

Wisconsin Department of Transportation 3D Technologies Implementation Plan

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Alan Vonderohe



Construction and Materials Support Center
University of Wisconsin – Madison
Department of Civil and Environmental Engineering

1. Vision Statement.

Adoption of three-dimensional (3D) methods and seamless data flows throughout initial survey, design, contracting, construction, as-built survey, and other applications included within the infrastructure lifecycle.

2. Introduction.

This plan is an update to, and extension of, an initial 3D Technologies and Methods for Design and Construction Plan that was developed in 2009. That plan had 2-year short-term and 5-year long-term planning horizons. It was used effectively by some participants as a guide and reference for activities and management support. Since 2009, functionality and utility of 3D technologies have expanded and new 3D technologies have emerged. Broad interest has been shown across the Department for investigation, evaluation, and adoption of these technologies to realize more efficiency and effectiveness in Departmental mission accomplishment.

The objectives of this updated and extended plan are to establish or reiterate justifications for the initiatives, identify and describe new initiatives, coordinate among the initiatives where appropriate, identify issues, recommend actions that will help realize synergistic benefits, establish or reiterate goals, identify responsible parties, and provide background on interests of potential additional plan participants. This plan addresses:

- Eight initiatives, components of which are either underway within WisDOT or proposed herein and relate directly to 3D technologies and methods (see Section 3).
- Background statements from business areas that are not currently formally associated with any of the eight initiatives but have expressed interest in outcomes and possible future participation (see Section 4).
- A management strategy for moving towards realization of the above vision statement.

3. Initiatives.

3.1. Height Modernization Program (Passive and Active Networks).

Background: WisDOT's Height Modernization Program (HMP) was initially funded by WisDOT in 1998. Additional funding from the National Oceanic and Atmospheric Administration / National Geodetic Survey (NOAA / NGS) began in 2001. The program has two components: 1) a passive network that densifies and improves the vertical component of Wisconsin's geodetic control network and 2) an active network consisting of continuously-operating reference stations, referred to as "WISCORS", that provides statewide support for real-time kinematic (RTK) Global Positioning System (GPS) positioning, with 3D accuracies at the 2cm level, without the need for local base stations.

The passive network is hierarchical, with monumentation and measurements that include the existing high-accuracy reference network, and new primary, secondary, and local stations. Measurements include static GPS and high-order differential leveling. The network is being installed in eight phases, working from south to north and east to west, then back east across the state (see Appendix A). Phases 1-7B are complete with published coordinates. Phases 7C, 8B, and 8 are scheduled for completion during 2013, 2014, and 2015, respectively.

During development and implementation of WISCORS, WisDOT's Geodetic Survey Unit partnered with not only NOAA/NGS, but also other state and local government agencies as well as educational institutions. Through cooperative agreements, partners have and continue to

contribute facilities, power, Internet access, and possible GPS hardware to the program. WisDOT has supplied most of the GPS hardware; all of the GPS software components; nearly all of the supplies and materials to construct the WISCORS monuments; and all information technology (IT) components to operate the system. WISCORS sites include public educational buildings, county facilities, municipal facilities, and a park. The network is operated and controlled by software running on servers in Madison. WISCORS data are archived and made available for post-processing applications (e.g., airborne GPS).

The first 24 WISCORS stations, in southern and eastern counties, were set operational in July, 2008. Other stations were brought on-line as the network was extended to the west and north. As of January 2013, at least 64 stations were operational, 11 were constructed in 2012, and the final six were scheduled for construction in 2013 (see Appendix B). The full network might include as many as 21 additional perimeter stations constructed by agencies in adjacent states, with data sharing provisions scheduled for completion in 2014.

WISCORS supports high-accuracy positional applications ranging from highway construction, to geodetic and land surveys, to utilities mapping, to precision agriculture. During 2012, WISCORS was being used extensively by WisDOT crews and contractors with rovers on highway construction projects. At least one Wisconsin contractor had deployed WISCORS-compatible receivers directly on their construction equipment in support of automated machine guidance (AMG) (see Initiative 4). Users gain access to WISCORS by subscription, which, heretofore, has been free of charge. As of January, 2013, the number of private and public sector registered users with access logins was estimated at about 1,000. In addition, the technological viability, the efficiency, and the cost-effectiveness of virtually all of the other initiatives in this plan depend upon completion and continued operation of the Height Modernization Program. HMP is now included in WisDOT's business plan.

Issues:

- Federal funding for construction of HMP has now ended. However, WisDOT plans to reallocate existing funding for completion of construction.
- WISCORS administration staff require a unique mix of skills including geodetic surveying, information technology and communications, and public relations.
- Every year, passive monuments are destroyed by highway and utility construction projects. To sustain the integrity of the passive network, a process should be developed that would recover monument replacement costs from highway and utility construction projects.
- The passive network requires an ongoing mark maintenance program to remain effective over the long term.
- WisDOT has submitted a 2013-2015 biennial budget request for a WISCORS user fee to address maintenance and operating costs for both networks.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Develop a WisDOT support group that continues advocating internally for sustained resources for HMP efforts.
- Advocate formation of an external users group that works for sustained support at the local, state, and national levels for HMP efforts by communicating the importance of the technology and how it benefits their business needs.
- Complete construction of the active WISCORS network and bring it to full statewide operational status.

- Continue to raise the awareness of management and upper management within WisDOT of the significance of HMP to the overall mission of the department and to the State of Wisconsin.
- Ensure continued funding (e.g., user fees, program revenue) for both passive and active networks.
- Increase the awareness of upper management of funding mechanisms for completion of passive network construction and for operation and maintenance of the active network 24/7.

Long-Term Goals (beyond 2 years):

- Complete construction and publication of passive network.
- Sustain both the active (24/7) and passive networks as operating systems servicing a host of internal and external users.

Lead Section: Bureau of Technical Services – Surveying and Mapping Section.

3.2. LiDAR and Digital Mapping Data Acquisition.

Background: Rapid technological advances are being made in LiDAR and digital mapping data acquisition technologies, while traditional means and methods for data collection are becoming obsolete and, in some cases, terminal due to phasing out of external institutional support or even necessary parts, supplies, and materials. During 2012, the Photogrammetry Unit conducted a survey of state DOTs concerning their status and plans for adoption and transition to these newer technologies. Results of the survey indicated wide variation among the states. It is clear that spatial data acquisition systems at DOTs are in a state of flux which is constrained by necessary changes in workflows and data outputs, variations in standards and procedures, training needs, costs of the technologies, and, perhaps most importantly, diminished human resources.

