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3D HIGHWAY DESIGN MODEL COST BENEFIT ANALYSIS

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16. Abstract
Since 2012, the Michigan Department of Transportation (MDOT) has progressively integrated 3D models into its project delivery processes as a reference information documents (RID) and initiated this research project to understand the viability of expanding the use of 3D models. The primary objectives of this research project were to research and evaluate construction costs to determine the return on investment (ROI), investigate and document contractor's current practices of using RID 3D models, explore ways to streamline plan production by delivering contractual model elements, and conduct an analysis of potential and actual risk reductions associated with issuing 3D models. Researchers engaged with industry partners and MDOT construction staff to understand the current uses of RID 3D models, identify opportunities for improvements, and assess the perceived risk of elevating the 3D model to be contractual. Additionally, the researchers conducted a statistical analysis of historical data provided by MDOT for projects tracked between 2012 and 2016 to assess the effects of 3D models as RID on bids and change orders. The findings of the study were then used to make recommendations for improving processes including education, outreach, and training; multi-disciplinary collaboration; and a framework for implementing contractual 3D models for construction. In addition, quantifiable benefits and costs related to the use of 3D models were used to determine a 5-year ROI.

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Disclaimer

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Executive Summary

The use of 3D models for highway construction is quickly becoming a preferred method throughout the transportation industry for communicating design intent. The Michigan Department of Transportation (MDOT) has been a national leader in the deployment of 3D models through its participation in the Federal Highway Administration's (FHWA) Every Day Counts (EDC) initiative. MDOT also recognizes the value of using 3D models to streamline project delivery and understands its place in the contractor community. Michigan contractors use 3D models for estimation of quantities for bidding, verification of plan sheets, and automated machine guidance (AMG) systems even though the traditional paper contract plans are the contract documents. As such, contractors developed the 3D models themselves.

In response to the contractors' regular use of 3D models for their operations, MDOT enabled the use of 3D models as Reference Information Documents (RID) in 2012 and now looks to expand the use by evaluating the market readiness to make 3D models contractual. MDOT initiated this *3D Highway Design Model Cost Benefit Analysis* research in 2017 to collect information to understand the current uses, benefits, and costs of 3D models for construction; calculate return on investment (ROI); and to assess the perceived and real risks to help inform MDOT's future decisions as they mature their 3D modeling processes.

The specific tasks of the study included identifying and evaluating costs and benefits from the existing RID process through surveys and interviews, conducting a detailed benefit cost analysis and risk assessment, and developing specific recommendations to improve and streamline current processes. Researchers interviewed contractors, design firms, and MDOT construction staff to understand the current uses of RID through a series of surveys and interviews. In addition, the researchers analyzed historical data to evaluate the effects of 3D models as RID on contractor bids and project change orders. The data and observations were then examined to assess construction risks, identify areas of improvements, and develop an ROI framework. Based on the results of the analysis and assessment, recommendations for improving processes were developed, including education, outreach, and training; multi-disciplinary collaboration; and a framework for internal collaboration and contractual 3D models.

The historical data statistical analysis revealed that project sizes of $5 million to $20 million benefit the most from the use of 3D models. However, 3D models (indiscriminate of project size) consistently produced bids that were lower than the engineer's estimate. When bids came in higher than the engineer's estimate, 3D models produced fewer change orders than 2D plans.

The calculated net benefit for MDOT's implementation of RID 3D models for years 2012-2016 was over $18 million. These savings translated into a 32 percent ROI, meaning that for every dollar invested in 3D models, MDOT received a return of 32 cents.

It was discovered that a key success factor when delivering contractual 3D models is being able to communicate the purpose and need of each deliverable. Market-ready applications were outlined to help MDOT implement authorized uses of 3D models to optimize benefits, including AMG (grading and paving), constructability reviews, public outreach visualization, survey layout, quantity take-off for earthwork, and risk management.

The findings emphasize the need for iterative and continued collaboration throughout design and construction to ensure constructability risks are identified and mitigated early in project delivery. Furthermore, the findings of this research provide supporting information for the development of a special provision that can be used as a fundamental step toward providing digital data as part of the construction contract. This supporting information includes defining a model inventory that captures

pertinent information about the model, including level of development (LOD), level of visualization (LOV), and managing the model data after award of the contract. These recommendations will help MDOT advance data integration and Civil Integrated Management (CIM)/Building Information Modeling (BIM) for highway construction, optimize the design documentation process, and improve processes for better risk management throughout digital project delivery.

Section 1. Introduction

Background

MDOT began a transition to digital delivery in 2012 by adding design base files and optional 3D models to the RID provided at bid. By 2015, MDOT starting requiring the RID to include 3D models. It has been assumed that MDOT and contractors benefit from the predictability, repeatability, and reliability of standardized roadway data delivered from design as RID. While project delivery is expected to benefit from 3D models, only a limited number of national studies exist that document project-specific levels of investment and benefits of using 3D models or a quantified ROI. Nevertheless, these studies report improved efficiency for construction inspection (Dean 2014), contract resource management through 3D clash detection and identification of cost impacts in the absence of 3D models (Parve 2013), and controlling pavement quantity yields (Federal Highway Administration 2014). MDOT is interested in learning from these previous studies to help quantify the benefits of the efforts to-date to implement 3D models, elevate the RID to contractual items, and identify additional uses and missed opportunities for leveraging these models.

Objectives

The study objectives are to collect information to document the current uses, benefits, and costs; to calculate the ROI that results from sharing reference information documents with and/or without 3D models; and to inform future decision making with policies and uses of digital deliverables. Specifically:

- Research and evaluate ways to quantify costs and benefits to calculate ROI.
- Investigate and document contractor's current practices of using 3D models as RID.
- Explore ways to streamline plan production and improve downstream use of elements from contractual 3D models.
- Analyze potential and actual risk reduction associated with issuing contractual 3D models.

Scope of Work

The scope of work of this research project is to quantify costs and benefits to calculate the ROI for 3D models, assess risks, and develop a framework for implementing 3D models. The products of this study will inform MDOT future decisions. The desired outcomes of this work are:

- Advancement toward the department's vision for data integration and BIM.
- Identification and elimination of waste in the design documentation process.
- Identification of missed opportunities for process improvements.
- Careful consideration and mitigation of risks associated with construction and digital project delivery.

Project Approach

The researchers planned the work based on the three major phases of the project, shown in Figure 1, to accomplish the four main objectives of the study.

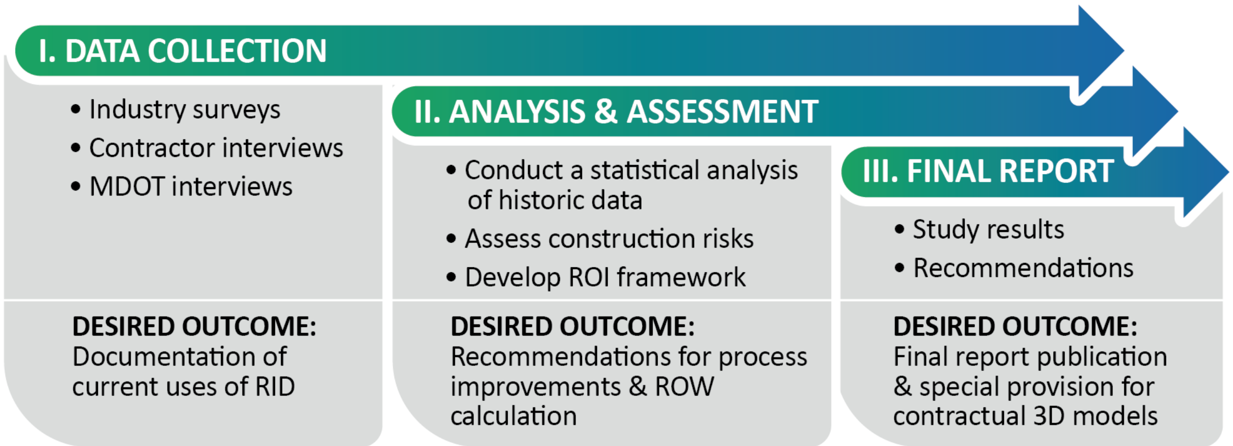

Figure 1. Research phases.

Data Collection

Phase I of this study explored the use of RID 3D models by Michigan contractors and design firms, and MDOT construction personnel, as outlined in Figure 2.

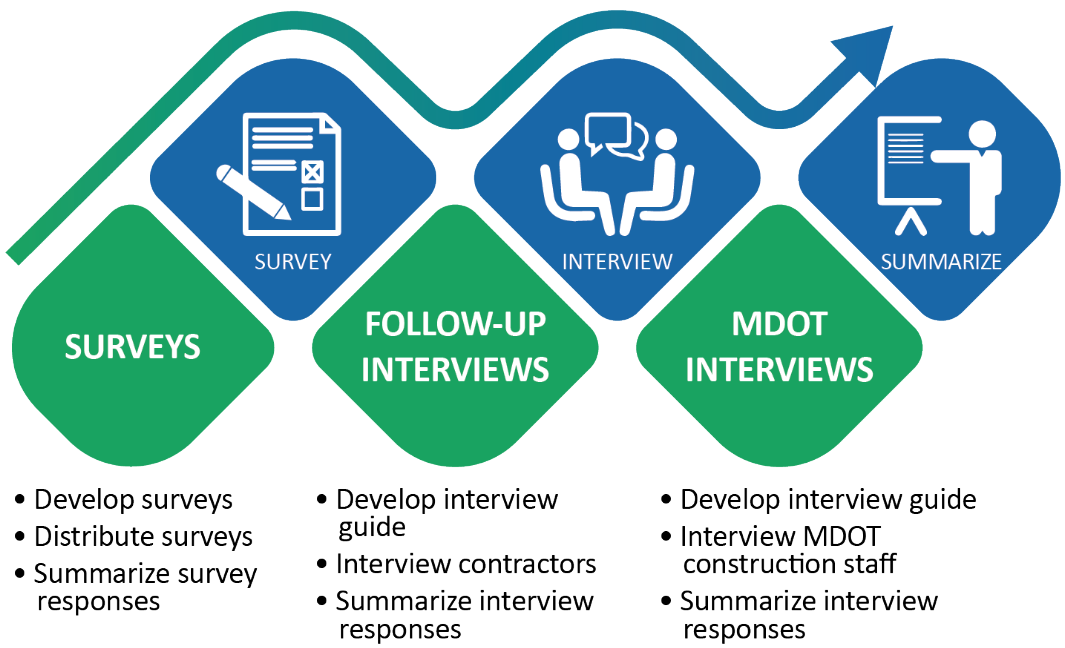

Figure 2. Steps to gathering data during Phase I.

The researchers worked with the Michigan Infrastructure and Transportation Association (MITA) and the American Civil Engineering Council (ACEC) to establish the best mechanism for soliciting the desired information. The recommendation from the industry stakeholders was to request information via surveys with the option for follow-up interviews. Two separate surveys were drafted and distributed by MITA and ACEC to their respective members.

The contractor survey was a fillable PDF that MITA distributed and collected. The design firm survey was created using MDOT's SurveyMonkey® account, and the link to the survey was distributed by ACEC. Both surveys included an option for follow-up phone interviews. A copy of all the surveys and the interview guides is provided in the appendices.

In addition to the industry surveys, researchers developed an interview guide to solicit information from MDOT construction staff regarding the use of contractors' 3D models to conduct inspection activities. Our team conducted four interviews with several engineers and inspectors with questions ranging from training currently available to construction staff to challenges and opportunities for using either RID or contractual 3D models.

Analysis and Assessment

In Phase II of the project, the researchers requested project cost data from MDOT related to the projects to better understand how RID 3D models affect project bids and change orders. The project cost data from 2012-2016 was provided in a tabular format comparing the engineer's estimate and bid amount for RID projects with models.

Final Report

In Phase III of the project, the efforts focused on summarizing the findings of the study into a final report and developing a special provision and guidelines for implementation. Researchers also worked with MDOT to deliver a workshop to share the findings of the study, and worked with key staff to define next steps to execute the implementation plan.

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Section 2. Results of Surveys and Interviews

Contractor Surveys and Interviews

A 24-question fillable PDF survey was designed to obtain input from contractors regarding their current practices in using 3D engineered models for bidding and construction activities. A total of 11 surveys were received from contractors who identified themselves either as a medium or large organization. Two contractors agreed to participate in follow-up interviews.

The survey questions fell under the following categories:

- Use of 3D RID models.
- 3D model data and file formats.
- General feedback and suggestions.
- Considerations for making 3D models contractual.
- Financial impacts.

Use of 3D RID Models

Most contractors use the MDOT RID 3D models to prepare files to be used for AMG construction equipment (i.e., grading, trimming, and concrete paving) (Figure 3).

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Figure 3. Example of AMG technology used for concrete paving.

However, they either have someone on staff develop the AMG-ready files or hire a consultant to perform this task. AMG is a modern construction technology that relies on 3D engineered models and modern surveying positioning systems, such as Global Navigation Satellite Systems (GNSS) and Robotic

Total Stations (RTS). Excavating, grading, and paving machinery are equipped with an on-board computer system and 3D surveying equipment. The computer system interfaces with the machine controller (or control box) through a control area network (CAN), and communicates with the surveying equipment controlling the positioning instead of using stakes, blue-tops, and string lines. The 3D model files are loaded through the computer 3D control software, which is used to run the machine guidance system. The operator can display values on the screen inside the cab, and measurements may be verified in real time as a quality control measure.

Other uses of the RID 3D models included:

- Performing quantity take-offs (QTO) for bidding estimates.
- Identifying inconsistencies between the RID files and the plans.
- Validating contractor independently created models.
- Determining storage locations (i.e., defining haul distances, balancing earthwork, locating batch plant locations, and identifying waste and borrow areas) during the bidding process.
- Creating 4D models to visualize schedules.

3D RID Model Data and File Formats

Table 1 summarizes the different software packages currently being used by survey respondents. Trimble Business Center (TBC) was the most commonly used software package used by the respondents.

Table 1. Software packages used by contractors working on MDOT projects.

