basic precast prestressed pavement concept consists of a series of individual precast panels that are post-tensioned together in the longitudinal direction after installation on site. Each of the panels are pretensioned in the transverse direction (long axis of the panel) during fabrication, and ducts for longitudinal post-tensioning are cast into each of the panels.	Poured in place	• CP Road Map (Track 7)	• Time/cost savings			
Roller Compacted Concrete (RCC)	Existing	PCC Shoulders, Low Speed Roads	**General:** A durable paving material that carries heavy loads. RCC is a stiff, zero-slump concrete mixture with the consistency of damp gravel comprised of local aggregates or crushed recycled concrete, Portland cement, and water. The mixture is placed and roller compacted with the same commonly available equipment used for asphalt pavement construction. The process requires no forms, finishing, surface texturing, or joint sawing and sealing.	Multi-lift HMA or PCC shoulders	• CP Road Map (Track 5) • RCC Guide	• Time/cost savings			
Warm Mix Asphalt (WMA)	Existing	HMA	**General:** Produced by reducing the viscosity of the asphalt binder at a given temperature. This reduced viscosity allows the aggregate to be fully coated at a lower temperature than what is traditionally required in HMA production. However, some of these technologies require significant equipment modifications. **Example:** Products currently available include Aspha-Min, WAM-Foam, Sasobit, Evotherm, Advera WMA, Asphaltan B.		• FHWA Website	• Pave at lower temperatures • Longer Paving Season • Allows longer pavement mix hauling distances			
Recycled Materials	Emerging	HMA/PCC/Base	**General:** Recycling project materials is a big opportunity to save time and cost, while conserving resources.			• Time/cost savings			
Cement, Lime, Fly Ash	Existing	Base and Soil Stabilization	**General:** Use of soil and base stabilization needs to be considered on critical projects. The weather-related impacts can be minimized with appropriate designs.						
Geogrids	Existing	SG	**General:** Used in a pavement system to serve as a construction aid over soft subgrades, improve or extend the pavement's projected service life, and reduce the structural cross section for a given service life.	Deep excavation/ stabilization	• "Improvement of Flexible Pavement With Use of Geogrid", The Electronic Journal of Geotechnical Engineering, Vol. 16				

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Geosynthetics	Existing	Separation Layer for Unbonded Concrete Overlays and PCC Pavements over Chemically Stabilized Bases	**General:** A viable, cost-effective alternative to more conventional materials as an interlayer in pavements. Requires minimal training and equipment during construction and can be placed rapidly. Can provide effective separation, drainage, and reduce bearing stresses and the effects of dynamic traffic loads.	HMA layer	• "Case Studies", Concrete on Top. http://www.concreteontop.com/index.php?q=node/6	• Time/cost savings			
Geotechnical Techniques	Existing	Embankments	**General:** SHRP2 effort to develop guidelines and procedures for (1) construction of new embankments and roadways over areas of unstable soils, (2) widening and expansion of existing roadways and embankments, and (3) improvement and stabilization of the support beneath the pavement structure.		• SHRP2 R02: "Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform"				
Flexible Growth Medium (Also, Bonded Fiber Matrix but some limitations identified, i.e. not applied on saturated soils, may require up to 48 hours without rain, etc)	Existing	Erosion Control/Slopes	**General** : "Biodegradable, High Performance-Flexible Growth Medium (HP-FGM) composed of 100% recycled and Thermally Refined™ wood fibers, crimped interlocking man-made biodegradable fibers, micro-pore granules, naturally derived cross-linked biopolymers and water absorbents. The HP-FGM is phyto-sanitized, free from plastic netting, requires no curing period and upon application forms an intimate bond with the soil surface to create a continuous, porous, absorbent and flexible erosion resistant blanket that allows for rapid germination and accelerated plant growth."	Straw bale, mulching; rolled blankets/mats	• "Flexterra HP-FGM". http://www.profileproducts.com/_media/product/media/471.FlexterraHP_FGMDataSheet_.pdf • "Project Case Study: Right-of-way revegetation challenge", Sarah Willnerd, CE News, June 2007	• Less time and labor to install; Can be used on steep or rough slopes as well			
Self-Consolidating Concrete	Existing	Bridges	**Example:** Common usage of Self Consolidating Concrete (SCC) in Sweden. SCC is not a new technology, but SCC research, development and implementation to the highly advanced level of common usage is a new achievement. **Benefits:** By using advanced SCC technology, Sweden is able to pour concrete in intricate forms and/or dense reinforcement situations significantly faster, with fewer workers, smaller pumps, and achieve high quality. SCC should lead to a longer life via superior coverage of reinforcement, and very low permeability. It provides significant benefit when post tension or other ductwork is present. Since vibration is not needed, ductwork cannot be pushed out of alignment or crushed.		• AASHTO/FHWA 2002 Scanning Project: Innovative Technology for Accelerated Construction Of Bridge and Embankment Foundations. Preliminary Summary Report				