In 2011, WisDOT obtained a Riegl VZ400 static LiDAR scanner. Survey staff in Central Office and the Southeast and Northwest Regions are trained to use it. However, these personnel have other responsibilities and learned skills diminish with lack of use. Furthermore, the regions have experienced loss of field staff and have requested that Central Office take the lead on development of scanning workflows and procedures and coordinate use of the scanner around the state.

Raw data from the scanner are processed at Central Office and have volumes so large they must often be transferred by shipping physical hard drives. As of January, 2013, Central Office is deciding upon the appropriate software platform(s) for raw data reduction and feature extraction and training two staff to use them.

LiDAR data were collected and used by consultants on WisDOT projects as early as the Marquette Interchange (2006-2007). Late in 2012, mobile LiDAR data were being collected by consultants and provided to WisDOT on contract on a number of projects. The specification developed for the associated one-year master contracts was developed from existing specifications used by USGS, CALTRANS, and other state DOTs. In addition to ground-based static and mobile systems, LiDAR data can also be gathered from the air aboard airplanes, helicopters, and unmanned aerial vehicles.

WisDOT owns a film-based mapping camera and rents an airplane from WisDOA to fly photogrammetric missions. WisDOT processes its own film, scans it, and uses the scanned

imagery for photogrammetric aerotriangulation and mapping. The camera is routinely calibrated by USGS, a service that is expected to be phased out by 2017. The film type currently used in the camera is expected to be available until 2020. In addition to addressing the obsolescence of film cameras, digital mapping cameras eliminate the need for film processing and scanning. Clearly, a transition to digital camera data acquisition is not only desirable but also necessary. Some DOTs have already done this and most others are in the transition process or planning for it. There are consultants who can provide digital mapping camera imagery, but WisDOT is not a high-priority client for them because corridor strip mapping is low volume versus large county-wide and state-wide block mapping.

Acquisition of a digital mapping camera could include airborne GPS/IMU for sensor orientation and yield associated savings by reduction of ground control for aerotriangulation. There are also potential impacts upon existing map compilation, data management, and image and map data archiving procedures and standards.

Given these developments, WisDOT's Facilities Development Manual (FDM), Chapter 9, Surveying and Mapping, that describes field and office procedures and standards for data acquisition, processing, and delivery, needs comprehensive review and revision.

Issues:

- There is a critical need for a LiDAR coordinator position to take charge of field operations with the existing sensor, train staff on hardware and software, coordinate overall LiDAR data acquisition, processing, and dissemination, and conduct research to stay abreast of developments in LiDAR technology.
- The existing LiDAR master contract specification needs review and improvement for increased robustness.
- Standards and procedures for in-house LiDAR data collection, processing, and accuracy need to be developed.
- LiDAR data processing software is rapidly evolving and new, more efficient and effective capabilities will become available on short notice.
- LiDAR and digital mapping cameras are expensive and are "disruptive" technologies in that they require new knowledge and skills and revisions in standards, procedures, workflows, and data flows. Strong cases must be made not only for procurement but also for adoption into business practices.
- Compatibility between the existing rented airplane and digital mapping camera alternatives must be determined.
- There are no back-ups for personnel performing critical photography acquisition functions so current personnel must be retained.
- There is no established calibration procedure for digital cameras and proposed calibration requires test flight(s) over targeted survey monuments.
- There is need for both in-class and on-the-job training for both data collection and analysis.
- Chapter 9 of WisDOT's FDM must be revised.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Fill a LiDAR coordinator position as soon as possible. This position has been approved and the process for filling it is underway.
- Develop a contract with UW-Madison assistance for research on LiDAR technology and training issues and film versus digital mapping camera processes. The research should address technical aspects, costs, potential benefits, standards and specifications,

personnel and training needs, options, and alternatives for adoption of LiDAR and digital mapping camera technology. The research should lay the groundwork for, and make recommendations concerning, development of a detailed implementation and transition plan. NOTE: This study should be coordinated with, and share information with, the broader department-wide study of LiDAR data applications proposed in Initiative 7.

- Building upon the UW-research, and in coordination with the Bureau of Aeronautics, develop and begin implementing a plan for adoption of LiDAR and digital mapping camera technology that includes both short-term and long-term components. Include budget costs for capital equipment, necessary personnel, and training. During plan development, consider the activities and findings of FHWA's Every Counts II initiative.
- Evaluate photogrammetric deliverables for 3D design practices.
- Revise Chapter 9 (Surveying and Mapping) of the FDM to bring it up-to-date.

Long-Term Goals (beyond 2 years):

- As needed, revise and update the implementation plan for adoption of LiDAR and digital mapping camera technology.
- Retain and/or seek skilled staff and human resources required by the implementation plan.
- Evaluate technological advances in spatial data acquisition and incorporate into updated implementation plan as appropriate.

Lead Section: Bureau of Technical Services – Surveying and Mapping Section.

3.3. 3D Design Process.

3.3.1. Statewide 3D Design Process.

Background: WisDOT's Methods Development (MD) team has an ongoing plan for full statewide deployment of Civil 3D, including tasks, milestones, and timelines. The plan addresses:

- Design products.
- New design workflows and functionality for:
 - Quantity take off (QTO) functionality in Civil 3D.
 - Pipe network functionality in Civil 3D.
 - Drainage analysis functionality in Civil 3D.
- Model format and content standards, including design-speed-based data density.
- Updated workflows to accommodate survey data management.
- Custom Subassembly library.
- Upgrades from Civil 3D 2012 to Civil 3D 2014.
- Investigation of the potential for collaborative design and archiving technologies (e.g., Autodesk's Vault),
- Redevelopment of training materials to address the upgrade to Civil 3D 2014.

One MD milestone for Sept 2013 is complete retirement of CAiCE as a roadway design software platform within WisDOT Region offices. Three milestones for July, 2014 are 1) complete retirement of MicroStation as a roadway plan production software platform within WisDOT Region offices, 2) requiring 3D Surface Model delivery on appropriate new design projects, and 3) requiring all new WisDOT roadway design projects, both in-house and consultant, being completely developed with Civil 3D, and the entire finished Civil 3D design project data set to be delivered at time of PS&E submittal.

