TECHBRIEF

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Automation in Highway Construction

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This document is a technical summary of the Federal Highway Administration reports *Automation in Highway Construction: Final Report—Volume I, Implementation Challenges at State Transportation Departments and Success Stories* (HRT-16-030) and Automation in Highway Construction: Final Report—Volume II, A Design Guidance and Guide Specification Manual (HRT-16-031).[1,2]

Introduction

This TechBrief summarizes the findings from the Federal Highway Administration (FHWA) research project Addressing Challenges in Automation in Highway Construction, which addressed gaps for automation implementation from project development through construction, success stories, and noteworthy practices for individual technologies. In addition, guidance was developed to help State transportation departments determine how to implement and use automation to accelerate project delivery. The final report includes the following two parts:[1,2]

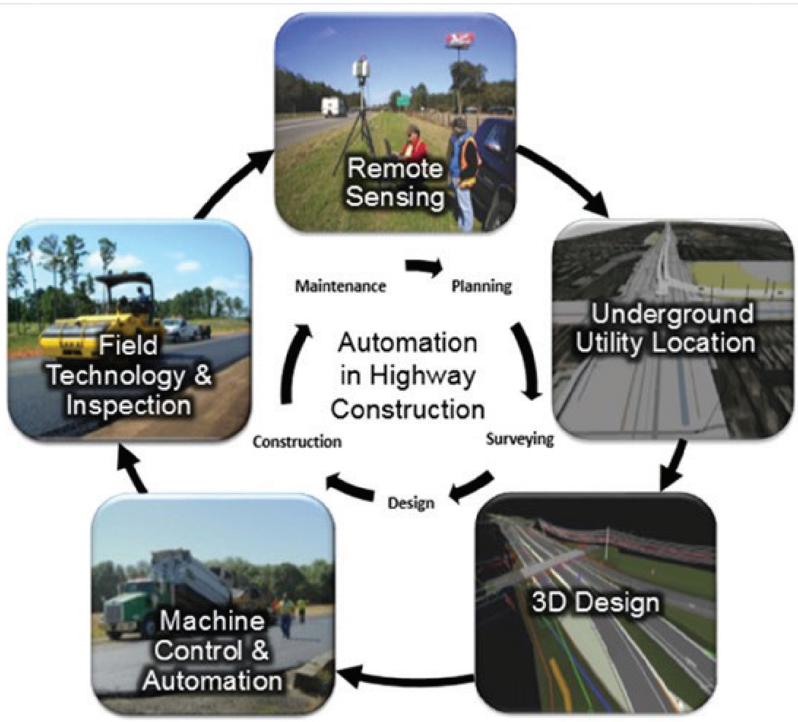
- *Automation in Highway Construction: Final Report—Volume I, Implementation Challenges at State Transportation Departments and Success Stories.*
- *Automation in Highway Construction: Final Report—Volume II, A Design Guidance and Guide Specification Manual.*

This TechBrief describes the key automation technology areas investigated during the project and highlights some of the applications and guidelines presented in the final report.

Key Automation Technologies

This effort focused on the five key technology areas depicted in figure 1. These technology areas were

Figure 1. Diagram. Key automation technologies throughout highway project delivery.



Source: FHWA.

selected with the understanding that, in order to fully implement automation during the construction phase of a highway project, technologies (e.g., systems, components, and software) and processes need to be implemented prior to construction during the planning, surveying, and design phases.

Remote Sensing (Light Detection and Ranging (LiDAR) and Three-Dimensional (3D) Laser Scanning)

Remote sensing describes 3D remote data acquisition using technologies such as LiDAR and other 3D imaging devices. Several State transportation departments own terrestrial static systems, and a few—such as California and Oregon—own mobile systems. These technologies vary in accuracy and precision. For example, 3D laser scanners measure millions of data points per second and generate a very detailed "point cloud" data set (figure 2 and figure 3).