Software Name	Description
Agtek	The Earthwork 4D Suite is a proprietary software used to process the data collected in the field with surveying instruments. The program is used to view, create, or edit 3D models. This program is produced by Agtek.
AutoCAD/Civil 3D	AutoCAD is a proprietary Computer Aided Drafting (CAD) program used to create and view drawings. Civil 3D is the design software that runs on the AutoCAD platform used to view, create, or edit 3D models. Both products are produced by the Autodesk Corporation.
Carlson	Carlson Software Suite is a proprietary design software that runs on multiple CAD platforms used to view, create, or edit 3D models. This program is produced by Carlson Software.
MicroStation/GEOPAK/ PowerGEOPAK	MicroStation is a proprietary CAD program used to create and view drawings. GEOPAK is the design software that runs on the MicroStation platform used to view, create, or edit 3D models. Both products are produced by Bentley Systems. PowerGEOPAK is a product that combines MicroStation and GEOPAK into one single installation.
Leica	Leica Captivate is a proprietary software used to process the data collected in the field with surveying instruments. The program is used to view, create, or edit 3D models. This program is produced by Leica Geosystems.

Software Name	Description
Topcon Magnet	Magnet Software Suite is a proprietary software used to process the data collected in the field with surveying instruments. The program is used to view, create, or edit 3D models. This program is produced by Topcon.
Trimble Business Center (TBC)	TBC is a proprietary software used to process the data collected in the field with surveying instruments. The program is used to view, create, or edit 3D models. This program is produced by Trimble Inc.

General Feedback and Suggestions

Most contractors noted that the quality of the RID 3D models has improved over time, and the digital design represents the contract plans accurately. However, responses regarding the type of information that should be included in a 3D model varied. There were three variations of the response:

1. Include the finished surface and all pavement layers without the side slope conditions (Figure 4).
2. Include all detailed information, including all pavement layers and side slope (Figure 5).
3. Include only the top finished surface with (or without) shoulders and side slope conditions (Figure 6).

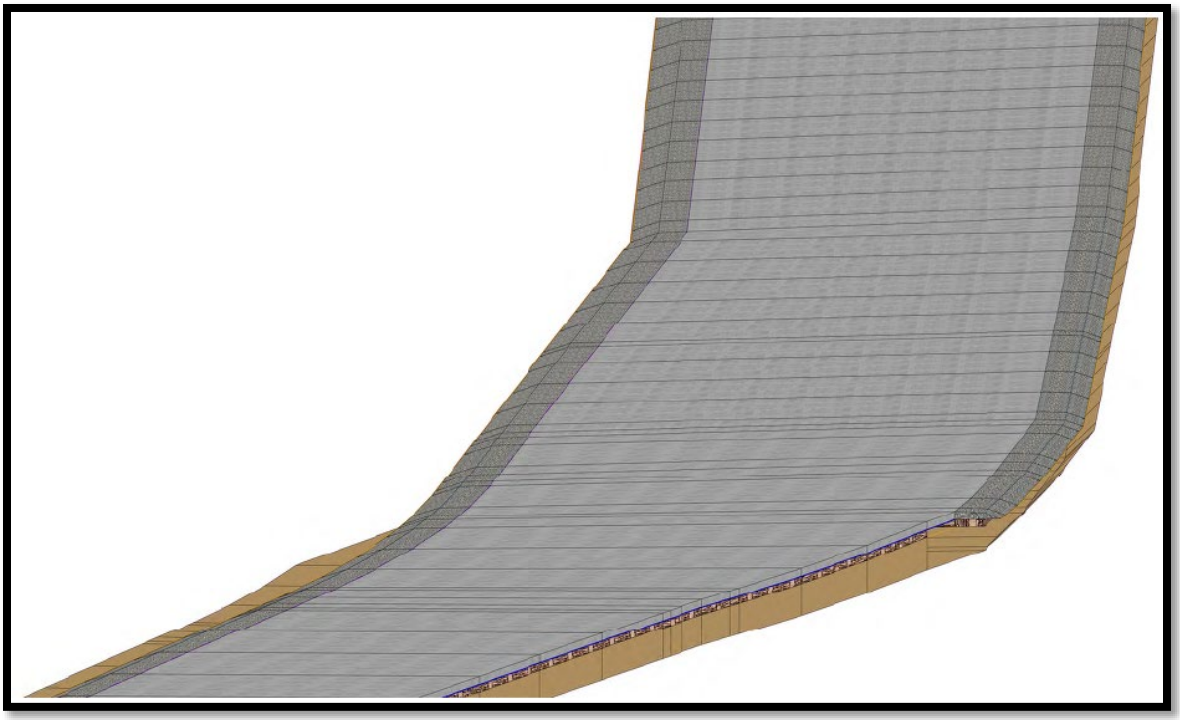

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Figure 4. Pavement surface model without side slope conditions.

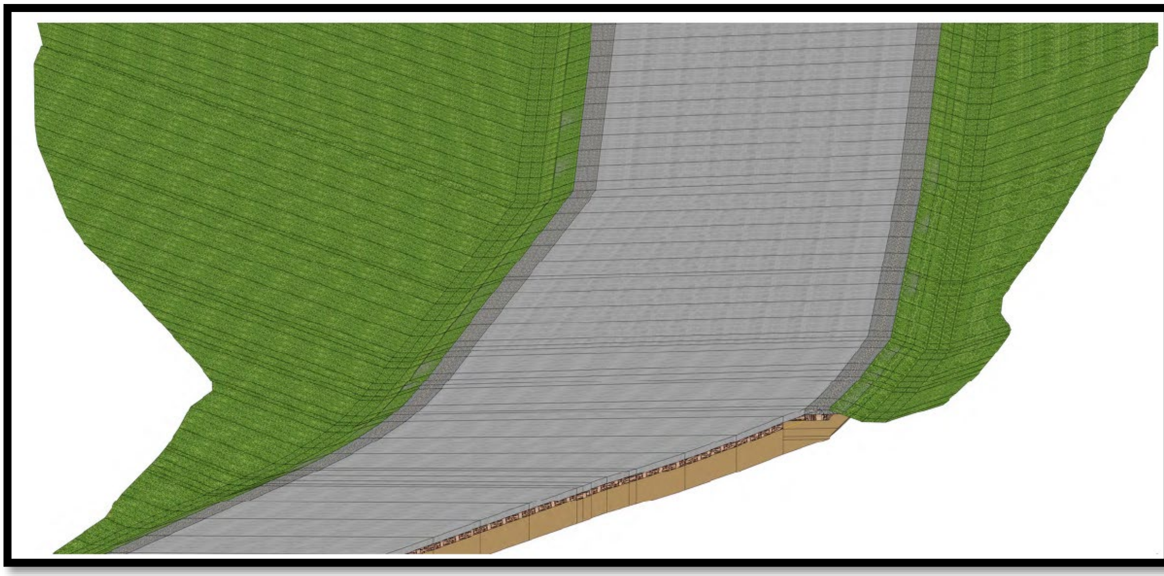

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Figure 5. Pavement surface model with slope conditions.

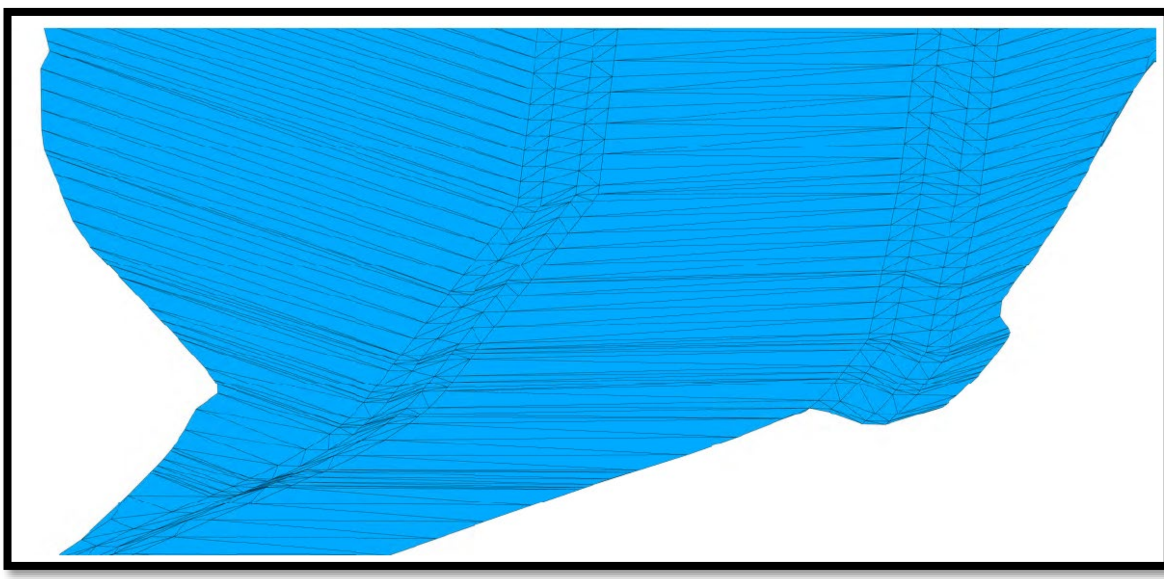

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Figure 6. Finished surface model with slopes.

While most respondents agreed that 3D line strings and LandXML files of alignments, profiles, and digital terrain models are beneficial or essential to their work, opinions differed on the benefits of delivering PowerGEOPAK(DGN) files of the current models. Some indicated DGN files were unnecessary, but the majority stated this information was beneficial or even essential.

In general, contractors are satisfied with the quality of RID 3D models; however, they would like to receive feedback from MDOT regarding the AMG models being submitted for construction use.

Contractors also indicated the quality of the model is checked in the field using laser levels, GPS, and total stations. Some contractors use a combination of in-house staff and subcontractors to perform the checks.

Model documentation was by far the most mentioned area of improvement regardless whether 3D models are RID or contractual. The majority of contractors noted that there is a need for creating a method for documenting changes to the models during construction as they occur. It can be inferred that changes to the models during construction may or may not require a change order depending on the needs. For example, minor changes to address contractor means and methods may not require change order but should be documented.

Considerations for Making 3D Models Contractual

Contractors agreed that the best mechanism to make models contractual would be through a special provision. They also noted that other owners who have made models contractual have done so through informal processes. However, they also warned that there may be a significant learning curve to consider when making 3D models contractual as the standard practice, although large contractors noted that the learning curve for them would not be as large compared to smaller contractors. To help with the learning curve, it was suggested to have experienced MDOT staff or construction engineering consultants on site to certify grades.

Most contractors also agreed that horizontal alignment sheets, pavement marking sheets, and signing sheets could be simplified or eliminated if 3D models were made contractual. Additionally, some contractors indicated that there is potential to eliminate typical sections and details, plan view construction, and profile sheets, as well as sheets for removal/construction and Maintenance Operation and Traffic (MOT) staging sheets. Other sheets could be evaluated and replaced over time.

Lastly, receiving changes to the model without proper documentation is considered high risk by contractors. Thus, it is highly recommended to create a process for tracking and monitoring all changes made to the model post-award including, at minimum, file submittal procedures, documentation and reason for the changes, responsible party for making the changes, and conflict resolution/escalation strategy. This process will help manage the risk associated with the exchange of digital data. In addition, making the models contractual would require a heavy investment on the contractor side, which they (medium to large contractors) are willing to do if MDOT is committed to making it a standard practice.

Financial Impacts

Contractor comments revealed that the cost of 3D models for AMG typically fall between 0.5 and 3 percent of the overall construction contract value, favoring the lower end of that range. It is uncommon for the cost of a model to surpass 3 percent of the construction contract value. Some contractors may pay up to $40,000 to develop what they consider a good model. However, the improved quality of the RID 3D models has made a significant difference in what contractors are paying for developing an estimating and AMG model. One contractor estimates that RID 3D models are currently saving them between 25 to 50 percent of the time it takes to create AMG models, which is equivalent to $750 per lane mile. Additionally, estimators spend substantially less time in performing quantity take-offs during the bidding process. This improved quality of the RID 3D models allows the contractors to have a better understanding of the design intent and creates estimates faster and more accurately. This results in contractors not having to inflate their bids as much to account for unknown risks. Overall, contractors are significantly more confident in the RID files than they have been in the past.

Contractors indicated that AMG also reduces the number of workers that once were dedicated to placing string line. One contractor indicated that in the past, a 4-person crew was needed for placing string line for every day of paving, which equates to approximately $10,000 per paving day just in operational cost. These savings in operational cost do not account for the gained efficiencies between string line method and AMG trimming and paving. Earthwork contractors noted that machine grading saves 30 to 40 percent on production cost compared to traditional construction methods. For example, savings are realized in cost of equipment and operator time, which ultimately impacts unit bid prices.

Contractors' views on how 3D models have impacted the number of design-related construction issues varied. Contractor experiences run the gamut of no observed difference in the number of design issues to significantly fewer. However, there is no evidence that the use of 3D models has caused additional design-related construction issues.

Responses to the contractor surveys are provided in Appendix A.

Design Firms Surveys

A 21-question online survey (Appendix B) was distributed to a broad base of design firms to garner anonymous input regarding their current practices in using 3D models for construction. There was a total of 16 respondents, and there were no follow-up interviews after the surveys were received. Most design firms that responded identified as being a small or medium-sized firm familiar with the MDOT RID process and 3D model requirements for highways. Most of the firms indicated extensive experience with delivering projects with these types of requirements. However, they also indicated that less than 10 percent of their designers have expert level modeling skills, which were usually senior-level designers with over five years of experience.

The survey was structured to include the following categories:

- Use of digital data during project development.
- Types of digital data and formats used in design-build projects.
- Concerns and perceived risks regarding contractual 3D models.
- Financial impacts.

Use of Digital Data During Project Development

Most respondents indicated models are mostly developed to review their own design to identify errors and omissions, and to collaborate (including real-time) with the project development team using the 3D model or PDF plan sheets with tools such as Bluebeam, Skype, and Bentley Navigator. Other uses included:

- Performing constructability reviews with MDOT construction staff.
- Computing earthwork and subbase quantities.
- Evaluating right-of-way impacts.
- Establishing slope stake lines and construction layout.
- Developing detail grades and checking drainage design items and clearances.

It was also noted that the only type of quantities being computed from the models are volumetric-type pay items (e.g., earthwork), and the models are rarely used for determining pay item measurements that are calculated by linear feet or square areas due in part to current limitations of the software.

Types of Digital Data and Formats Used in Design-Build Projects

Most designers working on design-build projects deliver surfaces, 3D line strings, and/or coordinate geometry in DGN files and LandXML formats. Only two respondents indicated that they deliver Autodesk Civil 3D (DWG) format files, with one of them expressing that the DWG format is arguably the modeling format most used by designers outside of the State Departments of Transportation market. One respondent indicated that geotechnical digital information is also delivered. This feedback demonstrates that even though DGN files are the most prevalent modeling format, other modeling formats and content are delivered during design-build projects.