MD is making a distinction between the terms “3D Surface Model” and “Roadway Model”. The 3D Surface Model’s primary purpose is for contractor use in automated machine guidance (AMG) activities. The Roadway Model will contain information from the 3D Surface Model, but will be much broader. It will include information necessary for, and derived from, design and construction. The Roadway Model concept and description will evolve through the period of this plan and several years beyond, growing in formality, content, and complexity as new uses for Roadway Model data are realized in other areas of the infrastructure lifecycle.

MD will investigate adding pipe networks (WisDOT assets) and utilities (both WisDOT and third-party assets) to Civil 3D design project delivery requirements as the first evolutionary step of the Roadway Model. Addition of these data, and adoption of appropriate software functionality, will enable pre-construction clash detection and allow designers to avoid proposed and existing facility components sharing the same space. These advances will eliminate both the need for manual clash detection procedures at design-time and design changes arising from clashes detected during construction. It should be noted that Civil 3D is limited in clash detection functionality. To take full advantage of Roadway Model constructability analysis potential, other Autodesk software, such as Navisworks, should be considered for implementation.

Extending past the period of this plan, the use of Civil 3D is expected to expand beyond design and construction. With future enhancements to the software, examples include field survey, photogrammetry, and impact analysis for environmental documentation. Other Autodesk civil engineering software offerings will be evaluated on an ongoing basis, as these software offerings have potential to supplement Civil 3D functionality in WisDOT processes.

Issues:

- There will continue to be retraining implications for keeping current with software advances and new software implementations.
- Maximum corridor frequency spacing standards have yet to be developed for pavement and concrete base course surfaces in 3D Surface Models.
- Robustness of 3D Surface Model content and design-construction data flows should be confirmed with contractor feedback and additional pilot projects.
- There are contractual and legal questions to be addressed when considering making Roadway Models a part of the contract documents.
- The concept of “Roadway Model” needs more development and documentation to address uses such as inspection and measurement of final quantities, traffic operations, utilities and access permitting, as-built input to future designs, and other infrastructure lifecycle uses of 3D technology.
- For a variety of functional areas within the Department to use the Roadway Model, formal conceptual, logical, and physical data models and information infrastructure models must be developed along with assignments of data management and custodianship responsibilities.
- Software functionality and data representations exist for extension of design into four and five dimensions, representing time and cost, respectively. Consultants with Southeast Freeways have adopted such technology and applied it to mega-projects such as the Mitchell and Zoo interchanges. Applicability of these technologies on a statewide basis needs evaluation.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.

- Continue development and execution of the extended deployment plan for 3D design as described above.
- Require 3D Surface Models as a design deliverable on new project starts, and maintain 3D Surface Model content requirements as related to AMG practices.
- Require development of all new (in-house and consultant) WisDOT roadway design projects in Civil 3D.
- Fully retire CAiCE and Microstation in the Region offices for WisDOT roadway projects.
- Develop 3D Surface Model content requirements for pavement and concrete base course surfaces.
- Implement the addition of pipe networks and evaluate 3D utility representation in Civil 3D projects delivery requirements and develop necessary associated workflows.
- Evaluate adoption of software functionality for clash detection, including Navisworks software.
- Monitor Southeast Freeway's use of 4D and 5D Roadway Models and other advanced spatial technologies and evaluate applicability on a statewide basis.
- Conduct pilot projects to continue to evaluate robustness of 3D Surface Model standards and data flows to contractors.
- Develop and document the initial concepts of "Roadway Model".
- Initiate discussion with BITS concerning Roadway Model usage goals and concepts at the enterprise level.

Long-Term Goals (beyond 2 years):

- Develop and execute an extended deployment plan for 3D design (and beyond). Update and extend the plan as needed.
- Evaluate 3D Surface Models as construction contract documents.
- Realize the "Roadway Model" concept by developing and implementing formal conceptual, logical, and physical data models. Include information infrastructure models, data management, and custodianship.

Lead Section: Bureau of Project Development - Roadway Standards and Methods Section.

3.3.2. Southeast Freeways 3D Design Process.

Background: The Zoo Interchange is the latest of Southeast Freeways' megaprojects to exploit and make innovations with 3D technologies. Automated machine guidance (AMG) was used as early as 2004 on the Marquette Interchange. AMG, building information modeling (BIM), and LiDAR surveys were used later on the Mitchell Interchange. As of January, 2013, the in-house portion of the Zoo Interchange design had completed 30% review and the consultant portion of the design had completed 60% review. Initial construction is scheduled to begin in 2013 on STH 100 and local roads.

During design on the Zoo Interchange, 3D modeling is being used for clash detection and resolution, BIM (4D integration with project schedule), visualization and animation (walk-thru and drive-thru). Clash detection has been done to support specialized requests and also on a comprehensive basis at collaborative sessions with all parties who have worked on different design components. Hundreds of conflicts have been detected and resolved with this process.

During construction, 3D models will support AMG, layout of items that are not contractor staking, quantity reporting and pay items, and development of electronic as-builts. Models will be updated as field conditions change. It is expected that at completion of construction there

will be an exportable as-built GIS shape file suitable for use in roadway maintenance, future designs, and other post-construction applications.

The models that have been, and are being, built contain at least 28 object classes, for example, grading surfaces, lighting, signals and signs, twelve types of utilities (existing and proposed), pavement markings, existing and proposed structures, and landscaping.

Issues:

- Much of the modeling capability and functionality has been developed by consultants. Southeast Freeways wants to have the capacity to perform these functions in-house.
- BIM has not yet been applied to project staging for detailing temporary traffic configurations to identify problems with drainage, turning radii, vertical or horizontal clearances, constructability, emergency access, grade differentials, and project interface issues.
- Applications of 3D modeling to support public information meetings and community presentations have not yet been explored.
- Structures are still being designed in 2D, then 3D models of them have to be built from plans.
- Details of development, management, and exportation of 3D as-builts have yet to be described.
- There is no Southeast Freeway library of 3D templates and typicals.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Design and begin development of a library of 3D templates and typicals.
- Develop and begin implementing a plan for in-house capacity for modeling and BIM functionality to include clash detection, design reviews, project staging, and public information applications. Use the Zoo Interchange as the practical platform.
- Evaluate Autodesk's Vault software for collaborative design, data management, and archiving.
- Investigate existing methods for determining qualitative and quantitative benefits of advanced spatial / temporal technologies. Modify, if necessary, and plan for application to Southeast Freeways' circumstances.