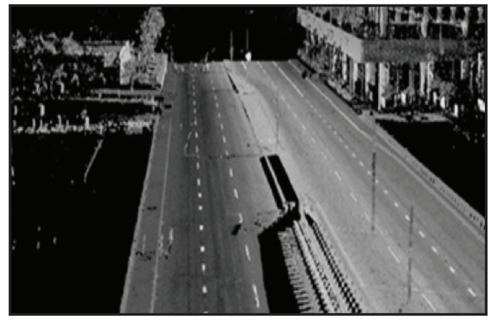
State transportation departments have been conducting research, demonstrations, and pilot projects to evaluate 3D mobile laser scanning systems. For example, the Alabama Department of Transportation investigated this technology, and Russell lists the following key benefits when used in transportation projects:[(3)]

- Increased safety for field crews and traveling public due to ability to avoid lane closures.
- Increased time savings due to a significant reduction in survey delivery time for an average project.
- Increased level of detail, accuracy, and scalability, which translates into efficiency and improved quantity

Figure 2. Photo. Example of terrestrial mobile LiDAR system.

Source: FHWA.

Figure 3. Photo. View of point cloud from mobile laser scanning system.



estimates because scanning provides more information on rutting, pavement condition, guard rails, bridges, overhead utilities, signs, etc.

Underground Utilities Location

Accurate identification of subsurface utilities involves a combination of 3D modeling software and underground location technologies such as geophysical techniques. More accurate information regarding existing utilities is needed, especially for urban environments, to identify conflicts during design and avoid guesswork and digging during construction. In addition, as-built utility plans can be completed for use in future projects and maintenance.

The transportation agencies that were interviewed for this project indicated limited implementation of underground utility-locating technologies. Due to existing workflows and policies, State transportation departments are subject to inaccurate or low-quality information provided by utility companies. In addition, highway projects place the liability for utility conflicts and relocation on contractors.

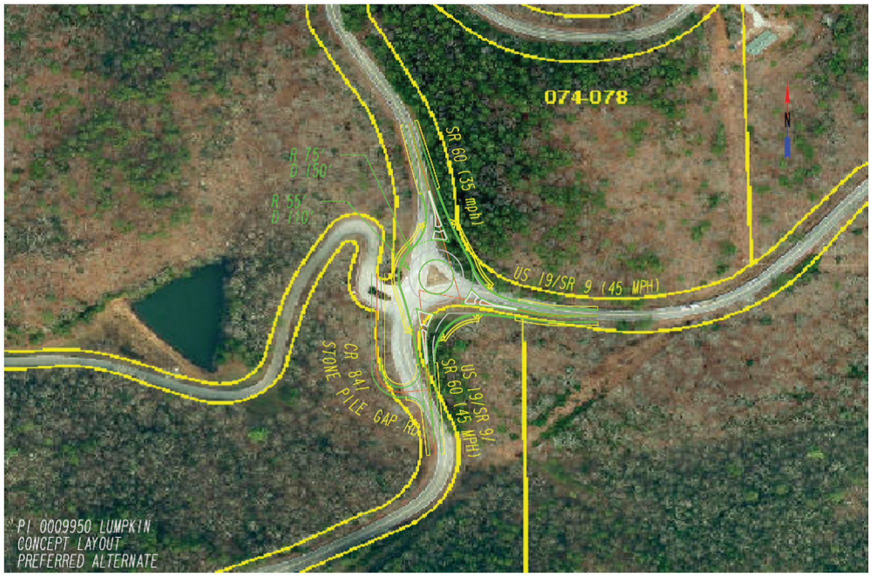
3D Design

3D design is a key process for implementing automation technologies. State transportation departments explain how the transition from two-dimensional (2D) to 3D design has been driven by contractors utilizing automated machine guidance (AMG) and having to reengineer 3D models from 2D plans. Contractors also use 3D models for bid preparation (because it leads to more accurate earthwork quantities), clash detection, field inspection, etc. Once agencies begin considering 3D design to support construction, they realize that the technology can benefit all phases of a highway project, including planning, design, maintenance, and operations.