Concerns and Perceived Risks with Contractual 3D Models.

Half of the respondents indicated that one of their biggest concerns for moving toward model-centric workflows is that the design milestones (30 percent design, 60 percent design, etc.) are based on the plan production process, not 3D design. Thus, there is confusion with what 30 percent design means in a model-centric workflow. One respondent also suggested that the model files should be reviewed at the milestone reviews using a standard process. The respondent was not aware that MDOT already has a process in place to do milestone reviews of 3D design data for roadway projects. However, other respondents noted they did not have enough information to form an accurate opinion. Other expressed concerns included:

- Accelerated timelines do not allow for thorough review.
- It takes duplicate effort to finish the contract plans.
- There is no proper definition of the authorized uses for the model.

Respondents also indicated that the following items take the longest to develop for the RID process:

- Proposed finished grade surface.
- Alternate surfaces (e.g., subgrade).
- 3D line strings.
- Drainage networks and structures.
- Utilities and cross sections.
- Unique areas where geometry is not simple (e.g., roundabouts).

Most of the respondents also noted that they have a peer design review process to ensure the quality of the models. However, several responses noted that they were not aware of any quality assurance review process within the consulting community before releasing the models for advertisement. The responses suggest that the consulting engineering community may not be aware of MDOT's internal processes for quality assurance review of design data models.

The respondents also indicated that the Level of Development (LOD) will drive what elements could become contractual items. Most designers felt that alignments and profiles could be made contractual right away. Proposed finish grade surfaces and 3D line string features could be made contractual only if the LOD was defined. For example, if the LOD is not defined, designers are less likely to agree to make a model element contractual. A comparison of the responses to make certain elements of the model contractual based on the understanding of LOD is shown in Figure 7. It is important to note that MDOT currently works with industry through the Digital Design Work Group (DDWG) to develop LOD definitions and requirements.

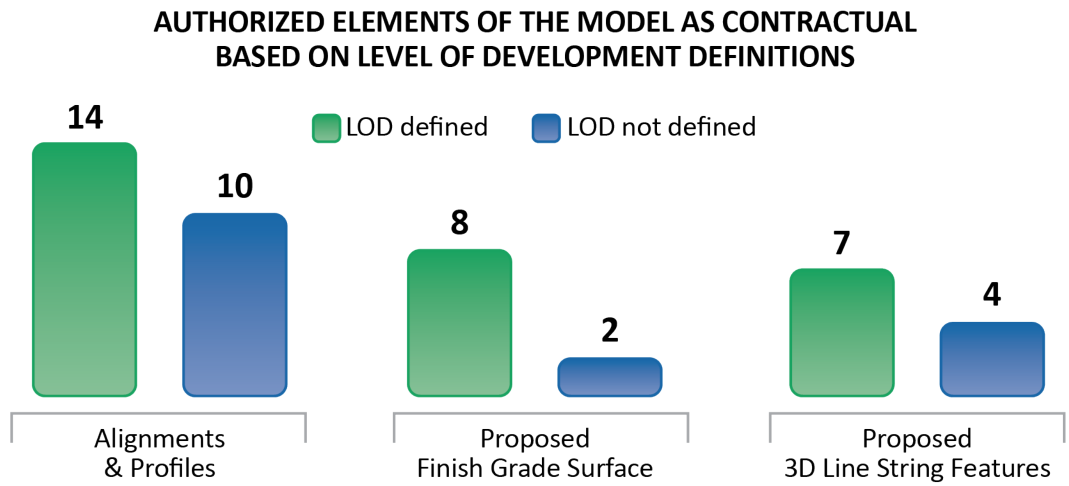


Figure 7. Distribution of responses for authorizing elements of the model as contractual based on whether LOD is defined.

Most designers have established practices to manage risk on a project regardless of producing a model to identify high-risk design elements. Model-centric workflows and design intent are interdependent and require confidence in the underlying data that enables sound decision making, in specific, the confidence in the accuracy of the existing conditions base survey models. The risk management practices most designers use include:

- Request higher level of survey as appropriate for design intent (e.g., design of drainage structures and estimation of quantities for in-lay projects).
- Work with surveyor to check profile elevation at bridge clearances and tie-in points.
- Work with construction staff to identify high-risk elements early and often during the development of the design model through a collaborative review of the design data model.

To put into context, the question was asked how the design data model could be used to identify the high-risk design elements typically encountered during construction. The responses indicated that a model-centric design process helps the designer to be more aware of communicating the design intent because the accuracy of the design is directly dependent on the accurate representation of the existing conditions. Respondents also indicated that most of the risk for design firms is to deliver a design data model based on incorrect assumptions of the existing conditions. Not having defined LOD requirements for a specific use case is another risk.

Financial Impacts

Most design firms indicated the typical cost associated with producing RID 3D models in addition to the contract plans was less than 10 percent of the design contract (or 1 percent of the construction contract). One respondent indicated the allocation was more around 20 percent. No other financial information was provided. However, it is important to note that as the civil software matures, designers reach expert competencies, and plan sheets are eliminated, this cost will decrease.

In the future, designers should plan to allocate a specific percent of the overall contract work to tasks related to developing, reviewing, and verifying the model for the authorized user. For example, today designers allocate a certain percent of the contract work to develop traffic control plans or cross sections sheets.

MDOT Construction Staff Interviews

Select MDOT construction staff were interviewed to understand their perspectives working with RID 3D highway models. The group represented two distinct roles: oversight (construction engineers) and quality assurance (inspectors). Some inspectors also served as leads for layout and inspection of AMG projects.

The interview guide (Appendix C) was designed to obtain input regarding the following categories:

- Inspector training.
- Standard equipment and software.
- MDOT construction processes.
- General feedback and suggestions.

Inspector Training

While there is no standard or formal training program for inspectors, each region provides ad-hoc training opportunities for inspectors through a variety of methods, including individual-based, on the job, peer-to-peer, or online learning. Other inspector training (i.e., materials testing and certification) is offered through the Michigan Technological University, Ferris State University, and some industry courses. Training specific to surveying and 3D highway models is offered through peer-to-peer training with an instructor from the Lansing office who travels to the district. Most inspectors indicated that trained expert assistance is more helpful than written guidance alone. The interviewees noted that MDOT previously attempted to create a formal training program for 3D models for AMG and for the use of Global Positioning Systems (GPS) survey equipment. However, due to personnel changes, this effort was on-hold. Nevertheless, the interviewees indicated that the training initiative is still a priority and it is starting to resurface. Some basic surveying training modules have been developed by the Cadillac Transportation Service Center, including how to use any new equipment, how to access models, and how to load models onto equipment. These modules are available in the winter and can be attended at the supervisors' discretion. This training was identified as a best practice that could be promoted statewide for consistency in application.

PowerGEOPAK training for inspectors is offered through the Bentley LEARN subscription program under MDOT's enterprise license agreement with the vendor. However, the consensus among the interviewees is that this training may be too in-depth for inspectors who would benefit more from a tailored curriculum and inspection-specific training on these platforms, as well as survey equipment. For example, most inspectors only use a limited number of the tools within the PowerGEOPAK software. The Bentley-developed online training may be adequate for design personnel, but may be overwhelming for construction staff. A suggestion was made to create a specific Bentley LEARN path for inspection work to be followed by MDOT-specific training.

Standard Equipment and Software

The consensus among the interviewees was that MDOT regions seemed to have sufficient equipment resources, including one Robotic Total Station (RTS) and multiple GPS rovers (three to five units), depending on the number of inspectors in the office. Interviewees indicated that for each AMG project, having one RTS and one GPS is ideal. Some regions have Transportation Service Center (TSC) equipment sharing agreements through as-needed staking contracts, and contractually require consultants to bring their own equipment as these responsibilities are typically subcontracted out.

Typical equipment issued to MDOT inspectors include:

- Computer hardware and mobile devices, such as laptops, and iPads.
- Surveying instruments (standardized on Leica brand), such as GPS receivers and rovers, robotic total stations (RTS) and their respective data collectors. Digital levels are also part of the standard surveying equipment. Surveying equipment was refreshed statewide two years ago.
- Phone hotspots (i.e., MiFi Verizon) are used for remote access via virtual private network (VPN) connection to the MDOT network from the field.

Interviewees indicated that GPS is used to check subgrade (dirt) while RTS equipment is used for checking aggregate base, pavement, sand, stone, and bridge elevations. This is due to the achievable accuracies for each type of equipment and the tolerance requirements for each of those activities. MDOT's continuously operating reference stations (CORS) and conventional base stations are used for collecting GPS measurements. However, CORS is the most widely used. Modern surveying equipment can also be used for collecting as-built information and should be considered moving forward.

The Leica Captivate software is used for all surveying activities, including data collection, layout, and verification using the 3D design data (i.e., AMG model). However, it was noted that it is difficult to view the different 3D design data types on the data collector, and that perhaps it would be useful to use other tools to view such data.

MDOT Construction Processes

Guidance for Using RID 3D Highway Models

Interviewees indicated that the proficiency with 3D models and CAD software vary among them, and that additional formal training on CAD is necessary. It was suggested that those who are most proficient participate in the online or on-the-job training, which helped develop skills with importing RID 3D highway model PowerGEOPAK data into their data collectors, collecting measurements in the field (e.g., for payment calculations, area calculations, sidewalks, pavement removal, irregular areas, slope restoration, etc.), and exporting the data from the data collector back to product. At a basic level, interviewees noted that inspectors may be able to use the alignments for layout and verifying locations or to spot check elevations against the plans. However, interviewees indicated that inspectors are aware that more can be done with the models. Interviewees also shared they would like further training on all the appropriate uses of the 3D models.

The consensus among interviewees was that there is a lack of guidance on what to do with valuable digital data that is being collected in the field for different activities (e.g., booking grades, measuring quantities, locating utilities) that could be used downstream (i.e., as-built records for maintenance inventory). The interviewees stated they were not aware of any MDOT guidance in place to help staff understand how this data could be processed, managed, or validated. Moreover, it is likely that new resources will be needed to perform these additional tasks because inspectors do not have the time during the life of the project to take on these additional responsibilities. It is worth noting that MDOT has various initiatives underway to create core training activities to address these challenges in the near future.

MDOT Design and Constructability Reviews

Interviewees indicated that construction staff (i.e., inspectors) are not consistently involved in constructability reviews. The current review process allows the inspectors to provide comments at defined milestone review phases (e.g. 30 percent design plan review, 60 percent design plan review, and 90 percent for Omissions, Errors, and Comment (OEC), etc.). However, some regions do not have a defined process for engaging the inspectors in the reviews, or inspectors are overcommitted and cannot participate in the reviews. There is interest in evaluating a transition from handwritten notes to using the Bluebeam Revu software for project collaboration, which MDOT is currently piloting.

MDOT Pre-construction Activities

During pre-construction, plan sheets and standard RID 3D files (alignments, surfaces, 3D lines, and cross-section sheets) are typically accessed via ProjectWise from the office and potentially remotely from an iPad from the field. It was noted that the inspectors are not accessing RID files from their iPad.

The interviewees noted that for AMG projects, the contractor is required to submit their 3D highway model before construction to be certified against the RID model by a subconsultant who develops an independent model. The subconsultant model is used to check both the RID model and contractor's model. Feedback is communicated to the contractor and the contractor updates their model accordingly. A final check is conducted once more before being accepted for construction. The interviewees also noted that using the 3D highway models on most projects would help with locating assets, verifying contract requirements, and collecting as-built information (e.g., storm sewers, curbs, etc.). However, they are not aware of any processes for handling the data after it is collected. There is an opportunity to improve the current process by providing contractual design data models and remove multiple models being created.

When asked about making the RID 3D highway models contractual, the interviewees expressed that the following items should be addressed to minimize potential claims:

- Develop specifications and guidelines for what and how the model will be used.
- Define roles and responsibilities for different actions.
- Establish timeframes for submittals and approvals throughout the process.

Construction Inspection Surveying Tasks

Interviewees explained that MDOT surveyors are not assigned to construction; thus, either in-house or consultant inspectors are trained and equipped to collect data to verify quantities themselves. Survey crews from design may sometimes assist as needed. Empowering the inspectors with the training and equipment enables their inspection process by not having to wait to receive survey data from surveyors to make decisions.

Construction Inspection and Verification of Earthwork Quantities

Interviewees explained that some contractors have requested surface-to-surface quantity calculation methods for at least 15 years, so construction staff is familiar with the technique but have not used it for a few reasons:

- Pay item specifications have not been updated to keep pace with modern AMG methods. The specifications require the use of cross-sections and grade lines to determine quantities. For example, the Metro TSC has used the contractor's model to calculate earthwork quantities, but use PDF cross sections to document pay quantities.
- There are no specifications or guidelines to direct staff on how to perform these techniques consistently and reliably.
- Inspectors have never received training on how to verify quantities using these new methods to build competency.

MDOT has an initiative to address these challenges in 2019. The plan is to start working collaboratively with the ACEC Survey Taskforce and the DDWG. MDOT is in the process of identifying a technical champion with strong survey and computer skills to lead the effort.

Construction Inspection Recording of As-built Plans

The responsibility for creating as-built plans is dependent upon which party performs the staking. For projects where the contractor directs the layout, they are responsible for updating the as-builts. Similarly, projects in which MDOT performs the layout, agency construction staff is responsible for documenting the as-built records. With respect to utility as-builts, the interviewees were not familiar with the Geospatial Utility Infrastructure Data Exchange (GUIDE) initiative. However, inspectors unanimously agreed that the utility location and as-built information should be stored in a GIS database as they are doing their inspections. This potentially would eliminate costly surprises for future jobs. One interviewee suggested that while the inspectors should be collecting this information on utilities, there should be additional resources allocated to managing and processing the data they are collecting.

General Feedback and Suggestions

Interviewees indicated that construction staff face numerous new challenges during AMG projects (Table 2), including:

- Consistent coordination with the contractor.
- Lack of guidance and established processes.
- Inadequate tools and training to work with 3D models.
- Inaccurate representation of existing conditions.

Table 2. Discussion on the challenges with 3D models during AMG projects.