Long-Term Goals (3-5 years):

- Develop capacity for 3D structural design.
- Fully implement the plan, developed under the short-term goal (above), for in-house capacity for modeling and BIM functionality.
- Realize the 3D as-built for the Zoo Interchange.
- Document and publish the qualitative and quantitative benefits of advanced spatial / temporal technologies as realized by Southeast Freeways.

Lead Section: Southeast Freeways.

3.4. Automated Machine Guidance (AMG).

Background: WisDOT has successfully developed a statewide specification for automated machine guidance (AMG) for grading operations. The AMG grading specification gives contractors the option of using AMG on any project that includes the construction staking subgrade item. It has been included in WisDOT's standard specifications since 2010.

WisDOT also has a provisional specification for AMG construction of hot mix asphalt (HMA) base course. This specification built upon the one for grading with modifications to the quality assurance (construction check) component. Under the AMG HMA specification, the tolerances on construction checks are more stringent than those for grading. This specification was included as a special provision on four pilot projects during 2011 and one pilot project during 2012. All HMA base course construction checks met the specified tolerances on the pilot projects, but the sample size was very small (12 check points) and inadequate to draw firm conclusions concerning this component of the specification. On the other hand, the pilot projects were very helpful in determining the “construction-readiness” of the 3D Surface Models.

As of January, 2013, WisDOT is not aware of any Wisconsin contractors who are using AMG for concrete base course, asphalt paving, or concrete paving. However, the technology is being used for these purposes in neighboring states (e.g., Iowa and Illinois). WisDOT will monitor practice and on-going activities both within and outside of Wisconsin, and intends to initiate development of AMG specifications for these purposes.

Issues:

- Robustness of the quality assurance component of the AMG HMA base course specification needs further testing.
- AMG technology also exists for construction of bridges and utilities. Ultimately, WisDOT will need to address these uses.
- The frequency of design changes during construction is considerably reduced by provision of 3D Surface Models by WisDOT to contractors. However, the impact of post-ward and construction-time design changes on workflows and data management (e.g., changes to 3D Surface Models) needs to be better understood.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Investigate conducting pilot projects to evaluate robustness of the quality assurance component of the AMG HMA base course specification. The pilot projects should also evaluate existing 3D Surface Model standards and data flows to contractors.
- Evaluate incorporation of the AMG HMA base course specification into WisDOT's standard specifications.
- Monitor and refine, if necessary, the AMG specification for grading.
- Monitor Wisconsin, Iowa, Illinois, and nationwide activities in AMG for concrete base course, asphalt paving, concrete paving, and initiate specification development.

Long-Term Goals (beyond 2 years):

- Complete development of and implement AMG specifications for concrete base course, asphalt paving, and concrete paving.
- Develop and implement AMG specifications for bridges and utilities.
- Monitor and refine existing AMG specifications.

Lead Section: Bureau of Project Development - Project Services Section and Roadway Standards and Methods Section.

3.5. Southeast Freeways Field Technology and Inspection.

Background: Construction project engineers for Southeast Freeways have been using real-time kinematic (RTK) GPS rovers, coupled with 3D models, in the field for a number of years. As model content grows in detail, field applications grow in number. Rovers / models have been

used for surface checks, earthwork quantities (including excavation below subgrade), sign placement, critical clearances, depth checks, locating and coordinating utilities, plan navigation, and verification surveys. Southeast Freeways is in the process of acquiring two ruggedized tablet computers that can either stand alone or be interfaced with GPS rovers. The tablets run standard PC operating systems and are WiFi enabled. They have cameras and video capability. There is potential for direct geo-referencing of images and video; utility relocation verification; in-field electronic note-taking (e.g., field entries to diaries), documentation, computation, and visualization; and, ultimately, linkage of these data to models for real-time model maintenance, project record keeping, pay items, and 3D as-builts.

Consultants are currently mapping existing utilities (to be used in design) using subsurface utility excavation (SUE) and RTK GPS or traditional surveys. This survey information is sometimes merged with as-built system maps to obtain a more complete 3D representation of utilities.

Stationary and mobile LiDAR surveys were used extensively on the Zoo Interchange to map existing terrain and structures. Designers were provided with point clouds, images, and extracted surfaces and features. LiDAR data have also been successfully combined with photogrammetric and ground survey data. Southeast Freeways has developed an integrated surveys specification that addresses all modes of terrain and feature mapping.

Issues:

- The tablet computers have yet to be field tested for ruggedness and functionality.
- Existing utility maps sometimes contain errors and omissions.
- There are emerging technologies for mapping utilities in 3D without excavation.
- Data collected with WisDOT's static LiDAR scanner have to be initially processed at Central Office, so those data need to be transmitted or shipped. In addition, there are limited numbers of staff who are trained in field use of the device.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- During 2013, pilot the use of ruggedized tablet computers on STH 100 at the Zoo Interchange. Determine effectiveness of interface with rovers and models, durability (field-worthiness), effectiveness and limitations of WiFi as applied to use of tablets, utility of image capture and referencing capabilities, best uses and overall effectiveness of tablet functionality.
- During 2013, pilot the use of electromagnetic (particularly, SPAR) technology for subsurface utility mapping on STH 100 at the Zoo Interchange. Do this as a component of Central Office's utility mapping initiative.
- Participate with the Surveying and Mapping Section in their LiDAR and digital mapping data acquisition initiative to help establish a path forward for more effective use of WisDOT's static LiDAR scanner and processing of its data.

Long-Term Goals (3-5 years):

- Apply lessons learned from 2013 pilot projects on tablet computers and SPAR technology to core contracts for the Zoo Interchange.
- Stay abreast of developments in field technology and plan for implementation as appropriate.

Lead Section: Southeast Freeways.

3.6. Utilities.

Background: Lack of information concerning location and character of subsurface utilities might incur substantial costs to transportation design and construction on recondition, reconstruction and major highway improvement projects. These include costs for utility relocation, construction delays, construction change orders, and design changes. Liability is, of course, also an issue with costs for claims, damages, delays, and environmental clean-up or mitigation.

These costs and liabilities might be considerably reduced by developing, maintaining, and sharing a three-dimensional (3D) utilities database. For example, a 3D utilities database, available pre-design, would enable design engineers to make informed decisions on avoiding utilities rather than requiring relocation prior to or during construction, which saves costs for both WisDOT and the utilities. It might also lead to minimizing utility relocations if avoidance is impossible or impractical. An accurate and current 3D utilities database would reduce the likelihood of catastrophic events during construction. The list of benefits is extensive.