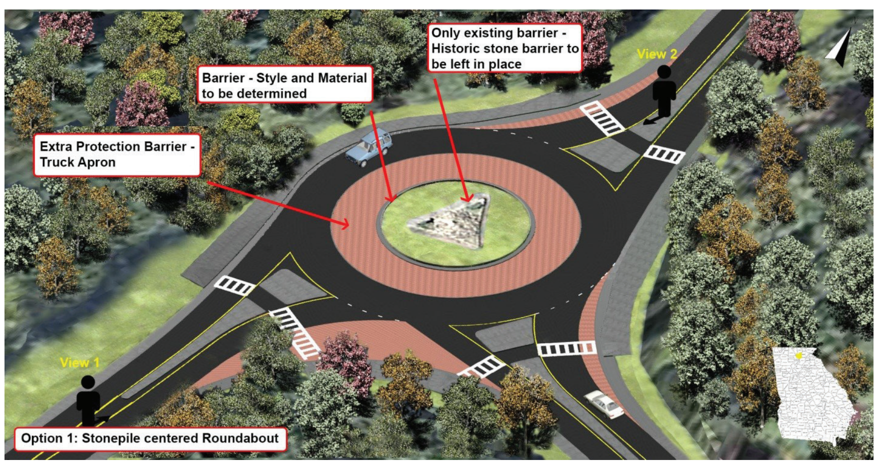
Benefits of 3D design include the following:

- Creation of more accurate construction documents and 3D as-built plans.
- Visualization for engineering analysis and communication with the public (figure 4).
- Detection of issues before construction.
- Conflict resolution applications (i.e., utilities).
- Use in AMG.
- Quantities calculations.

Figure 4. Diagrams. Comparison between 2D plan view and visualization with 3D modeling.



A. Original 2D plan view layout for roundabout project.



B. Rendering of the same roundabout project created with 3D modeling.

As part of the FHWA Every Day Counts initiative, there are significant ongoing efforts within the 3D Engineered Models for Construction track to assist State transportation departments in transitioning from 2D to 3D design. This track includes a series of webinars, trainings, technical publications, a website, and a technical services support center.

Construction Automation

Construction automation involves heavy construction equipment guided or controlled with position-location information, such as from a global navigation satellite system (GNSS) receiver or a land-based positioning system. On highway projects, 3D design data are typically used to control dozers, motor graders (figure 5), trimmers, excavators, milling machines, and pavers. Existing equipment may be retrofitted for AMG.

Benefits of AMG include better control of quantities, increased productivity (around-the-clock operations), increased accuracy and precision (less backfill/earthworks errors), more uniform surfaces, reduced surveying costs and time, fuel savings due to the reduced number of passes, and increased safety due to fewer people setting up stakes and checking grades. In addition, as-built plans can be generated with output from stringless pavers and other equipment systems.

Field Technology and Inspection

Transportation agencies have partially deployed a number of existing market-ready technologies for construction quality control and monitoring. These technologies include intelligent compaction (figure 6), ground penetrating radar, infrared thermal profilers, real-time smoothness profilers, and concrete temperature and maturity meters. In addition, a number of field inspection tools are now available to assist construction administration personnel, such as tablets, smartphones, GNSS rovers, and telematics.

Figure 5. Photo. GNSS guided subgrade motor grader.

Source: FHWA.

Figure 6. Photo. Example of intelligent compaction for asphalt.

Source: FHWA.

The benefits associated with the 3D field and inspection technologies previously described include the following:

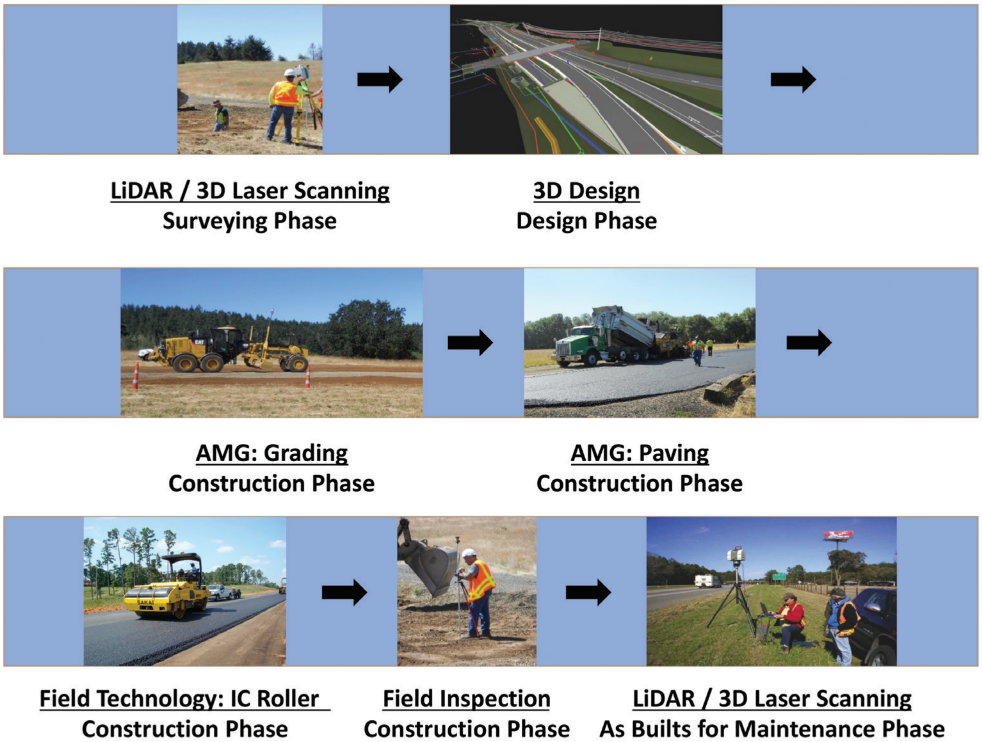
- Improved materials quality, uniformity, and consistency with faster feedback.
- Continuous and more complete coverage.
- Elimination or reduction of coring new and existing pavements or structures and other destructive and labor-intensive testing methods.
- Increased safety with fewer people setting up stakes and checking grades.
- Increased efficiency and productivity.
- Improved communication.

Automation Integration

Figure 7 illustrates how 3D design models created with 3D laser scanning data and 3D design are used during construction operations. For example, earthworks and material placement is followed by paving, compaction, and finally field inspection and scanning of the final product for as-builts.

With automation integration, 3D digital data from one phase are used to inform actions in the next phase. Survey data are used to develop designs, design data are used to construct and inspect work, and as-built data are used to measure completed quantities and are available for operating and maintaining the asset. Automation integration depends on open-data formats that allow data to be used in a variety of

Figure 7. Illustration. Automation technology use throughout a highway project timeline.



Source: FHWA.

applications. It also depends on accurate survey control, which allows 3D data to be associated with a geographic coordinate system and consolidated.

Applications and Guidelines

Implementing a coordinated approach to enabling automation in highway construction is a large task. Automation technology implementation at a State transportation department has an impact on a variety of internal and external stakeholders, as depicted in table 1.

Implementation can be facilitated by modifying a number of policy areas generally found in manuals and construction specifications, as noted in table 2. Early-adopting State transportation departments made significant progress through focused implementation strategies. Transportation agencies have made significant efforts to advance policies and standards for 3D design, deliver 3D design data to construction, and update construction specifications to manage 3D data use associated with AMG and inspection. Current efforts include consideration of changing survey needs, generating 3D design data review protocols, and standardizing measurement and acceptance processes with field technology.

Automation technology implementation also requires capital and human resource investments, including new hardware and software purchases, job function adjustments, and training. Training in particular is often cited as a barrier to implementation. Practical, hands-on-training needs are greatest in 3D design, computer-aided design and drafting (CADD) automation, and inspection with field technology.

Table 1. Stakeholders for automation implementation.

Internal Stakeholders	External Stakeholders
• Information technology. • Survey. • Design. • Contracts. • Construction.	• Contractors and consultants. • Local public agencies. • Small and disadvantaged business entities. • State licensing boards.