Challenge	Comments	Suggested Resolution(s)
Coordination with contractor	• Deploying consistent positioning methodology with the inspector and the contractor working off different primary control and coordinate systems. • Contractors do not always provide sufficient notification to the inspectors that work is ready for verification.	• Define a certain level of coordination to ensure consistent positioning methodology between the inspectors and contractors. • Add contractor timelines to the AMG specifications and/or allocating sufficient time in the schedule for reviewing the models.
Guidance and processes	• There is no clear guidance for managing and keeping track of model changes. • Contractors do not always place stakes in the ground.	• Create a protocol for file naming/storing all updated versions in ProjectWise. • Develop specification for making stakes contractual based on the construction office, or equip each office with sufficient survey equipment to check contractor work without requiring stakes.
Tools and training	• The size and complexity of the 3D models make it difficult for inspectors to open and view the data from the ProjectWise system on a laptop computer or an iPad. • Inspectors do not know how to review the quality of the 3D model and do not trust it for verification activities.	• Define processes and develop guidance for opening files from ProjectWise or for reviewing outside of the ProjectWise environment while maintaining model version/integrity. • Develop specific training opportunities to educate inspectors on proper techniques/protocols for reviewing models.
Representation of existing conditions	• There is inaccurate representation of existing conditions, such as incorrect pipe sizes and curb lengths, and/or missing driveways.	• More resources should be spent on developing accurate representation of the existing conditions as part of the 3D model development process.

Benefits of 3D Models and RID

The feedback provided by all interviewees (Table 3) did not include any measurable benefits, however, they shared their observations and opinions regarding:

- Impact on change orders and claims avoidance.
- Impact on safety.
- Impact on construction timelines.

Table 3. Discussion on the benefits of 3D models and RID.

Benefit	Comments
Change orders and claims avoidance	• 3D models appear to provide opportunities to identify issues earlier for AMG projects given the ability for MDOT construction inspectors to go into the field to review the contractor's model in advance. • Models that are based on standards make it easier to identify issues. • The communication between contractor and inspector on-site has improved for AMG projects.
Safety	• One inspector was required to perform quality assurance when using the model, thus reducing the number of people exposed on the grade. • More distance can be maintained between the grader and inspector. However, focusing on an iPad screen can be distracting and cause staff to be less aware of their surroundings.
Construction timelines	• Construction timelines are more aggressive with accelerated schedules becoming the new norm. The efficiency of the AMG technology is allowing those aggressive schedules to become more achievable.

Section 3. Statistical Analysis of Historical Data

Hypothesis Testing and Analysis Approach

The benefits of using 3D models in highway project development and delivery—including increased productivity, reduced risks, fewer change orders, and improved quality, etc.—are well recognized; however, whether such benefits culminate in tangible savings for MDOT projects, as in competitive bid prices and lower construction costs, is yet to be established. To examine further, researchers conducted a statistical analysis of cost performance data obtained from 261 highway projects delivered with and without 3D models.

The analysis entailed a statistical comparison of project-level cost metrics followed by hypothesis testing to further evaluate whether providing RID 3D models resulted in cost benefits to MDOT. The key questions of interest for the statistical analysis included:

1. Does the use of 3D models as RID result in overall lower bid prices when compared with those projects using traditional 2D plans?
2. How do 3D models as RID compare with conventional 2D plans in establishing accurate project estimates?
3. Given the variability in site conditions and project scope of work among the projects, is the observed evidence consistent enough to conclude that the use of 3D models as RID results in significant financial benefits to MDOT?

Researchers used data from a spreadsheet provided by MDOT that included the following information for 261 projects tracked since 2012:

- Letting date
- Letting item number
- Job number
- Route number
- Region
- Inclusion of cross-sections (PDF)
- Inclusion of survey deliverables
- Inclusion of 3D model
- Engineer's estimate
- Bid amount
- Final contract amount

The researchers used the historical data to test whether providing 3D design modeling as RID resulted in organizational benefits by measuring the predictability of contractor bids. The predictability of bids and the effectiveness of design intent communication were measured by comparing contractor bids against engineer's estimate using the project information provided by MDOT. Furthermore, researchers took information received from contractors during the surveys and interviews to provide context to the statistical analysis regarding the effectiveness of communicating design intent.

Definition of Metrics

To evaluate the cost performance of projects delivered using RID 3D models and 2D plans, two cost metrics were adopted: *award growth* and *cost growth*.

Award growth is a percent change in cost between the original contract bid (or awarded contract value) and the engineer's estimate; it measures how much the original contract bid (or contract award) deviates from the engineer's estimate. Note that the award growth is an indicator of the contractor's perception of risks and is influenced by a myriad of factors, such as market competitiveness, inaccurate estimating, fluctuations in material prices, opportunities for cost savings, and contingencies to cover uncertainties during construction. An *award growth* greater than zero indicates that the awarded contract value is higher than the engineer's estimate. Alternatively, an *award growth* less than zero indicates that the awarded contract value is lower than the engineer's estimate. The *award growth* will be used to determine how RID 3D model deliverables affect the variability of bids and help improve communication of design intent to reduce contractor's perceived risk.

$$\text{Award Growth} = \frac{\text{Awarded Contract Value} - \text{Engineer's Estimate}}{\text{Engineer's Estimate}}\ x\ 100$$

Equation 1. Formula for calculating award growth parameter.

Cost growth is a percent change in cost between the final contract and the awarded contract value. *Cost growth* can occur due to a myriad of factors that result in contract modifications, such as unforeseen conditions and events, errors and omissions in contract documents, schedule change, scope change and creep, and inaccurate estimating. A *cost growth* greater than zero indicates the final contract value is greater than the awarded contract value. Alternatively, a *cost growth* less than zero indicates the final contract is lower than the awarded contract value. The *cost growth* will be used to determine whether inclusion of RID 3D models helps identify unforeseen situations and/or errors and omissions, as well as estimate quantities more accurately to minimize the additional cost of change orders.

$$\text{Cost growth} = \frac{\text{Final Contract Cost} - \text{Awarded Contract Value}}{\text{Award Contract Amount}}\ x\ 100$$

Equation 2. Formula for calculating cost growth parameter.

Additionally, the researchers conducted a targeted analysis using *award growth* and *cost growth* for projects delivered by the regions considered to be more advanced in producing RID 3D models. The Bay and the Southwest regions were included in the second targeted analysis. This targeted analysis was performed to help identify factors that may contribute to the overall results, such as experience of designers with the modeling tools and familiarity of contractors with 3D design data among others.

Method of Analysis

The researchers' method of analysis was to compare the metrics of two project types: projects using RID 3D models and those using 2D plans. In statistical terms, these two project types were herein referred as two populations of interest. Note that MDOT initially provided a dataset of 261 projects for analysis. The researchers also determined known outliers to be removed from the population samples. Three projects were identified as having changes to the original scope of work. Sources involved with those projects informed researchers that significant scope changes unrelated to the use of 3D models were made, and therefore should be excluded from the study. Once those three projects were removed from the population samples, the researchers conducted an additional analysis to identify other statistical outliers. The statistical outliers were identified based on the computation of an interquartile range (IQR), which was then used to calculate regular and extreme outliers. The metrics that are within the range of 3.0 times the IQR were deemed as regular outliers yet retained within the dataset, and conversely, those that were outside the range of 3.0 times IQR were considered as extreme outliers and were removed. Note that the statistical convention recommends the use of 1.5 times the IQR range as the threshold for identifying outliers; however, recognizing that the cost performance metrics of highway projects inherently have a high level of variability, owing to many factors, such as project size, project type, and complexity etc., the researchers adopted a more liberal threshold for identifying outliers.

The final population samples used in the hypothesis testing are listed in Table 4 and Table 5.

Table 4. Population samples used in the hypothesis testing for award growth.

Population Sample	Statewide Population Size	Regional Population Size
RID 3D Models Projects	65	24
Traditional 2D Plans Projects	193	61

Table 5. Population samples used in the hypothesis testing for cost growth.

Population Sample	Statewide Population Size	Regional Population Size
RID 3D Models Projects	64	24
Traditional 2D Plans Projects	188	60

Figure 8 provides a graphical representation of the results, and Table 6 and 7 show the calculations performed to identify outliers to be removed from the population samples.

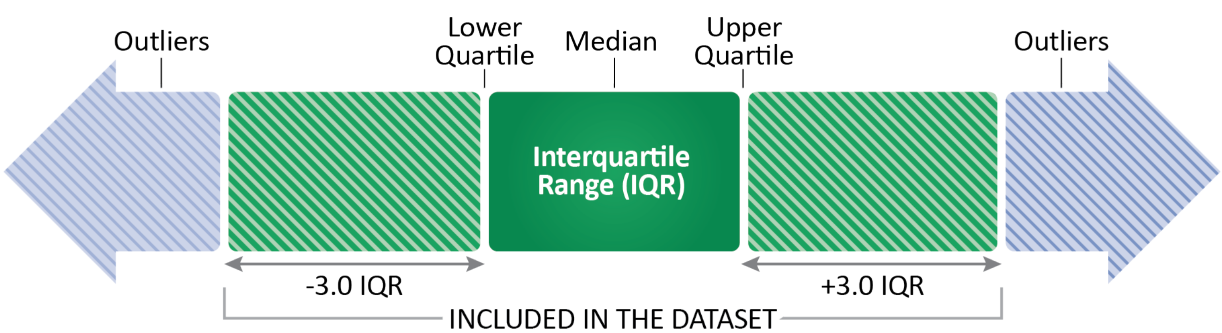


Figure 8. Calculation of IQR for determining outliers to be removed from statistical analysis.

Table 6. Criteria to identify outliers for award growth and bid growth (2D plans)

Statistical Measure	Award Growth	Cost Growth
Lower Quartile	-7.1%	-5.1%
Upper Quartile	10.6%	2.6%
IQR	17.8%	7.8%
- 3 x IQR	-60.4%	-28.5%
+ 3 x IQR	63.9%	26.0%

Table 7. Criteria to identify outliers for award growth and bid growth (3D models)

Statistical Measure	Award Growth	Cost Growth
Lower Quartile	-10.7%	-3.9%
Upper Quartile	7.9%	1.5%
IQR	18.6%	5.4%
- 3 x IQR	-66.5%	-20.0%
+ 3 x IQR	63.8%	17.7%

Summary of Results

Award Growth Between RID 3D Model and Traditional 2D Plan Projects

Statewide Project Data Set

Table 8 presents the statistics of award growth for projects using 3D models and 2D models. Figure 9 presents a Beeswarm plot that compares the award growth for projects using 3D models and 2D models. The vertical distribution of data points in the Beeswarm plot shows the extent of statistical dispersion along the vertical axis, while the horizontal distribution indicates the tendency of data points to cluster around a central value.

Table 8. Historical data award growth analysis summary (for all regions).

Award growth – All Regions	2D Plans	3D Models
Count	192	65
Average	+3.0%	-1.4%
Standard Deviation	15%	15%

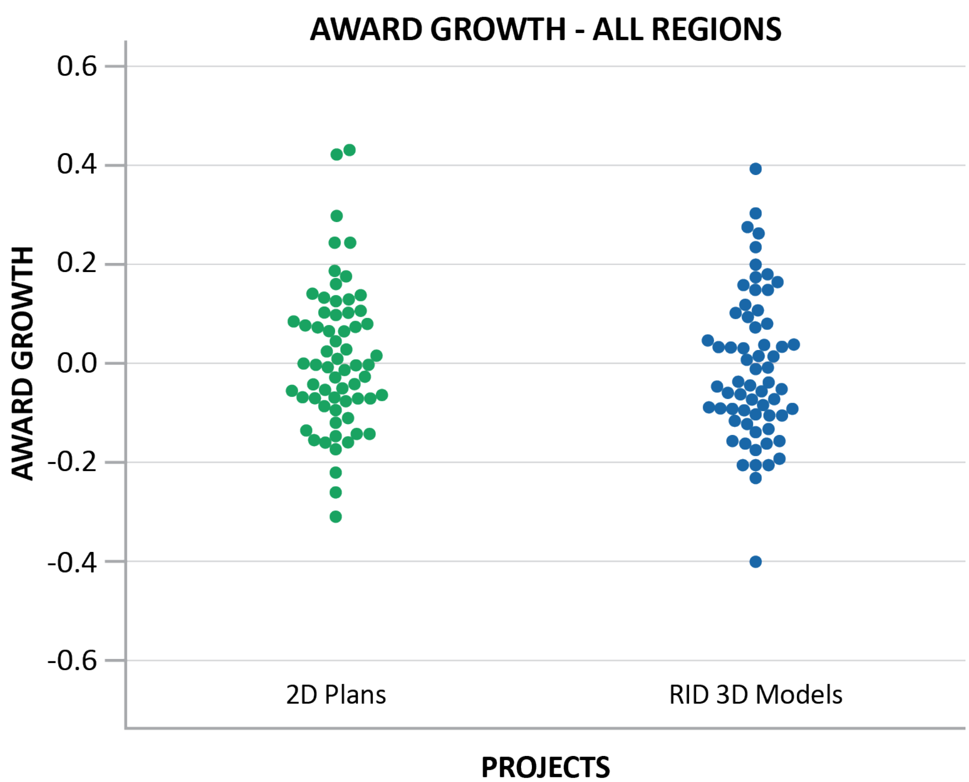


Figure 9. Comparison of award growths of projects of all regions.

The historical data showed that when RID 3D models were used in lieu of traditional 2D plan deliverables, MDOT received bids that were closer to the engineer's estimate. The original contract bids on projects using RID 3D models were on average 1 percent lower than the engineer's estimate, whereas the original contract bids were 3 percent higher than the engineer's estimate on projects with 2D plans.

In addition, as Figure 9 indicates, there is significant overlap in *award growth* values between projects using 3D models and 2D plans. This observed overlap is expected since the *award growths* are influenced by other factors as well.

These results coincide with the contractor survey responses, which were validated during the follow-up interviews. Most responses indicated that contractors perceive a lower risk when bidding on projects with RID 3D models compared to traditional 2D plan deliverables. This lower risk is due to the RID 3D models being consistent with the plans. Contractors indicated that the models produced by MDOT and their consultants are of good quality and representative of the design intent.

Southwest and Bay Region Data Set

Table 9 and Figure 10 present the statistical summary and a visual comparison, respectively, of award growths of projects in the Southwest and Bay Region. The historical data showed that projects with RID 3D models received an average bid of 2.5 percent under the engineer's estimate. Alternatively, projects with traditional 2D plan deliverables on average received bids of 2.6 percent above the engineer's estimate. During the follow-up interviews, contractors indicated that their perception of risk is lower with 3D model deliverables; thus, the contingency built into the bids to take account for errors and omissions is not as large as in the past.