These notions are not new, but technologies for locating, characterizing, and mapping subsurface utilities are now emerging and improving. In addition, design concepts and tools are also moving towards multi-dimensional capability with WisDOT now in the process of implementing 3D design methods statewide.

The issues surrounding utilities mapping are of national and statewide prominence. At least five utilities mapping and data management SHRP2 projects, one NCHRP project, and one ACRP project have been recently completed or are underway. There are AASHTO and TRB committees actively involved in studying subsurface mapping technologies and institutional and legal issues associated with utilities locational data. WisDOT's Utilities Unit undertook a 2012 study that included identification of issues, stakeholders, a literature review, a survey of other state DOTs, and potential policy modifications concerning utilities data collection and management. Also in 2012, WisDOT's Northeast Region conducted a pilot project to assess the effectiveness of one of the subsurface mapping technologies in locating a given gas main.

The mapping technologies include electromagnetic field sensors, ground-penetrating radar, acoustic sensors, reflective seismic wave sensors, and platforms with combinations of these. Most of the technologies are now integrated with real-time kinematic (RTK) GPS and/or inertial measuring units (IMUs) for referencing to horizontal and vertical datums as opposed to surface features and topography.

Each of the technologies has different limitations concerning, for example, horizontal and vertical accuracy, effective depth, need for positioning the sensor directly over the subsurface feature to be mapped, need for manual interpretation of complex images, need for tracer wires (which not only must be there, but must also remain attached to the facility being mapped), and need for physical access points to the facility. In addition, there are questions concerning data representation; data model and format compatibility with design, BIM, and GIS software; and data responsibility, access, sharing, liability, and archiving.

Not to be overlooked is an existing technology called "subsurface utility excavation" (SUE). This involves water or air excavation of material over a buried utility. WisDOT currently allows SUE, which is detailed in section (3.3) of its Utility Accommodation Policy:
<http://www.dot.wisconsin.gov/business/rules/docs/09-15-45.pdf>

While more intrusive to the right-of-way with regards to methodology, SUE provides data that is more accurate than subsurface mapping technologies since the buried utility is exposed and surveyed. Many state DOTs include SUE as a pre-design item in an improvement project, that is, the cost is paid for by the DOT as part of the project. FHWA has also determined that SUE is a reimbursable cost, and has encouraged its use since 1991. See:

<http://www.fhwa.dot.gov/programadmin/sueindex.cfm>

Even if WisDOT did not use federal funds for SUE work in advance of project design, it might be acceptable by utilities for them to share in a portion of the cost if it would save them many more dollars instead of relocating should WisDOT be able to design around them.

Issues:

- Utility companies are leery of data sharing.
- To include requirement for placement of tracers in utility permits:
 - Need specifications on placement.
 - Need identification of responsibility and method for QA/QC on placement.
 - Need to coordinate with utilities to develop policy.
 - Need to perform periodic inspections to maintain the requirement
- Which data acquisition technologies are most viable for WisDOT purposes?
- What are the costs of data acquisition and who will pay for it?
- Data collection protocols and standards, to include tolerances and spatial frequency.
- Utility inventory data models and standards.
- Data exchange standards and specifications.
- Data and record-keeping responsibility and standards.
- Integration with other WisDOT information systems.
- For avoidance of utility conflicts during design, need roadway model to include pipe networks, structures, signal bases, etc.
- Need specifications on spatial frequency of SUE.
- Involvement of Diggers' Hotline.

Short-Term Goals (2013):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Upper management needs to make a decision on use of improvement dollars for SUE for preliminary design.
- Develop draft policy on implementation of SUE on specific WisDOT highway improvement projects.
- Select a few projects to begin using SUE on a test basis.

Intermediate-Term Goals (2-3 years):

- Prepare a work plan for meeting these intermediate-term goals. Include a timeline for each goal.
- Build upon findings from the 2012 Northeast Region's pilot project and the 2013 SUE pilot projects by conducting 3-5 additional pilot projects on use of the technologies.
 - Work with WTBA and a subset of utilities.
 - Preliminary identification of pilot projects to be raised at joint PDS Chiefs meeting in January, 2013.
 - Use SUE, electromagnetic SPAR technology, and possibly ground-penetrating radar.
 - Conduct mapping during preliminary survey so results can be used during design.
 - Conduct mapping as needed during construction.

- Develop and implement policy on including tracer placement in utility permits.
- Conduct outreach to utilities and contractors. Include them as participants in the activities of above goals.
- Stay informed on developments in research, implementation, and policy at the national level and within other state DOTs.

Lead Section: Bureau of Technical Services – Utilities Section; Bureau of Highway Maintenance - Permitting Section.

3.7. Roadway Lifecycle Uses of LiDAR Data.

Background: Photolog Unit personnel convened a LiDAR focus group that met a number of times in 2009 and 2010. The group conducted a literature review on transportation applications of airborne, mobile, and static LiDAR; identified potential WisDOT applications; identified specific roadway objects and features that are inventoried and described spatially by WisDOT; hosted demonstrations by four different vendors of mobile LiDAR, and proposed pilot projects focused upon shoulder slopes and clear-zone encroachments with considerations for safety. The group has not been active since 2010.

There is now renewed interest in LiDAR in a number of additional WisDOT business areas:

- Investment in static LiDAR technology by the Surveying and Mapping Section.
- Use of mobile LiDAR by Southeast Freeways and the I/39 megaproject.
- The Bureau of Traffic Operations has expressed interest in LiDAR applications arising from an urgent need to upgrade their software and approach to management of inventory and asset information.
- The Traffic Operations (TOPS) Lab, at UW-Madison, which conducts frequent simulation studies for the Bureau of Traffic Operations, seeks LiDAR representations of roadways, structures, furniture, and the surrounding environment.
- The Bureau of Structures foresees potential use of LiDAR for not only measurement of horizontal and vertical clearances but also bridge inspection.

Potential applications of LiDAR range from safety (e.g., clearances, side slopes, pavement/shoulder drop-offs) to planning, to project scoping, to outdoor advertising, and, of course, to engineering surveys as inputs to design and post-construction mapping of as-built facilities. Moreover, since the initial focus group met in 2009 and 2010, there have been advances in the technology itself such as fusion of X,Y,Z point clouds with image data and improvements in feature-extraction software.