Table 2. Policy areas affected by automation technology implementation.

Survey Manual	• Establishing control to support automation technology needs (e.g., site localization). • Inclusion of metadata. • Early identification of project topographic survey accuracies. • Use of remote sensing. • Non-traditional survey products (e.g., point clouds and • 3D solids).
Design Manual	• Selection of subsurface utility location technologies. • Application of 3D models in design development. • Revisions to standard details.
CADD Manual	• 3D model standard content, density, and data segmentation. • 3D model review protocols. • 3D model outputs for construction.
Construction Specifications	• Controlling work: plans and working drawings. • Controlling work: conformance with plans and specifications. • Controlling work: construction stakes, lines and grades. • Controlling work: inspection of work. • Controlling work: quality control plan. • Measurement and payment. • Earthwork, fine grading, base course and paving.
Construction Manual	• Construction data management. • Low accuracy positioning. • High accuracy positioning. • Field technology inspection protocols.

Remote Sensing (LiDAR and 3D Laser Scanning)

Different remote-sensing methods are applicable under different conditions. The selection process must consider the area to be surveyed, land use, terrain, time sensitivity, existing roadway type and length, urban areas, traffic volumes, and traffic speeds. Remote-sensing data outputs include standard topographic mapping products; a registered, classified point cloud in E57 format; digital photo mosaic files (if available); detailed metadata; and a survey narrative report detailing quality control.

Underground Utilities Location

While subsurface utility information may be presented in 3D, 3D information can provide a false sense of security if the quality of the 3D location is unclear. The American Society of Civil Engineers 38-02 standard defines four quality levels (QLs) for subsurface utility data.[4] Of these levels, QL-A is the highest level of accuracy resulting from directly locating the utility. QL-B designates the location with subsurface geophysical locating technologies. QL-C is the most common, involving surveying surface features such as manholes and valve boxes. QL-D is the lowest quality based on ad hoc records.

There is inherent uncertainty in utility locations of all quality levels. Consideration should be given to the organization of 3D utility data to distinguish the different quality levels for design development, plan production, and clash detection. Two effective strategies are separating CADD data into separate files for each quality level, which supports developing rules to apply the appropriate buffer for clash detection, or using color to distinguish between different quality levels in plans. Collecting higher QL information earlier in the design–construction process can reduce the risk of unexpected utility conflicts or utility strikes. A new standard is being developed to record as-built and as-found subsurface utilities during construction.

3D Design

Digital terrain models (DTMs) and 3D line strings are approximations. They are exact through horizontal and vertical tangents and other areas of constant width and grade but are an approximation through horizontal or vertical curves. The distance between points (data density) in DTMs and on 3D line strings determines the accuracy with which the design intent is depicted. 3D models are incomplete and imperfect but are still sufficient for construction if the accuracy is controlled by using the appropriate data density.

The 3D model outputs that are useful in construction can be standardized and described in terms of the presented information, data density, and data segmentation, all of which can be used for design production purposes or to support four-dimensional (4D) modeling. These outputs, if subject to robust data review protocols, can form a model-of-record that is used in construction by both the contractor and engineer. The data density required for AMG is typically 1 ft on horizontal or vertical curves and 5 ft in tangents. Data points are also required at key stations, including horizontal and vertical geometry points (such as begin/end points of curves and high/low points), superelevation stations, offset geometry points (such as begin/end points of lane tapers), drainage facilities, and guardrail and barrier limits.

Model review protocols are needed to ensure that the 3D data are consistent with plans and other contract documents. They must also ensure to sufficiently depict the design intent and meet the content, density, and segmentation needs of construction and also that they are sufficient for the intended construction uses. At this time, 3D model review is largely a manual and visual process. An important consideration is that not every triangulation issue needs to be resolved and not every transition needs to be smooth. The individual conducting the review should be knowledgeable of how the data will be used in construction. Figure 8 illustrates two visual data review protocols for surface data. Coloring surface triangles by slope can identify triangulation problems, while displaying contours at an interval similar to construction accuracy can reveal issues that will lead to blade shudder in AMG operations.