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High Performance Concrete	Existing	Bridges	**General:** By using HPC or UHPC DOTs expect to gain significant advantages in the mechanical properties and durability of concrete. Tradeoffs of using UHPC include increased cost of materials, increased batch time for mixes, modification of forms due to increased shrinkage, and long setting and curing times that occupy precast beds.		• Tech Transfer Summary, ISU/Iowa DOT: TR-574. http://www.iowadot.gov/operationsresearch/boardmembers/2011/feb/Final%20Reports/TR-574%20Tech%20Brief.pdf				

Existing / Emerging Technologies in the Area of Intelligent Construction: Improved Construction Practices and Materials

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Accelerated Bridge Construction (ABC) Techniques	Existing	Bridges	**General:** Innovative design and construction solutions already exist to create new bridges and rapidly replace old bridges. These techniques make it possible to move large, prefabricated bridge elements or even major bridge systems. While total design and construction timeframes that do not affect traffic may remain significant, road closures may be limited to days or even hours using accelerated bridge construction (ABC) techniques. Main components of ABC include: Precast Elements (i.e. abutments & piers, complete precast concrete superstructure systems) Complete composite steel superstructure systems Modular Construction (segmental piers, space frame superstructures) Placement Methods Accelerated Geotech Work (hybrid drilled shafts) Ultra High-Performance Concrete (UHPC).	Traditional construction practices-such as erecting beams and framework, tying deck reinforcing steel, placing deck concrete, and allowing concrete to cure- are time-consuming and disruptive to traffic.	• Tomorrow's Bridges: A Renewal Project Brief Summarizing Bridge Research in SHRP2 (April 2011) • Iowa and Utah DOT 2008 ABC Workshop Reports • FHWA Fact Sheet 16: "States Across the Country Implement Accelerated Bridge Construction" (Fall 2010)	• These techniques make it possible to move large, prefabricated bridge elements or even major bridge systems • Road closures may be limited to days or even hours using accelerated bridge construction (ABC) techniques • Ultimately, results in improved safety, productivity and quality			
Temporary Bridging	Existing	Bridges	**General:** Floating, prefabricated or built in place structures to avoid or minimize environmental impacts.		• NCHRP Research Results Digest 330 (2008)	• Time/cost savings, minimized environmental impacts			
Trenchless Technology for Culvert Rehabilitation	Existing	Culverts	**General:** Innovative techniques to rehabilitate the corrugated steel pipe culverts. **Examples:** Cured-in-place pipe (CIPP) lining and a sliplining system using high-density polyethylene pipe (HDPEP) liners. **Montana DOT Highways for Life Demo** : By using trenchless technologies, MDT was able to perform the work without closing any lanes or interfering with traffic flow.		• FHWA's Highways for Life: Montana Demonstration Project: Innovative Culvert Rehabilitation Using Trenchless Technologies (2009) • "Culvert Liner Demonstration Held in Texas". http://www.trenchlessonline.com/index/webapp-stories-action?id=1679	• Eliminated traffic delays, lane closures and associated costs • Improved safety • Easily installed			