The Photolog Unit is a department-wide collector, steward, and provider of data for WisDOT. As such, the photolog van travels Wisconsin's Interstate, U.S., and State Trunk highways, on a 2-3 year cycle, collecting digital images every 0.01 miles. The images are geo-referenced horizontally, vertically, and linearly by an on-board position orientation system (POS) that integrates a distance measuring instrument (DMI), differential GPS, and inertial sensors. The POS collects vehicle position, velocity, attitude, track, speed and dynamics. Horizontal and vertical coordinates (accurate to about one meter) are collected five times per second to facilitate calculation of roadway curvature and grade. With significant modification and upgrade, the photolog van might be a potential platform for mobile LiDAR data collection.

Issues:

- The full range of potential LiDAR applications across WisDOT is not currently understood and documented.

- The required accuracies, resolutions, and forms of data representation for the various applications are also unknown.
- There are opportunities for planning-level LiDAR data sharing (e.g., WisconsinView and with local governments) that need to be explored.
- The capabilities and limitations of various forms of LiDAR data collection technologies (e.g., airborne, static, mobile) need to be better understood and matched with the requirements of WisDOT's range of applications.
- The very large volumes of data (e.g., multiple petabytes for statewide surveys) acquired by LiDAR have undetermined information technology infrastructure constraints.
- LiDAR point clouds must be processed to extract desired feature representations, requiring skilled staff and considerable effort.
- Costs, benefits, and potential return-on-investment for the broad range of WisDOT applications have not been studied.
- It is not known if the photolog van is an appropriate platform for mobile LiDAR collection.
- In-house versus consultant-based LiDAR data collection and feature extraction alternatives need to be understood.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- As soon as possible, form a study group for department-wide applications of LiDAR data.
- Have the study group conduct or oversee an investigation that addresses at least:
 - Applications and their required accuracies.
 - Whether or not the photolog van is an appropriate platform to support priority applications.
 - Costs and benefits.
 - Management of very large volumes of data generated by raw LiDAR data collection.
 - Feature extraction capabilities and requirements.
 - In-house versus consultant-based alternatives.
 - Opportunities for data sharing with other agencies and local governments.
 - Identification of options and development of recommendations.

NOTE: The proposed study should focus upon applications beyond those administered by the Surveying and Mapping Section which is conducting a detailed study of LiDAR at the engineering-survey-specification level (see Initiative 2). There should be coordination and information sharing between the two studies. Together, the two investigations should establish a path forward for adaptation of LiDAR technology and its uses on a department-wide basis.

- Based upon outcomes of the proposed investigation, prepare and begin executing an implementation plan for LiDAR technology. The implementation plan should identify dependencies, set priorities, and sequence the different applications of LiDAR data so they can be addressed incrementally. Furthermore, the implementation plan should be coordinated with the plan to be developed by the Surveying and Mapping Section (see Initiative 2).

Long-Term Goals (beyond 2 years):

- As needed, revise and update the implementation plan for adoption of LiDAR technology.
- Retain and/or seek skilled staff and human resources required by the implementation plan.

- Evaluate technological advances in LiDAR data acquisition and feature extraction and incorporate into an updated implementation plan as appropriate.
- Based upon data management findings of the study and aspects of the subsequent implementation, identified above as short-term goals, develop a long-range strategy and implementation plan for management of extremely large volumes of LiDAR data for department-wide applications.

Lead Section: Bureau of State Highway Programs – Data Management Section; Bureau of Traffic Operations.

3.8. Information Technology Infrastructure.

Background: Three-dimensional technologies are used to acquire, analyze, and manipulate large volumes of data that must be stored, maintained, disseminated, and ultimately archived. These technologies include LiDAR; digital cameras; film scanners; photogrammetric workstations; subsurface detection and mapping systems; design, construction, building information modeling, visualization, animation, and simulation software. Data volumes, for individual applications, can exceed multiple petabytes. Planning for implementation of such technologies must take place within a pragmatic context of information technology capacity and constraints. Conversely, planning for information technology capacity expansion and upgrades must be done in informed light of resource requirements for exploitation of new spatial technologies in data acquisition, manipulation, and application business areas.

Consideration must be given to true business requirements of the Department to address questions such as:

- What is the timeline or roadmap for inclusion of 3D technologies into daily business processes?
- Who (including external business partners) needs what data or data components?
- How much data do they need?
- When is the data needed?
- In what form is the data needed?
- Is all data gathered, required to be stored or just the reduced, analyzed portion of data? And for what length of time?
- Is the data shared between locations? If so, is the raw data or a subset shared and in what format will it be shared?
- What portion of the data gathered needs to be centrally available?
- Does any data need to be associated and stored with any of the electronic documents that are stored for records? (This potentially impacts WisDOT's document management system.)
- How does software process the data to understand potential local area network (LAN) / wide area network (WAN) impact? And, subsequently, which data needs to be backed-up?
- What is the RDA for data associated with the 3D technologies?
- What is the cost/benefit for financial support for internalizing 3D capabilities?
- What is the financing model for expansion of the IT Infrastructure to accommodate future 3D technologies?

Answers to such questions assist with decision-making on resource and data management needs ranging from disk and network capacity and speed, to data retention and archiving, to choice of appropriate platforms (e.g., server vs. workstation), to funding for deployment and maintenance for expanded infrastructure. To obtain these answers, the Bureau of Information Technology Services (BITS) needs to be keenly aware of business area workflows and

associated data flows well in advance of expected deployments. At the same time, business areas planning for adoption of 3D technologies must account for costs, not only of the technologies, themselves, but also of any necessary expansion or upgrades and lifecycle maintenance to the supporting information infrastructure.

Much 3D data undergo a three-step process of acquisition, extraction, and application. For example, LiDAR and ground-penetrating radar (GPR) technologies typically acquire data that is much larger in volume and far different in form than are needed by end-users. LiDAR point clouds and GPR images are massive amounts of raw data that must be manipulated and analyzed to extract the reduced surfaces and feature-based data sets that are needed by end users. The same is true for photogrammetric data, whether the raw data are from digital cameras or film scanners.

Some 3D data acquisition or application business needs are project based (e.g., design and construction) and others are statewide or enterprise based (e.g., photolog and GIS). Furthermore, there is potential for various post-design-and-construction, broader-based uses of project-based data. Data volumes and utility vary greatly among these needs.

BITS is represented on the Management Group for the 3D Technologies Implementation Plan and will be involved in, or actively aware of, the goals for each of its initiatives.