Table 9. Historical data award growth analysis summary (for Southwest and Bay Regions)

Award growth – Southwest and Bay Regions	2D Plans	3D Models
Count	61	24
Average	+2.5%	-2.6%
Standard Deviation	14%	16%

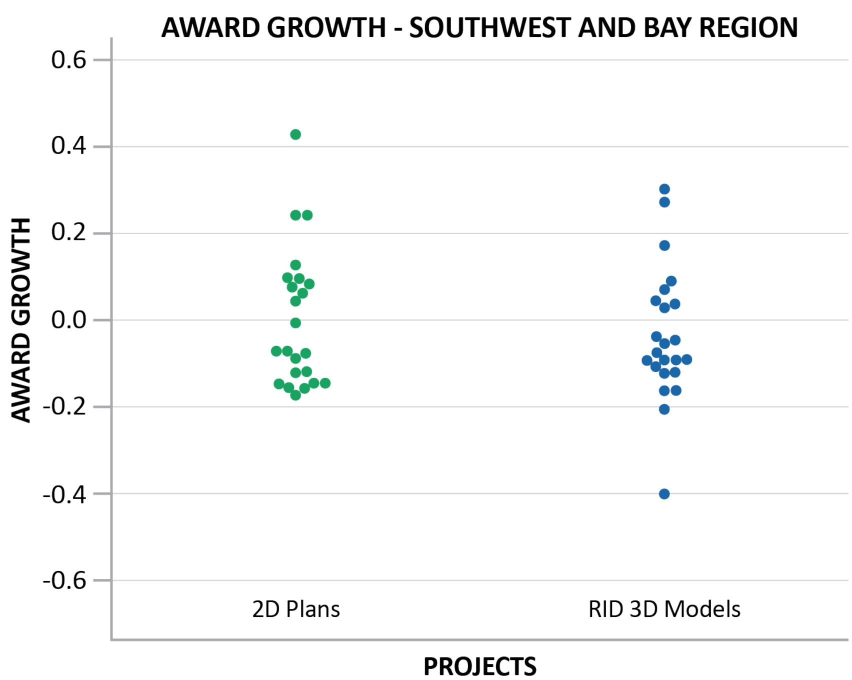


Figure 10. Comparison of award growths of projects in Southwest and Bay Regions.

Figure 11 compares the average award growth for projects using 2D plans versus 3D models statewide versus in the Southwest and Bay Regions.

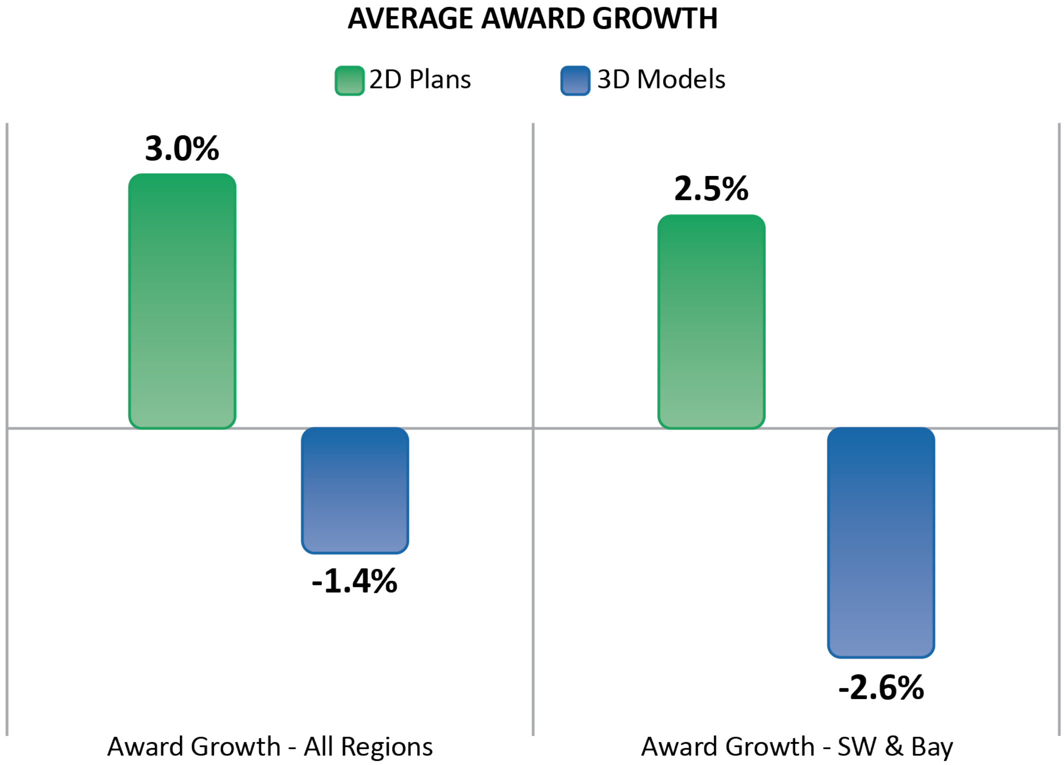


Figure 11. Average award growth comparison for statewide and regional population samples.

Cost growth Between RID 3D Model and Traditional 2D Plan Projects

Statewide Project Data Set

Table 10 and Figure 12 present the statistical summary and visual comparison, respectively, of *cost growth* of projects in the statewide dataset.

In general, the historical data showed that MDOT project estimates are within 2 percent of the actual cost of construction. The statewide dataset did not show any preference for 3D models over 2D plans regarding cost growth; both showed an average 1.2 percent cost savings relative to the original programmed cost, although the lower standard deviation of cost growth for 3D model projects indicates more consistent communication of design intent.

Table 10. Historical data cost growth analysis summary (for all regions).

Cost growth – All Regions	2D Plans	3D Models
Count	189	62
Average	-1.2%	-1.2%
Standard Deviation	8%	5%

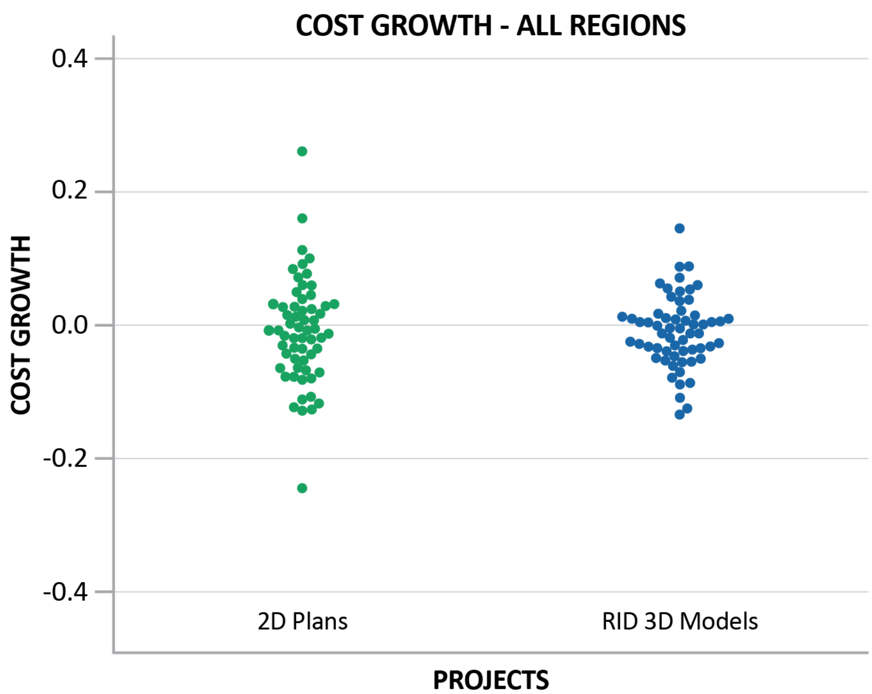


Figure 12. Comparison of cost growths of projects for all regions.

Southwest and Bay Region Data Set

Table 11 and Figure 13 present the statistical summary and visual comparison, respectively, for *cost growth* of projects in the Southwest and Bay Regions.

Similarly, the historical data showed that MDOT's estimates are within 2 percent of the actual cost paid during construction. In the Southwest and Bay Regions, projects with RID 3D models are saving MDOT roughly 1 percent of the contract award amount, while 2D plans save roughly 2 percent. Furthermore, the lower standard deviation of cost growth for 3D projects indicates more consistent communication of design intent.

Table 11. Historical data contract growth analysis summary (for Southwest and Bay Regions).

Cost growth – Southwest and Bay Regions	2D Plans	3D Models
Count	61	23
Average	-1.6%	-0.8%
Standard Deviation	7.4%	3.8%

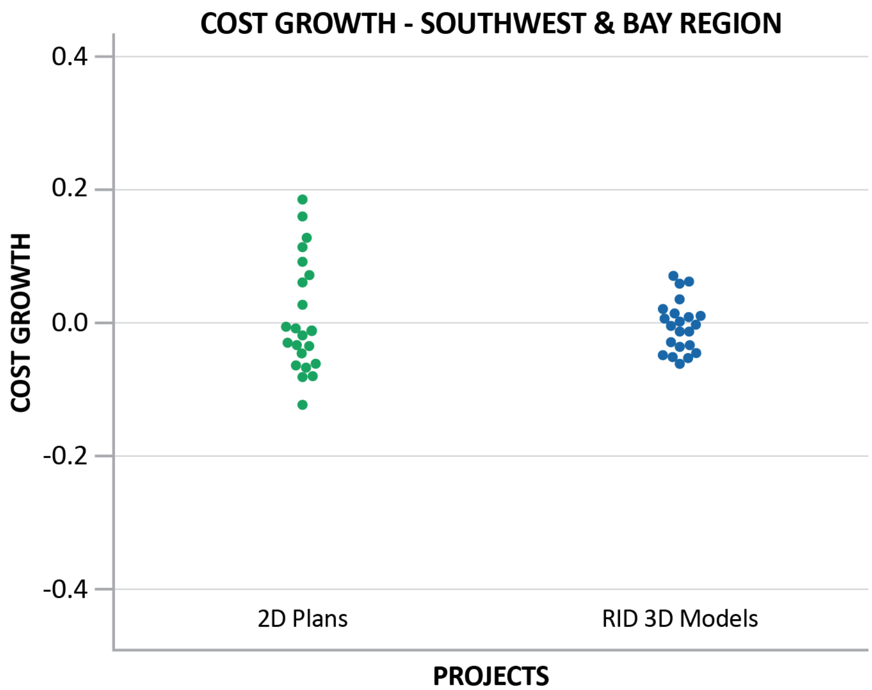


Figure 13. Comparison of cost growth of projects in Southwest and Bay Regions.

Figure 14 compares the average cost growth for projects using 2D plans versus 3D models statewide versus in the Southwest and Bay Regions.

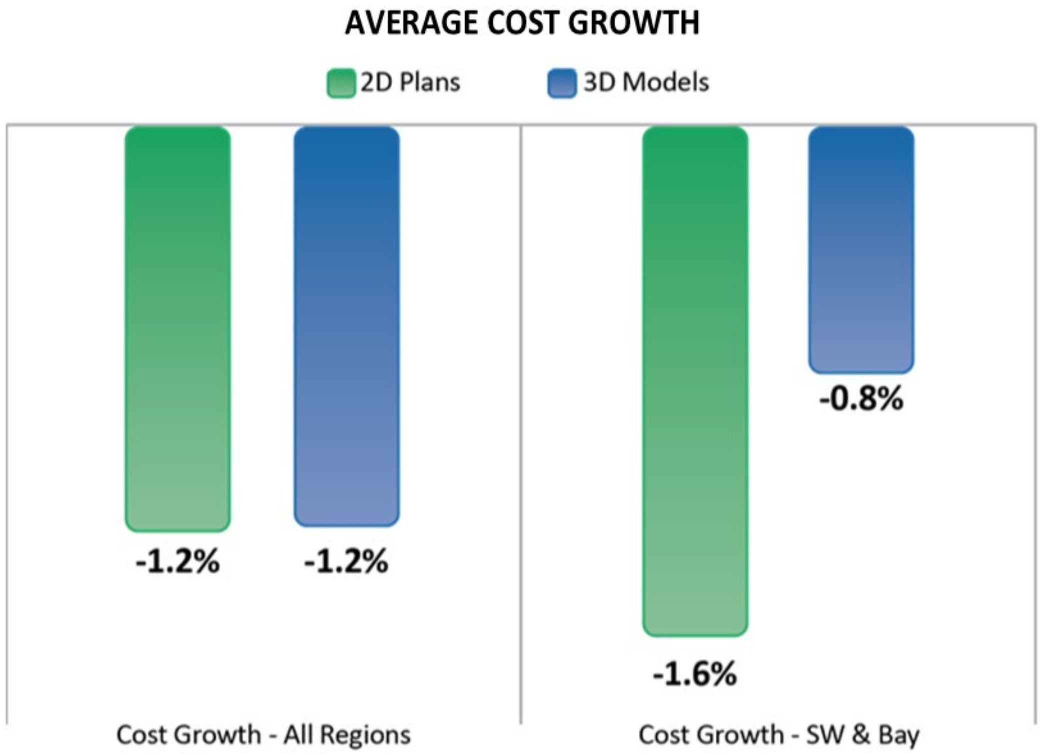


Figure 14. Average cost growth comparison for statewide and regional population samples.

Understanding the Variance of Population Samples

Figure 9, Figure 10, Figure 12, and Figure 13 show the presence of significant overlap in the distribution of award growth and cost growth values between 3D and 2D projects. In other words, the difference between the averages of 3D and 2D projects is not farther than their own ranges due to a high level of variability within their datasets. Therefore, it is imperative to conduct a statistical evaluation to analyze if there is a true underlying causation behind the observed difference between 3D and 2D projects or if this observed difference is simply out of chance.

Researchers used a t-test to analyze the variance of the two measures *award growth* and *cost growth*. Under this statistical test, a test statistic, **T-stat**, is computed using the observed mean and variance of two datasets. The T-stat, which is analogous to a signal-to-noise-ratio, is calculated as the ratio between difference in observed means between the two datasets and their variance. The larger the T-stat, the more statistical significance to the observed difference in means. The T-stat provides a basis for statistical hypothesis testing to evaluate if one dataset is statistically different from another. The T-test procedure utilizes a cut-off value, **T-critical**, that provides the basis of acceptance or rejection of a statistical hypothesis. The T-critical value is derived from the sample size and the level of significance of the test.

Since the objective of this study is to explore the apparent incremental benefits (i.e., lower growths) of RID 3D models over 2D plans, one-tailed “directional” test was utilized for hypothesis testing. The following hypotheses were considered in the statistical analysis:

Null Hypothesis: There is no underlying difference between RID 3D models and 2D plans in controlling *award growth* and *cost growth* of projects:

$$H0: \bar{x}_{3D} - \bar{x}_{2D} = 0$$

Equation 3. Null hypothesis for a one-tailed (lower tail) analysis.