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Geosynthetic Reinforced Soil, Integrated Bridge System	Existing	Bridge Embankments	**General:** Geosynthetic Reinforced Soil (GRS) technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. The technology has evolved into the GRS Integrated Bridge System (IBS), a fast, cost-effective method of bridge support that blends the roadway into the superstructure. GRS-IBS includes a reinforced soil foundation, a GRS abutment, and a GRS integrated approach. This method has significant value when employed for small, single-span structures.	Standard pile cap abutments on deep foundations, others	• FHWA Geosynthetic Reinforced Soil, Integrated Bridge System Interim Implementation Guide (January 2011) • Every Day Counts Initiative	• The system is easy to design and economically construct. It can be built in variable weather conditions with readily available labor, materials, and equipment and can easily be modified in the field.			
Mechanically Stabilized Earth (MSE) Walls and Expanded Polystyrene (geofoam)	Existing	Embankment/ Foundation Systems	**Case Study/Abstract:** The I-15 Reconstruction in SLC, UT required rapid embankment construction in an urban environment atop soft lacustrine soils. Research evaluated and compared the construction time, cost, and performance of three embankment/foundation systems used on this project: (1) one-stage mechanically stabilized earth (MSE) wall supported by lime cement columns; (2) expanded polystyrene (geofoam) embankment with tilt-up panel fascia walls; and (3) two-stage MSE wall with prefabricated vertical drain installation and surcharging. The geofoam embankment had the best performance based on settlement and rapid construction time considerations, but is more costly to construct than a two-stage MSE wall with PV drain foundation treatment. The one-stage MSE wall with lime cement treated soil was the most costly, and did not perform as well as expected; thus, it had only limited use on the project.		• "Rapid Construction and Settlement Behavior of Embankment Systems on Soft Foundation Soils", Farnsworth et al., Journal of Geotechnical and Geoenvironmental Engineering (2008)				
Alternative Fill Materials: Expanded Polystyrene (EPS) Geofoam	Existing	Embankments	**General:** EPS geofoam is a lightweight, rigid foam plastic that is approximately 100 times lighter than most soil and at least 20 to 30 times lighter than other lightweight fill alternatives. Because it is a soil alternative, EPS geofoam embankments can be covered to look like normal sloped embankments or finished to look like a wall. Reduces loads on underlying soils, and helps build highways quickly without staged construction. Because EPS geofoam weighs only two pounds per cubic foot, large earthmoving equipment is not required for construction. After the material is delivered to the site, blocks easily can be trimmed to size and placed by hand. In areas where right-of-way is limited, EPS geofoam can be constructed vertically and faced, unlike most other lightweight fill alternatives. It also can be constructed in adverse weather conditions.		• FHWA "Expanded Polystyrene (EPS) Geofoam" Tech Brief 2006	• Easy, quick installation even under adverse site and weather conditions	• Cost		

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CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies)	Existing	Scheduling Staging Plans	**Example:** CA4PRS software program to obtain the best estimate of the length of freeway that can be rehabilitated or reconstructed within the project constraints (construction windows, lane closure tactics, pavement materials, pavement structure, mix design, and contractor resources).	Current approaches often result in work activities being sporadic with periods of time with no activity.	• CP Road Map (Track 7), Caltrans & University of California Transportation Research Center • CA4PRS 2009 Brochure	• Time/cost savings • Free group license for all State DOTs			
Variable Advisory Speed Systems	Existing	Work Zone Traffic Management	**General:** VASS provide drivers with advanced warning regarding traffic speeds downstream to help them make better decisions. BYU/UDOT study to investigate their effectiveness concluded that VASS were effective on weekends during evening peak hours when there was traffic slow down. Also found that there was no statistical difference when there was no traffic slow down.		• "Evaluation of the Effectiveness of a Variable Advisory Speed Systems on Queue Mitigation in Work Zones", Saito et al., BYU/UDOT 2011				
Mobile Barrier Systems	Existing	Work Zones	**Ongoing Research:** Study to evaluate the benefits and limitations of using a mobile barrier systems (MBS) in future work zone safety strategies and investments. The systems have been tested, primarily for their ability to withstand impacting vehicles. This research aims to evaluate: the efficiency in deploying and removing the system, its impacts on the work operations, the impacts on worker safety and productivity compared to traditional protective measures, and the types of projects for which it is most suitable.		• "Use, Test & Evaluation of a Mobile Work Zone Barrier System", OSU/ODOT				