Short-Term Goals (1-2 years):

- Prepare a work plan for meeting these short-term goals. Include a timeline for each goal.
- Perform a project to determine network capacity requirements to meet 3D needs and identify ways to increase capacity and performance. Study will include a recommendation for changes in technology to meet 3D requirements, expected costs, and a proposed timeline for implementing recommended technology.
- Perform a project to determine data storage needs for 3D and capacity at remote and central sites and identify ways to increase capacity, performance and sharing of data between regional and central office for DTSD. Study will include a recommendation of needed changes in technology for meeting upcoming 3D requirements, expected costs and a proposed timeline for implementing recommended technology.
- Perform a project to evaluate ESRI LiDAR extensions and usage at DOT. Provide recommendations on usage, data inter-relationships, any additional costs and a schedule of implementation if warranted.
- Determine architectural strategy for integration between 3D data and GIS applications and what additional services DOT will seek to provide with 3D data (e.g., 3D web services to DOT applications).
- Complete EDSM pilot and determine any related costs for full-scale implementation.
- Assist DTSD with their technology goals and provide guidance on issues related to Information Technology.
- Implement recommendations within reasonable time and budget from the network capacity or data storage projects.
- Continue to be involved and represented during execution of this 3D Technologies Implementation Plan.

Long-Term Goals (beyond 2 years):

- Continue to implement recommendations as funding is provided from short-term goals.
- Re-assess capacity needs at least every 2 years.

- As needed, revise and update the DOT Strategic Plan for adoption of 3D-related technology.
- Continue to assess inter-relationships of 3D data and how it can be used in other applications or services.
- Retain and/or seek skilled staff and human resources required by the Implementation Plan.
- Evaluate technological advances to assist business areas with their 3D technology goals.
- Continue to be involved and represented during execution of this 3D Technologies Implementation Plan.

Lead Section: Bureau of Information Technology Services – Application Development Support – Modal & Corporate Section.

4. Additional Plan Participants.

4.1. Bureau of Structures.

Background: Currently, the Bureau of Structures uses a number of software tools for design and analysis. These tools typically have limitations related to 3D and 4D design. For example, the current design process has geometric and structural (e.g. materials) components. These components are supported by separate software platforms. The Bureau wants to explore the potential for integrated 3D and 4D geometric and structural design software to improve both the efficiency and effectiveness of bridge design. FHWA has a current research project on geometric and structural design integration.

In addition, there is a need for more powerful subsurface (geotechnical) representation and analysis software. The software now in use represents two-dimensional locations of boreholes along with their profiles. The analyst has little or no information concerning substrata at other than borehole sites. There are existing software products that spatially interpolate among boreholes and represent the subsurface in three dimensions. There would be benefit in being able to recognize variation in subsurface conditions below a proposed substructure unit. Ultimately, the Bureau, along with the Bureau of Technical Services, would like to move towards integrating and sequencing of subsurface information (including utilities) in the design process.

3D design outputs would also benefit the structural component fabrication process. Currently, fabricators build their own 3D models from 2D plans.

Recently, the Bureau provided 3D models to Southeast Freeways for their use in building information modeling (BIM) and project simulation for the Zoo Interchange. The Bureau would like not only to explore BIM but to extend Southeast Freeways' effort to include sequencing of concrete pours and erection of structures.

The Bureau also has interest in applications of 3D data acquisition technologies. The Bureau is involved in oversize/overweight vehicle permitting because of clearances (both horizontal and vertical) and dynamic load capacities of existing structures. Clearances (that must be known to within an inch) change over time because of, for example, pavement overlays. Mobile and static LiDAR have demonstrated potential for determining clearances and WisDOT's Photolog Unit collects statewide data on a routine basis. However, Photolog does not currently have LiDAR data acquisition technology. WisDOT's Surveying and Mapping Section has a static LiDAR device.

Bridge inspection is a routine business operation of the Bureau. It includes locating and characterizing structural defects (e.g. cracking or spalling in concrete). LiDAR also has potential to assist in this task by collecting dense clouds of X,Y,Z data points that could be used to represent existing surface conditions of structural components. These data would then have potential for integration with an existing 3D structural model (e.g. archived from as-built) to support reanalysis. The TRB Structures Section of Committees (AF00) is investigating this possible application.

4.2. Bureau of Traffic Operations.

Background: The Bureau of Traffic Operations envisions considerable utility of 3D technologies and data in their business operations. For example, the inventory of pavement markings and signage is currently managed with an out-of-date software tool and data model. There is a need for more robust spatial representation of these data. Spatial representations of additional features such as signal bases, heights of traffic control facilities, and subsurface connections are needed as inventories for more efficient and effective decision making.

Components of such 3D data could be collected either on a routine basis (e.g., by photolog LiDAR) or on a project basis with mobile or terrestrial LiDAR. Alternatively, there is potential utility of 3D as-builts, including subsurface information, as data inventory and input for future designs. Currently, existing as-builts cannot be loaded into design files.

There is also potential for using 3D roadway models with visualization and animation tools for design of traffic control (e.g., signage, pavement markings, barriers, cross-overs) on upcoming construction projects. Virtual 3D drive-throughs could be used during design to analyze, for example, sight distances to signs and the overall visual experience of a driver traveling through alternative configurations of controls at a construction site. 3D roadway models could be used with traffic simulators for more complex analysis at complicated intersections (e.g., sequenced roundabouts). Some of these applications require 3D information outside the right-of-way, such as buildings, vegetation, and other visual obstructions, and the surrounding terrain.

The Bureau often works with the Traffic Operations and Safety (TOPS) Laboratory at UW-Madison which has a full-scale driving simulator that can immerse subjects in a virtual driving environment. The Ford Fusion vehicle operates exactly like an on-street vehicle, with the visual world observed through a 240-degree screen frontward projection and rear projection in both the side and rear-view mirrors. A system approach provides researchers with a better understanding of the interaction between drivers and proposed/existing road designs by analyzing behavioral data collected such as eye movements, steering behavior, lane placement, acceleration/deceleration profiles, and comprehension. The TOPS Laboratory also has developed software methodologies that allow automating/streamlining safety studies, conducting road inventories, and improving the quality of GIS datasets along a road network. Such advanced tools can make practical and beneficial use of 3D models of physical reality and actual designs. As a result, the TOPS Laboratory is often seeking LiDAR scans of roadways, intersections, and the environment to further improve the quality of the datasets used for their analysis as well as the quality of the datasets provided to the Bureau as project deliverables.