Construction Automation

With performance-based construction specifications, contractors can determine the optimal range of automation technologies to suit the mix of construction activities and project constraints. Performance-based specifications also enable inspectors to use field inspection technologies to measure and inspect work. In their specifications, State transportation departments need to incorporate aggressive but achievable tolerances and allow the engineer flexibility to adapt to the capabilities, methods, and experiences of the contractor and inspectors. This flexibility can be incorporated by the requirement for an automation technology work plan under the Controlling Work: Quality Control Plan section.

The automation technology work plan should document the following:

- The control to be used and the site localization.
- GNSS base station setup or mapping projection.
- The method for determining low accuracy positioning.
- Unique identification of the 3D model of record to be used for construction and inspection.
- Specific uses or requirements for 4D and/or five-dimensional models.
- How and when layout and construction outcomes will be checked.
- How and when pay quantities will be measured.
- Protocols for daily calibration of field technologies.

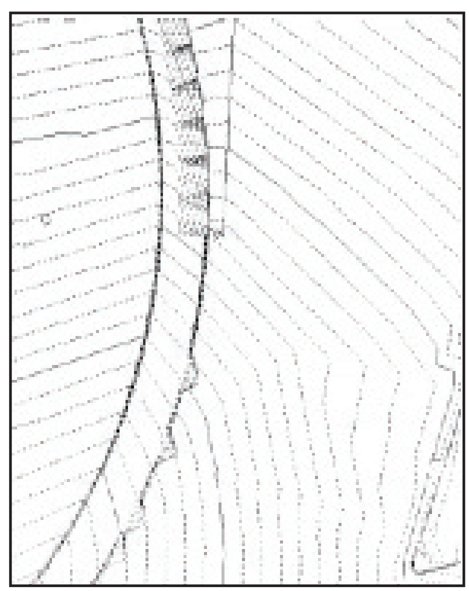
Field Technology and Inspection

The two primary considerations for implementing field technologies for inspection are the model-of-record

Figure 8. Photos. Visual review protocols for surface data.

Courtesy of Hatch.

A. Coloring surface triangles by slope.



Courtesy of Hatch.

B. Display of contours at an interval similar to construction accuracy.

acceptance and inspector tool selection. When an inspector has the 3D data depicting the design intent and a tool with the appropriate accuracy for the data's intended use—either to accept or measure completed work—then field inspection technologies can allow the inspector to check tolerances and capture as-built survey observations quickly and with minimal exposure to construction equipment.

The minimally sufficient data for a model of record are coordinate geometry for control points, primary alignments, existing ground surfaces, and final ground surfaces for temporary and final roadways. Additional 3D data may be useful depending on the automation technologies used by the contractor or the familiarity of the inspectors with field technologies. Often, simple 3D line strings are sufficient, such as pipe flow lines for excavation and pipe laying, curb and ditch lines, and shoulder break points. Even 2D line strings can be beneficial where only horizontal layout is needed. This could be for striping or guardrail placement.

The following equipment is necessary for implementing field technology for inspection:

- A computer with CADD software to review the model of record and work with collected as-built data.
- A GNSS rover with access to a real-time kinematic solution.
- A data collector with construction software to interact with the model of record in real time, record as-built observations, and process observations to measure quantities.
- A total station (preferably robotic) when high-accuracy observations are needed.
- A level (preferably digital) when high-accuracy elevations are needed.

With the 3D data at the inspector's fingertips on a data collector, volumes, areas, and lengths can be computed in real time, reviewed, and incorporated into daily inspection reports. Stored observations can provide a durable record that substantiates the quantities in the event of disputed quantities or claims while also providing a digital, 3D as-built record.

Conclusion

Coordinated planning for automation in highway construction has the potential to add significant value across project delivery, especially in construction. Digital data migration in and out of the construction phase is one limiting factor to fully exploiting automation's potential benefits. The challenge of digital data management is to optimize the collection and creation of data such that they are available in the right resolution when needed.

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