Alternative Hypothesis: The use of RID 3D models results in higher cost savings than 2D plans in controlling award growth and cost growth of projects:

$$H1: \bar{x}_{3D} - \bar{x}_{2D} < 0$$

Equation 4. Alternate hypothesis for a one-tailed (lower tail) analysis.

Recall that the negative values of *award growth* and *cost growth* indicate the project has resulted in cost savings when compared with the engineer's estimate, while the positive values indicate cost increases. The more negative the reported number is, the higher the cost savings.

Variance Analysis for Award Growth

The results of the T-test are summarized in Table 12. For all statewide projects, the absolute value of the T-stat (2.06) is greater than the T-critical value (1.66) at a 98 percent confidence level. As such, the rejection of the null hypothesis at a high confidence level indicates strong statistical evidence to conclude that the use of RID 3D models improves cost outcomes relative to 2D plans statewide. In other words, when RID 3D models are used, the bid amount is typically lower than the engineer's estimate on a statewide level.

Table 12. Results of the T-tests for award growth.

Statistical Term	Statewide Award Growth	Southwest and Bay Regions Award Growth
Mean	3D Models: -1% 2D Plans: 3%	3D Models: -3% 2D Plans: 3%
Standard Deviation	3D Models: 15% 2D Plans: 15%	3D Models: 16% 2D Plans: 14%
Absolute value of T-Stat	2.06	1.39
T-critical at 95% confidence level	1.66	1.69
Level of Significance P(T<=t)	98%	91%

For projects in the Southwest and Bay Regions, the absolute value of T-stat (1.39) is less than T-critical for a one-tailed analysis (1.69) at a 95 percent confidence level. Although we fail to reject the null hypothesis at 95 percent confidence level, there is sufficient evidence to reject the null hypothesis at a slightly lower confidence interval at 91 percent. The alternate hypothesis concludes that the use of RID

3D models results in higher cost savings than 2D plans in controlling award growth across all regions, and specifically within the Southwest and Bay Regions.

Furthermore, a confidence level of 95 percent is only used as a convention for making decisions related to acceptance or rejection of a statistical hypothesis. Note that the confidence level or P-value is generally considered as the measure of evidence against null hypothesis, while higher confidence levels (or lower p-value) corresponds to stronger evidence. The general rule of thumb is: *when the consequences of Type 1 error (i.e., claiming an effect that is absent or false positives) is of serious concern, a larger confidence level (or lower P-value) is preferred. Alternatively, when the consequences of Type 2 error (i.e., failing to detect an effect or false negatives) is of serious concern, a smaller confidence level (or higher P-value) is preferred.*

At a confidence level, greater than 95 percent, there is strong evidence to conclude that the use of RID 3D models has more beneficial effect on submitted bids than 2D plans in the Southwest and Bay Regions, as well as across all MDOT regions.

Variance Analysis for Cost Growth

The results for the T-test are summarized in Table 13. For all statewide projects, as the absolute value of T-Stat (0.43) is less than T-critical for a one-tailed analysis (1.66), the null hypothesis can only be rejected at a confidence level of 67 percent, which is not strong. Similarly, for projects in the Southwest and Bay Regions, the absolute value of T-stat (0.65) is less than T-critical for a one-tailed analysis (1.67), while the null hypothesis can only be rejected at a confidence level of 74 percent, which is fair.

Table 13. Results of T-test statewide cost growth.

Statistical Term	Statewide Cost growth	Southwest and Bay Regions Cost growth
Mean	3D Models: -1% 2D Plans: -1%	3D Models: -1% 2D Plans: -2%
Standard Deviation	3D Models: 5% 2D Plans: 8%	3D Models: 4% 2D Plans: 7%
Absolute value of T-Stat	0.43	0.65
T-critical at 95% confidence level	1.66	1.67
Level of Significance P(T<=t)	67%	74%

In both cases, these results indicate that the statistical evidence does not favor the use of RID 3D models or 2D plans. However, it is important to note that final contract costs are typically influenced by various factors, such as scope change or differing site conditions, which can neither be controlled in a real-world environment nor mitigated with the use of RID 3D models. The following section explores another dimension to the analysis—project size—in order to draw a more meaningful conclusion as to the effect of 3D models as RID on cost growth.

Variance Analysis by Project Size

Hypothesis testing indicated that there is strong evidence to conclude that the use of RID 3D models would generally result in bids lower than the engineer's estimate; however, the observed statistical evidence is not consistent enough to make such strong conclusions about cost growth rates. To investigate further, researchers expanded the variance analysis of award and cost growths to investigate the trends by projects of different sizes. The key questions of interest are:

1. Does the use of the RID 3D models provide more benefits for projects of a particular size than others?
2. Is the available statistical evidence more pronounced in projects of a particular size?

Researchers stratified the historical data into three subsets based on their bid amounts: (i) less than $5 million; (ii) between $5 and $20 million; and (iii) greater than $20 million. Table 14-16 provide a summary of the average award growth and cost growth by project size. In addition, the table presents the adjectival description of the evidence inferred based on T-tests and the corresponding confidence levels.

Table 14. Sample sizes to determine award and cost growth by project size (statewide).

Project Size	2D Plans	3D Models
< $5 M	142	44
$5 M - $20 M	41	19
> $20 M[1]	10	2

[1]Hypothesis testing using T-tests ***was not conducted as the sample size was too small*** *to draw reasonable conclusions.*

Table 15. Award growth results by project size (statewide)[1].

Project Size	2D Plans	3D Models	Evidence in Favor of 3D Models (Confidence Level)
< $5 M	3.1%	0.4%	Moderate (84%)
$5 M - $20 M	2.8%	-6.1%	Very Strong (99.4%)
> $20 M[2]	1.2%	-1.1%	N.A.

[1] The benchmark is the engineer's estimate.
[2] Hypothesis testing using T-tests ***was not conducted as the sample size was too small*** *to draw reasonable conclusions.*

Table 16. Cost growth results by project size[1].

Project Size	2D Plans	3D Models	Evidence in Favor of 3D Models (Confidence Level)
< $5 M	-1.8%	-0.9%	Moderate[2] (80%)
$5 M - $20 M	0.3%	-2.3%	Strong (90%)
> $20 M[3]	3.5%	7.3%	N.A.

[1] The benchmark is the project award amount.
***[2]** The cost growth for this project size is more favorable to 2D plans.*
*[3] Hypothesis testing using T-tests **was not conducted as the sample size was too small** to draw reasonable conclusions.*

As the results indicate, the use of 3D models provided the greatest benefit, in terms of lower average award growth and cost growth, to projects procured between $5 and $20 million with strong statistical evidence. On average, projects with 3D models produced bids 6 percent lower than the engineer's estimate, while those with only 2D plans produced bids nearly 3 percent higher than the engineer's estimate. This translate into nearly a 9 percent apparent cost savings when delivering 3D models. More importantly, projects with 3D models resulted in fewer change orders compared to those with only 2D plans. Final cost of projects with 3D models were 2.3 percent lower than the engineer's estimate, while those with only 2D plans resulted in a 0.3 percent increased cost. Projects with 3D models resulted in an overall savings of 2.6 percent when comparing final cost to the engineer's estimate.

For smaller projects (i.e., of size less than $5 million), the 3D models did not yield cost savings in comparison with the engineer's estimates but produced bids that were about 2.7 percent lower than 2D plans. However, while both 3D and 2D categories exhibited slightly lower final construction costs than their corresponding bid amounts, the hypothesis testing indicated moderate strength of evidence in favor of 2D plans.

Overall Cost Savings and Overruns

To provide additional context to the rigorous statistical analysis of MDOT's project portfolio, researchers calculated the overall absolute cost savings/overruns attributed to 3D models and 2D plans. Table 17 summarizes the savings MDOT has observed based on the sample of projects provided, which can be attributed to the use of 3D models.

Table 17 and 18 provide the sum of all engineer's estimates, bid costs, and final contract costs for projects that used 3D models as RID and for projects that only used 2D plans. Note that all outliers were excluded from this analysis.

Table 17. Overall cost savings and overruns of 3D models versus 2D plans (millions of dollars, statewide).

Categories	2D Plans	3D Models
Total Engineer's Estimates	$1,148.9	$288.3
Total Bid Costs	$1,159.2	$277.4
Total Final Contract Costs	$1,168.1	$275.4
Net Cost Savings at Award	-$10.2	$11.0
Net Cost Savings at Project Closeout	-$8.9	$2.0
Net Program Cost Savings	**-$19.2**	**$12.9**
Percent Program Cost Savings	**-1.7%**	**4.5%**

Note: Totals may not add due to rounding.

Table 18. Summary of overall calculated benefits of 3D models versus 2D plans (millions of dollars, statewide)

Description of Benefits	Calculated Benefits
Cost Savings of 3D over 2D	*$32.2*
Percent Cost Savings of 3D over 2D	*2.2%*

The net cost savings at award represents the difference between total engineer's estimates and total bid costs (positive indicates cost savings, negative indicates cost overruns). Similarly, net cost savings at project closeout represents the difference between total bid costs and total final contract costs. The net program cost savings is the sum of the net cost savings at award and net cost savings at project closeout (i.e., the difference between the total engineer's estimates and the total final contract costs).

Across the selected portfolio of projects, MDOT observed a net cost savings of $12.9 million across projects using 3D models (4.5 percent of the total engineer's estimates for projects using 3D models) and a net cost overrun of $19.1 million across projects using 2D plans only (1.7 percent of the total engineer's estimates for projects using 2D plans).

The net cost savings of projects using 3D models over projects using 2D plans (i.e., the difference in net program cost savings between projects that use 3D models and projects that used 2D plans) was $32.2 million, or 2.2 percent of the total engineer's estimates (across both projects that used 3D models and projects that used 2D plans) for this selection of projects. The analysis of absolute cost savings indicates that MDOT has already observed notable net cost savings overall from the engineer's estimate to the final contract cost.

Interpreting the Results

Summary

Based on the discussions presented in this section, the following observations are made:

Award Growth:

- 3D models consistently produced bids that were lower than the engineer's estimate resulting in cost savings to the agency, and when the bids were higher than the engineer's estimate, 3D models produced bids with lower award growths than 2D plans.
- 3D models provide the greatest benefit to projects procured between $5 million and $20 million than those of other sizes.
- The statistical evidence is very strong in favor of 3D models for projects procured between $5 million and $20 million, whereas the strength of such evidence is deemed moderate for smaller projects.

Cost Growth:

- On average, projects using 3D models had final contract costs slightly lower than their bid prices.
- From a statistical perspective, the use of 3D models had a strong advantage over 2D models for projects procured between $5 million and $20 million; however, 3D models could not demonstrate such benefits in smaller projects.

Observations:

While the smaller projects did not have the strong statistical evidence that favors 3D models over 2D plans, committing to a standard workflow using 3D models will benefit the organization long term.

It is important to note that the statistical analysis did not consider any other factors affecting benefits beyond the comparison between engineer's estimate, received bids, and final project cost. Some additional factors to consider in the future are the effect of 3D models on:

1. Increased workforce utilization to produce contract plans by reducing the number of unnecessary plan sheets. The current process to create 2D plans is a by-product of the already established model-centric design workflow using modern software; however, designers spend additional time detailing sheets with information already produced in the model. This duplication of work occurs on all projects required to produce plan sheets, regardless of size.

2. Lower bids due to reduction of contractor operational cost. One unintended result of 3D model-based design and AMG is the increased competition between contractors. One contractor interviewed indicated experiencing lower operational cost when using AMG, which often translates into a lower bid. Contractors leveraging 3D models and AMG technology can often outbid the competition. This type of healthy competition may result in overall better bids for the department.

Therefore, it can be argued that both the quantitative and qualitative benefits favor 3D models for all projects regardless of size.

Missed Opportunities for Realizing Additional Benefits

The study revealed that 3D models are mostly being used by the contractor to prepare their bid estimates and AMG operations. However, there are other areas in which MDOT could realize additional benefits, such as the use of 3D models for collaborative reviews. The key to maximizing the benefits of a model-centric design approach is to develop a 3D model that includes elements that allow virtual clash detection review and constructability analysis based on reliable and accurate representation of both existing conditions and proposed features. A multi-disciplinary collaborative review early in the design is a more efficient way to review projects and is effective in providing meaningful and timely feedback to affect design changes to minimize change orders in the field.

The differences between a plan and model-centric design approach in affecting cost is best illustrated by the MacLeamy Curve (CURT 2004). Figure 15 is an adaptation of the MacLeamy Curve to highlight how the current project delivery processes for highway projects can be adapted to use 3D models and stakeholder collaboration to identify high-risk elements as early as possible to realize the maximum benefits of the technology.

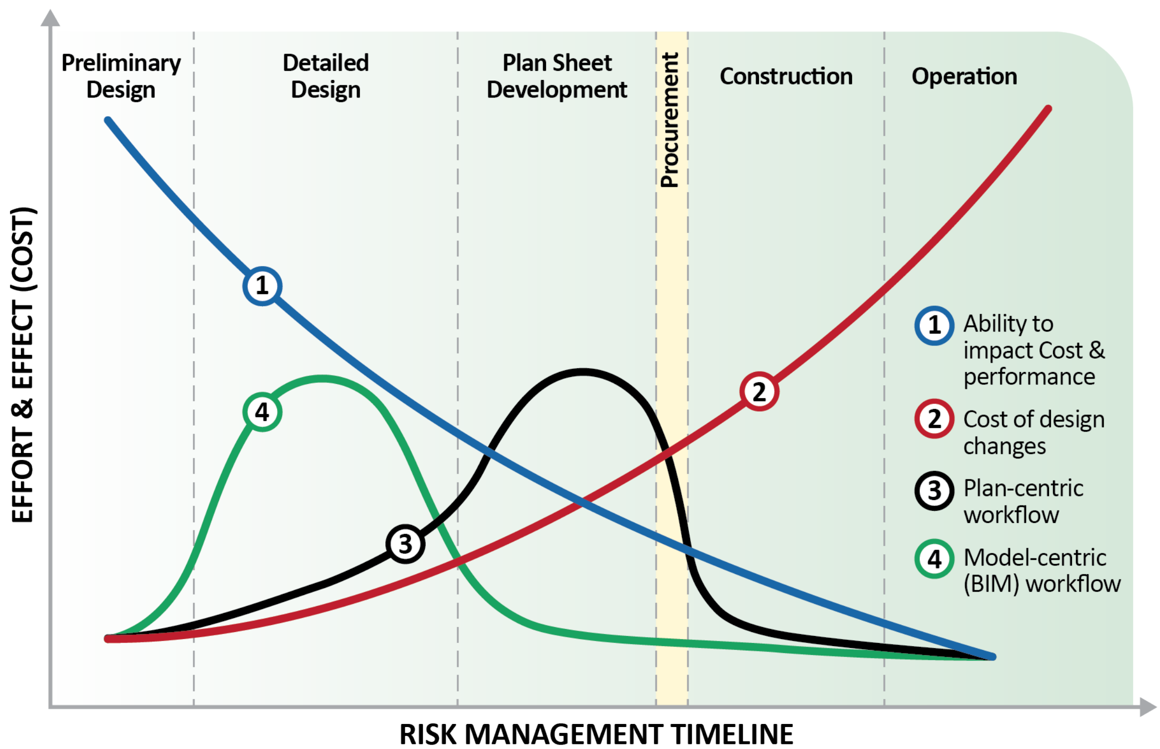


Figure 15. Relationship between level of effort and effect (cost) associated with design changes during project delivery using plan-centric and model-centric (BIM) workflows.