4.3. Real Estate Section.

Background: The Real Estate Section believes they could make effective use of roadway models and 3D technologies for visualization, animation, and simulation to support their

business activities, including right-of-way acquisition, management of access changes, and litigation of property owner appeals. These activities involve communication of proposed or enacted changes to the physical environment and infrastructure. There is need to convey information on past, present, and future conditions. Parties include property owners, business owners, attorneys and court officials.

For example, during the acquisition process prior to construction, roadway models coming from design could be used with visualization tools to show property owners different post-construction still views of their property – something that cannot be done with two-dimensional plans. Animations would further enhance this process.

For access changes to businesses, animations (e.g., drive-throughs) of alternative routes, to simulate the experiences of customers, would be very effective, not only in communicating with owners and but also in litigation of owner appeals. Coupling of animations with traffic simulation models would enable communication of potential effects on access to businesses resulting from changes to roadways at distances removed from the businesses themselves.

Technologies for doing these things exist and Real Estate has some experience with data and tools provided by consultants for demonstrations or special projects. In some cases, data requirements include not only the roadway model but also 3D representations of buildings and surrounds. Staff often fall back upon publically-available web-based technology such as Google Earth. Such information, of course cannot be integrated with highway designs.

5. Management Group.

There are relationships and interdependencies among the initiatives and goals presented in this plan. That is, achievement of some goals depends upon achievement of others, which might or might not be within the same initiative. Each initiative has an identified lead Section or Sections. The plan also identifies business areas that are not currently formally associated with any of the seven initiatives but have expressed interest in outcomes and possible future participation. The work and interests of the various groups described in this plan needs coordination, support and advocacy, reporting mechanisms, and means for outreach.

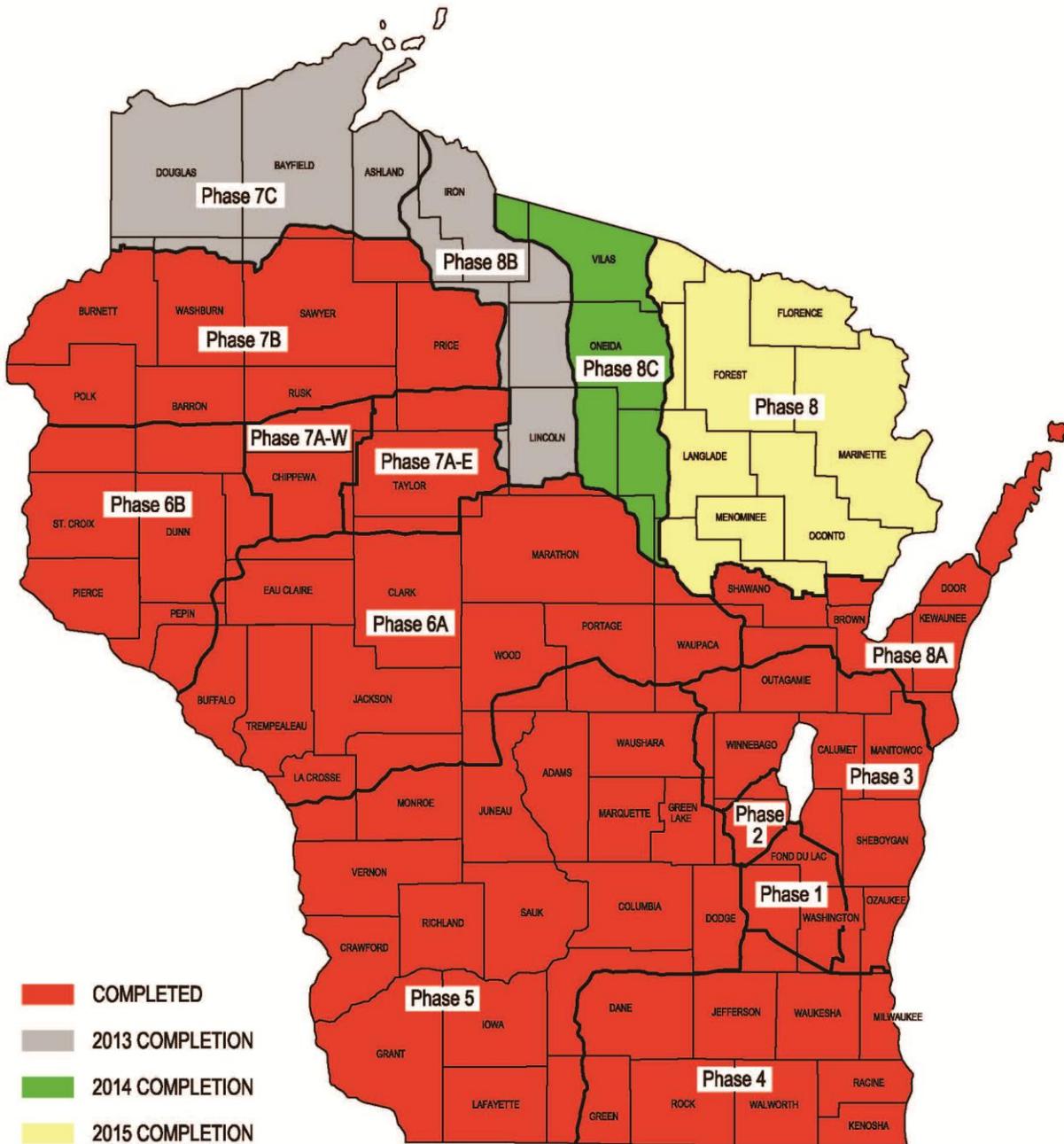
We, therefore, recommend appointment of a 3D Technologies Management Group, chaired by a bureau director, that keeps abreast of and coordinates the activities recommended in this plan, provides a reporting structure for the recommended groups and activities, keeps upper-level management informed of progress, advocates for the overall effort, and develops outreach mechanisms to keep the broader transportation community aware of and involved in the planned activities. The Management Group should

- Include at least one representative from each of the seven initiatives.
- Include broader Departmental representation.
- Be appointed no later than March 1, 2013.
- Meet, as they determine appropriate, with leads from the seven initiatives.
- Revisit and update this implementation plan at least annually.
- Remain functional until completion of the activities recommended within this plan.

Appendix A.

Status of Height Modernization Passive Network Phases (January, 2013)

HEIGHT MODERNIZATION PROGRAM PASSIVE NETWORK STATUS



Status as of January 2013

Appendix B.

Status of Height Modernization Active Network (January, 2013)

HEIGHT MODERNIZATION PROGRAM WISCORS NETWORK STATUS