For example, the Wisconsin Department of Transportation (WisDOT) started using a model-centric approach to manage risks on its mega projects (typically over $1 billion). WisDOT had been tracking the source of change orders and identified the top risk elements that typically result in costly design changes during construction. These high-risk design elements are listed in Table 19 (Parve 2013).

Table 19. Design elements identified as high or low risk.

Design Element	Risk
Structures (general, bridges, and walls)	High
Drainage/Utilities	High
Earthwork	Low
Electrical/ITS	Low
Traffic Control /Signs	Low

Section 4. Return-on-Investment Framework

This section describes the spreadsheet template created to compute the ROI for investing in 3D engineered models. The spreadsheet template was developed as a companion document to this report. The purpose of this ROI tool is to automate the calculations using a user-friendly template based on the assumptions presented herein.

Assumptions

Costs

The only costs identified with producing RID 3D models and contract plan sheets are:

- Additional 10 percent of professional engineering services contract. This figure was based on the higher end of the range from the survey responses, which is in line with what the contractor pays a subconsultant to produce 3D models for AMG and QTO.
- Professional engineering services cost of 9 percent of the construction contract (value provided by MDOT).
- Any cost associated for hiring additional full-time equivalent (FTE) staff for Engineering Support. The template assumes an additional FTE.
- Any cost associated with professional services to configure software.

Benefits

Other studies have identified multiple benefits that can be realized from using 3D models, but many are difficult to quantify. Therefore, researchers listed several qualitative benefits, and quantified benefits based on the reduction of change orders only using information from the historical data provided by MDOT and a recent national study (Federal Highway Administration. 2018) regarding change order costs. Qualitative benefits identified during this and previous studies include:

- Contractor perceived lower bidding risk.
- Improved plan quality.
- Increased bidding competition.
- Improved safety for construction staff due to reduced exposure to heavy equipment.
- Improved efficiency by construction staff using 3D models and modern surveying equipment to verify contract requirements.

The only quantifiable benefit used for calculation was an estimated reduction of change orders due to quantity deviations, and errors and omissions based on the following information:

- The average percent cost incurred by MDOT during years 2012-2016 due to change orders was 5 percent based on the historical data.
- Change orders are due to many reasons, many of which cannot be avoided by using 3D models.
- Change orders due to quantity deviations and errors and omissions may be avoided when using 3D models.
- The national average percent of change orders due to quantity deviations is 12 percent.
- The national average percent of change orders due to errors and omissions is 12 percent.

Other Benefits for Considerations

Other benefits that were not captured during this study may be considered in future calculations.

Mobile Lidar Mapping System

Mobile mapping systems that use survey-grade lidar sensors allow agencies to collect existing conditions more efficiently and provide data that can be used for multiple applications. The concept of "collecting once and use many times" is how the benefits may be realized. The Oregon Department of Transportation estimated a 300 percent, 3-year ROI for the implementation of a mobile mapping system (Sillars, et al. 2018). The ROI was a direct calculation of the costs to implement and maintain the system and the benefits of using collected data to produce 3D surveys for design projects, records for asset inventory, and annual reports of vertical clearances for all state-system bridges.

Estimated Savings Resulting from Low Bids

The historical data revealed that bids come in closer to the engineer's estimates when using 3D models. As previously discussed, this is due to the contractors' ability to use the RID 3D model files for QTO and AMG operations. Most of the cost to implement AMG is incurred by the contractor, as the owner does not own AMG equipment. The investment on the owner side is minimal, typically only incurring cost related to the efforts for upgrading software and training, and adding staff to support the implementation of 3D models. However, the benefits are high and are reflected in the significant lower bids received. The Oregon Department of Transportation recently saved $4.4 million from low bids received on three projects (Squire 2018). The low bidder on all three projects, a medium-sized contractor, had invested in AMG systems for all construction operations and was able to significantly outbid their competition.

Material Overruns

The use of AMG systems can help control material overruns. For example, the Missouri Department of Transportation saved 8,500 cubic yards of concrete overruns (an equivalent of $600,000) by allowing the contractor to use 3D milling and concrete paving on an unbonded concrete overlay project in 2010 (Maier, et al. 2017). This specific example negates the opinion that resurfacing projects are not worth the effort to create a 3D model.

Efficiency Gained in Construction Inspection

Previous studies (Sillars, et al. 2018) indicate that 3D models and AMG technology save contractors 66 percent time checking grades and up to an 85 percent reduction in staking time. While there no direct financial advantage to the owner, the ability to complete a project within a compressed schedule is an unintended benefit of the technology. When construction inspection staff is equipped with modern surveying equipment and trained on how to use 3D models for verification and quantity measurements, productivity may increase by as much as 50 percent. (Maier, et al. 2017) (Sillars, et al. 2018) There may be opportunities in the future to document efficiencies during construction inspection when using 3D models and modern surveying equipment to make visual inspections and verification of contract requirements.

Spreadsheet Template Organization

The spreadsheet template has three tabs: Dashboard, General Inputs, and Annual Benefits and Costs. Table 20 describes each of the tabs used in the template.

Table 20. Description of worksheet tabs used in the ROI template.

Worksheet Tab	Description
Dashboard	• This tab has one table listing all the values of the resulting ROI calculations, including the average annual construction program for the 5-year period, as well as corresponding costs and benefits, 5-year ROI, breakeven year, and net present value using 3% and 7% discount rates.
General Inputs	• This tab has five tables and is designed for the user to input specific information. Table 1 contains line items for general inputs for determining cost of 3D models. • Table 2 contains line items for costs associated with staffing to support 3D models. • Table 3 contains line items for costs (in dollars) by fiscal year. The three line items are: annual construction program, annual amount of change orders, and PE costs. • Table 4 contains the cost calculations for the 5-year period reported in Table 3. • Table 5 contains line items with values calculated from the historical data. • Table 6 contains one line item to enter savings from low bids due to low bidder using AMG construction by fiscal year.
Annual Benefits and Costs	• This tab has five tables. • Table 1 lists qualitative benefits. • Table 2 lists the quantifiable benefits. These calculations are based on three benefit streams: estimated change order avoidance due to quantity changes, as well as errors and omissions; and estimated savings from low bids. • Table 3 lists all the calculated costs, including additional cost to produce 3D models, staff to provide technical support, and any professional services needed for implementation.

General Inputs

This is the area of the spreadsheet model in which the user enters information regarding costs and benefits identified during the study to calculate the ROI of implementing 3D models. Figure 16 shows the legend for this tab. The cells shown in yellow indicate a field for the user to enter information. The cells shown in gray have a formula that calculates a value based on the input, and the cells shown in green show information not used in any of the calculations, but values computed from the historical data statistical analysis. All other tables in the General Inputs tab of the spreadsheet model are shown in Figures 17-22.

Michigan Department of Transportation 3D Highway Design Model Cost Benefit Analysis

This worksheet is used to calculate MDOT's return on investment for the implementation of RID 3D models.

Legend: = user input = calculation = for information only

Figure 16. Legend for general inputs tab.

Table 1. General Inputs		
Input Category	**Input**	**Notes and Assumptions**
Professional Engineering services cost as percent of construction cost	9%	Value provided by MDOT
Cost to produce 3D models as percent of design contract	10%	Assumption based on survey responses

Figure 17. Table 1 of the "General Inputs" tab captures cost of producing 3D models as a percent of overall design contract value.

The "General Inputs" tab (Figure 17) of the spreadsheet model allows the user to enter the cost of producing 3D models as a percent of the overall design services contract.

Table 2. Staffing Information		
Input Category	**Input**	**Assumptions**
Engineering Support Staff for 3D Design (numbers of FTEs)	1	Should only include staff specifically hired for this effort (assumption is one FTE)
Hourly Rate for Engineering Support Staff ($/HR)	$ 40	Enter average hourly rate
Loaded Rate Factor	1.2	Enter MDOT's loaded rate factor
Salary Increase Factor	1.02	Assumes 2% raise annually
Professional Services for 3D Model Implementation	$ -	One time cost to pay a vendor or consultant to configure software, training, etc.

Figure 18. Table 2 of the "General Inputs" tab captures cost related to addition of staff to provide technical support of models.

Table 3. Costs by Fiscal Year ($)							
	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Annual Construction Program	$ 1,350,000,000	$ 1,175,000,000	$ 1,306,000,000	$ 1,187,000,000	$ 1,229,000,000	$ 1,229,000,000	$ 1,326,000,000
Annual Amount of Change Orders							
Annual Professional Engineering Services Cost (Assume 10% of overall construction budget)	$ 121,500,000	$ 105,750,000	$ 117,540,000	$ 106,830,000	$ 110,610,000	$ 110,610,000	$ 119,340,000

Figure 19. Table 3 of the "General Inputs" tab captures the annual construction program and the cost of change orders if known. The bottom row calculates the cost of producing 3D models based on the information entered in Table 1.

If the actual cost of producing a 3D model is known, the spreadsheet model could be modified to input the annual cost to produce 3D engineered models directly into the table shown in Figure 19 instead of being calculated from the information entered into the table shown in Figure 17.

Table 4. Cost Calculations		
Category	**Calculation ($)**	**Notes and Assumptions**
Average annual construction program ($) from 2012-2016	$ 1,249,400,000	
Average Profession Engineering services cost ($)	$ 112,446,000	Average PE cost between 2012-2016 (assumed 10% of construction cost). Formula = average annual construction program x 10%
Loaded Salary for Engineering Support Staff Needed for 3D Design	$ 99,840	Base salary plus fringe benefits. Formula = Hourly Rate x 1.2 x 40 hours/week x 52 weeks/yr

Figure 20. Table 4 of the "General Inputs" tab shows the calculation of all costs based on the previously entered information.

Table 5. Calculated Values from Historical Data		
Input Category	Input (%)	Notes and Assumptions
Average percent of change orders due to quantity changes	12.0%	According to a 2018 national study, 12% of all change orders are due to quantity changes.
Average percent of change orders due to errors and ommissions	12.0%	According to a 2018 national study, 12% of all change orders are due to errors and omissions.
Average award growth for 2D projects with contract values $5 M - $20 M (in percent)	2.8%	Calculated average award growth from historical data. award growth is defined as the percent difference between received bids and the engineer's estimate between 2012-2016. On average, MDOT's bids came in 7% higher than the engineer's estimate. This is considered a 7% increase in cost of the construction program due to perceived contractor risk (high risk)
Average award growth for 3D projects with contract values $5 M - $20 M (in percent)	-6.1%	Calculated average award growth from historical data. award growth is defined as the percent difference between received bids and the engineer's estimate between 2012-2016. On average, MDOT's bids came in 1% lower than the engineer's estimate. This is considered a 1% savings of construction program due to perceived contractor risk (low risk)
Average cost growth for 2D projects with contract values $5 M - $20 M (in percent)	0.3%	Percent difference between bids and final contract pay out (calculated from projects between 2012-2016). Positive numbers indicate additional cost due to change orders. Negative numbers indicate MDOT paid less than the original bid.
Average cost growth for 3D projects with contract values $5 M - $20 M (in percent)	-2.3%	Percent difference between bids and final contract pay out (calculated from projects between 2012-2016). Positive numbers indicate additional cost due to change orders. Negative numbers indicate MDOT paid less than the original bid.
Average percent of change orders per year	5.0%	Average percent for all change orders from historic data

Figure 21. Table 5 of the "General Inputs" tab shows information related to the cost of change orders.

The historical data analyzed during this study revealed that, on average, MDOT paid 5 percent of the overall construction program for change orders. A national average was used to estimate the percent of change orders due to quantity changes and errors and omissions for the calculations. Researchers were not able to obtain this type of information for the historical data used in the analysis without a significant level of effort on MDOT staff. Researchers were informed that currently MDOT does not have a standard way to document the quality of inspection items based on pay item. While this information may be available, it would be laborious to obtain it as there is no consistent way to report it in the construction management database. MDOT staff would have had to retrieve documentation for each change order for each of the projects from ProjectWise and then speak with each inspector to understand the cause for each change order. Thus, it was decided to estimate the cost based on national averages.

As a result, researchers recommend to institute standard ways to document the source of change orders so MDOT can run reports directly from the construction management system to review the nature of change orders. Having a standardized way to report the categories of change orders would allow the system to produce automated reports. Standardized ways to document change orders offer better project control of quantities and quality of the work. Also, tracking the cause of change orders may help identify areas that would benefit from multi-disciplinary collaborative reviews using the digital data. However, the effort to make these changes would be significant, and may require additional research to determine the best way to improve the documentation of change orders. The following categories are suggestions of standard ways of documenting change orders:

1. Change order due to quantity deviations by pay items (e.g., earthwork, structural items).
2. Change order due to errors and omissions by type.
3. Change order due to unforeseen conditions by type (e.g., unknown location of subsurface utilities).
4. Scope changes.

Table 6. Benfits by Fiscal Year ($)					
	2012	2013	2014	2015	2016
Savings from low bids (due to low bidder using AMG construction)					
	$ -	$ -	$ -	$ -	$ -

Figure 22. Table 6 of the "General Inputs" tab captures any savings due to increased competition and lower bids as a result of contractor using AMG construction equipment.

In many cases, the contractors that fully invest in AMG technology, typically can cut operational costs that allow them to submit a more competitive bid. This information, when available, may be tracked and entered in this table to calculate these types of benefits.

Annual Benefits and Costs

This area of the spreadsheet model reports all the calculations for benefits and costs based on the information entered in the General Inputs tab. The benefits and costs are calculated for each year (2012-2016), which are also summarized for the 5-year period. Figure 23 shows the legend for this tab. The cells shown in yellow indicate a field for the user to enter information. All other tables in the Annual Benefits and Costs tab of the spreadsheet model are shown in Figures 24-26.

Michigan Department of Transportation 3D Highway Design Model Cost Benefit Analysis
This worksheet is used to calculate MDOT's return on investment for the implementation of RID 3D models.
Legend: [yellow] = User Input Fields; [light blue] = Formatting; [white] = Calculated Fields and Notes

Figure 23. Legend for the "Annual Benefits and Costs" tab.

Table 1. Qualitative Benefits	
Lower bidding risk	Confirmed with historical data, on average contractors submit bids closer to the engineer's estimate on projects with 3D data.
Improved quality	Assumes designer is reviewing the model more effectively due to the visualization nature of 3D design.
Reduced change orders	Assumes project development team is using 3D models to conduct constructability reviews to identify errors and omissions, and unforeseen situations due to design

Figure 24. Table 1 of the "Annual Benefits and Costs" tab lists the qualitative benefits.

Table 2. Quantifiable Benefits ($)							
		Year 1	Year 2	Year 3	Year 4	Year 5	
Benefit Streams	**Total**	**2012 ($)**	**2013 ($)**	**2014 ($)**	**2015 ($)**	**2016 ($)**	**Notes and Assumptions**
Estimated change order avoidance (due to quantity changes)	$ 37,482,000	$ 8,100,000	$ 7,050,000	$ 7,836,000	$ 7,122,000	$ 7,374,000	Annual construction program x average percent of MDOT change order value per historical data (all projects) x 12% (percent of change orders for this category). According to a 2018 national study, 12% of all change orders are due to quantity changes.
Estimated change order avoidance (due to errors and omissions)	$ 37,482,000	$ 8,100,000	$ 7,050,000	$ 7,836,000	$ 7,122,000	$ 7,374,000	Annual construction program x average percent of MDOT change order value per historical data (all projects) x 12% (percent of change orders for this category). According to a 2018 national study, 12% of all change orders are due to errors and omissions.
Estimated savings from low bids	$ -	$ -	$ -	$ -	$ -	$ -	Annual savings from low bids due to low bidder using AMG construction methods (calculations from Table 6 in the General Inputs Tab)
Total Benefits	**$ 74,964,000**	**$ 16,200,000**	**$ 14,100,000**	**$ 15,672,000**	**$ 14,244,000**	**$ 14,748,000**	
Cumulative Benefits		**$ 16,200,000**	**$ 30,300,000**	**$ 45,972,000**	**$ 60,216,000**	**$ 74,964,000**	

Figure 25. Table 2 of the "Annual Benefits and Costs" tab lists the calculated values for each benefit stream for each year of the 5-year period.

The methods for calculating each of the benefit streams are shown in Equations 5-7.

$$Benefit\ Stream\ 1 = (Annual\ MDOT\ Construction\ Program)\ x\ (C1\ ) x\ (C2)$$

Equation 5. Estimated change orders due to quantity changes.

$$Benefit\ Stream\ 2 = (Annual\ MDOT\ Construction\ Program)\ x\ (C1\ ) x\ (C3)$$

Equation 6. Estimated changes due to errors and omissions.

$$Benefit\ Stream\ 3 = Annual\ Savings\ Directly\ Entered\ in\ Table\ 6\ of\ the\ General\ Inputs$$

Equation 7. Estimated savings from low bids.

Where

Benefit Stream 1 = Estimated change order due to quantity changes
C1 = Average percent of MDOT change orders from historical data (5 percent)
C2 = Average percent of change orders due to quantity deviations per national study (12 percent)
C3 = Average percent of change orders due to errors and omissions per national study (12 percent)

Table 3. Costs ($)								
		Pre-	Year 1	Year 2	Year 3	Year 4	Year 5	
Cost Category	Total	Implementation	2012 ($)	2013 ($)	2014 ($)	2015 ($)	2016 ($)	Notes and Assumptions
Additional cost to produce 3D models (designer additional level of effort to produce both 3D RID files and contract plans)	$ 56,223,000	$ -	$ 12,150,000	$ 10,575,000	$ 11,754,000	$ 10,683,000	$ 11,061,000	Average cost to produce 3D models in addition to plan sheets (assumes an additional 10% cost of the design contract). Calculated based on general input tab. Formula = annual design contract value (for that year)*0.1 (additional cost for 3D design). It is assumed that this cost would decrease over time based on maturity of the practice and elimination of plan sheet production.
Cost to support 3D design	$ 529,963	$ 99,840	$ 101,837	$ 103,874	$ 105,951	$ 108,070	$ 110,231	Assume average FTE loaded salary x number of FTE for each year of the 5-YR period. Assumes 2% annual raise. May remove per MDOT request. The CADD support group provides support whether they develop 3D models or not, this is considered an overhead cost not associated with 3D models.
Professional services used to implement 3D design	$ -	$ -	$ -	$ -	$ -	$ -	$ -	If hired Bentley or other professional service to help with 3D implementation. This would be a one time cost. Calculated from input tab. Assumes cost took place in year one
Total Costs	**$ 56,752,963**	**$ 99,840**	**$ 12,251,837**	**$ 10,678,874**	**$ 11,859,951**	**$ 10,791,070**	**$ 11,171,231**	
Cumulative Costs		**$ 99,840**	**$ 12,351,677**	**$ 23,030,550**	**$ 34,890,501**	**$ 45,681,571**	**$ 56,852,803**	
Net Benefit	**$ 18,211,037**	**$ -**	**$ 3,948,163**	**$ 3,421,126**	**$ 3,812,049**	**$ 3,452,930**	**$ 3,576,769**	
Cumulative Net Benefit		**N/A**	**$ 3,948,163**	**$ 7,369,290**	**$ 11,181,339**	**$ 14,634,269**	**$ 18,211,037**	
ROI		**N/A**	**31.96%**	**32.00%**	**32.05%**	**32.04%**	**32.03%**	

Figure 26. Table 3 of the "Annual Benefits and Costs" tab summarizes the calculations for all cost categories, net benefits, and ROI.

The method for calculating each of the benefit streams are shown in Equations 8-10.

$$Cost\ Category\ 1 = (Annual\ Cost\ of\ Professional\ Services)\ x\ (D1)$$

Equation 8. Estimated cost to produce 3D models.

$$Cost\ Category\ 2 = (FTE\ Salary)\ x\ (FTE) + Annual\ Salary\ Increase$$

Equation 9. Cost for additional technical staff to support 3D design.

$$Cost\ Category\ 3 = Annual\ Cost\ for\ Software\ Professional\ Services$$

Equation 10. Cost for additional professional services for software configuration.

Where

Benefit Stream 1 = Estimated change order due to quantity changes
D1 = Additional professional services cost to produce 3D models (assumed to be 10 percent of design contract value)
FTE Salary = Average salary for technical support staff
FTE = Number of FTE added to support 3D design (assumed to be 1)

ROI Results

The 5-year ROI calculations for the MDOT implementation of RID 3D models for years 2012-2016 were determined by using Equation 11, and are summarized in Table 21.

$$\mathrm{ROI} = \frac{\text{Total Benefits} - \text{Total Costs}}{Total\ Costs}\ x\ 100$$

Equation 11. ROI calculation.

Table 21. Summary of calculations for the 5-year ROI of MDOT's implementation of RID 3D models.

Value	Output ($)
Average Construction Program ($)	$ 1,249,400,000
Timeframe	5 Years
Cost Over Timeframe ($)	$ 56,752,963
Benefits Over Timeframe ($)	$ 74,964,000
Net Benefits	$ 18,211,037
5-Year ROI (%)	32.03%
Breakeven Year	Year 1

Section 5. Recommendations for Process Improvements

The existing workflow for project design development includes consuming base map data (e.g., surface models, aerial imagery, planimetrics, and other existing condition data) into a CAD environment from which the design is based. The designer uses a suite of applications to incorporate engineering decisions into the CAD environment that builds a digital representation of the project. The design development process is entirely model-centric up to this point given the programs are inherently model-centric to produce plan sheets. At defined milestone intervals (in accordance with design guidance/policy), the design development is reviewed to ensure the project is on-schedule and certain considerations are incorporated as early as possible. Once the project design is completed, the final plan sheets are bound into a bid set from which contractors formulate their bids. The RID includes the model files for informational purposes only.

The findings of the research indicated that there is room for improvement regarding education of current use of 3D models and training that is specific to inspection and verification, multi-disciplinary collaboration, data management, and design deliverables based on authorized uses.

Education, Outreach, and Training

Establishing an educational outreach program is important to reinforce and increase the awareness that 3D modeling is the new standard design method for MDOT projects. This effort would help consultants understand the priorities for developing their staff. Transitioning to model-centric workflows requires designers to be highly proficient in modeling tasks. The following are recommendations based on the research findings:

- Develop a framework around modeling for infrastructure that considers level of effort, required deliverables, and compensation based on a model-centric process rather than the current plan-centric 30/60/90 percent completion. The current process is model-centric in nature with plan sheets being the final output. However, setting the priority to produce a design model rather than creating plan sheets will help consultants plan for adequate training of existing staff, recruitment of new designers with the right skill sets, and a compensation schedule that is more in line with a model-centric process.
- Create a specific training program for construction staff. This new training will help fill the current gap between design and construction. It is important to inform all managers about the skill sets necessary for new inspectors to be able to successfully use the new tools and keep up with the technology contractors are already using. The effort for this program should be consistent with position descriptions to develop skills required for model-based construction engineering and inspection. Furthermore, sustained proficiency can be optimized through regular use of skills and recurring training opportunities that build advanced skills consistent with technology maturity.
- Engage with other project development and asset inventory staff to educate them on the multiple products that can be derived from 3D models already being developed for construction.

Perhaps the first actionable item recommended because of this research is to develop specific training for inspectors on the tools and processes required to perform quality assurance and verification tasks. A framework for developing guidance for training construction staff is shown in Table 22. This framework stresses a diverse set of training mediums that inspectors can leverage for improving their understanding and proficiencies of digital design data.

Table 22. Recommendations for development of core knowledge area topics and training framework.

Core Knowledge Area	Suitable Topics	Training Medium
Policy and procedures Updates to construction specifications and manuals should be made to ensure alignment with the use of digital data (e.g., items to be checked, tolerances, timing).	• Overview of policies and specifications for 3D model-centric activities. • Overview of model-based inspection activities. • Selection of appropriate survey equipment for different activities based on accepted tolerances.	• Live webinar for initial regional training. • Online videos and updated construction guidelines and specifications.
Surveying basic concepts General overview of mapping fundamentals. It may be beneficial to work with local colleges to develop a basic online course.	• Coordinate systems, project scale-factors, and site localization.	• Online video tutorials • Quick reference sheets.
Survey hardware and software skills Instructions for using modern surveying equipment. It may be beneficial to work with equipment vendor or surveying consultants to develop a sustainable training program.	• Overview of survey equipment setup, data collection and analysis techniques. • Equipment use, demonstrations, situational learning, troubleshooting, and train-the trainer opportunities.	• Initial “train-the-trainer” hands-on training. • Equipment and software training manual. • Online video tutorials and on-the-job training.
Digital data software skills Instructions on using various programs on specific hardware, including mobile applications, CADD software, and databases.	• Operation of data collection software and the use of digital to verify location and elevations and measure quantities. • Reviewing and updating CADD data.	• Initial “train-the-trainer” instructor-led and hands-on training. • Online video tutorials and on-the-job training
Data Management Instructions for managing data files, including version control, review and validation of data, and collaboration tools.	• Naming convention, workflows for data management, file types, and acceptable formats.	• Live webinar for initial regional training. • Online videos and updated CADD guidelines and specifications.

As MDOT continues to build its online training resources in the Support Services, it is recommended to add a section on 3D Models for Construction Engineering and Inspection with content related to best practices and appropriate selection of tools for specific applications.

It is also important to include training modules for viewing the construction model using tools available for iPads, given that these mobile devices have been selected as standard equipment provided to inspectors as part of the e-Construction initiative.

Multi-Disciplinary Collaboration

It is also recommended to define a process for implementing multi-disciplinary collaboration. The models being produced by design to-date are only being leveraged by the contractor. The potential to incorporate these models during the project development process is significant given a proper framework is set in place to guide users. Thus, the researchers recommend the following:

- Establish a plan to implement multi-disciplinary collaboration. The plan should include specific activities to occur within a defined timeline. The plan should be supported by an executive champion who has the authority to provide resources for executing the plan, a technical champion who can lead the team in creating the specific steps to accomplish the overall goal, and a representative from each discipline within the organization who will be affected by the plan.
- Develop online training content highlighting an overview of 3D model-based design and BIM so other disciplines can understand market-ready uses, derived products, and current initiatives and software tools being deployed to facilitate the full deployment of this practice.
- Create guidance for properly managing projects in which 3D design is being used for multi-disciplinary collaboration. This guidance should include guidelines such as a decision-matrix for selecting projects most suitable for multi-disciplinary collaboration, purpose and need for the data, roles and responsibilities of team members, data management, level of development, level of visualization, product deliverables and data exchanges, and review of criteria protocols.

One of the common challenges with accelerated schedules on projects using models is the limited ability to conduct sufficient reviews of models throughout design development and for changes during construction. Collaboration among stakeholders is imperative to ensure the review time is optimized and meets quality expectations. While traditional design development uses milestones (e.g., 30 percent, 60 percent, 90 percent, etc.) to initiate reviews and revisions, the transition to a model-centric review schedule should be more iterative and occur at project delivery stages such as environmental assessments, preliminary design, right-of-way acquisition, OEC, hand-over to construction, and hand-over to operations and maintenance. MDOT already has some of these review stages defined, thus closing the gap may not be as large of an effort as starting from scratch.

During design development, model reviewers from relevant disciplines should collaborate early and often to ensure accuracy of construction documents, compliance with standards/policy, and mitigation/awareness of risks associated with adverse impacts to the construction process.

Framework for Contractual 3D Models Requirements

The researchers evaluated current MDOT design submittal requirements, initiatives related to 3D models (i.e., the implementation of 3D models for bridges), and used the input received from consultants and contractors during Phase I to make the recommendations herein.

This section of the recommendations provides general guidance for contract administration of projects with contractual 3D models.

General Requirements

Purpose and Need

A key success factor when delivering contractual 3D models is being able to communicate the purpose and need for each deliverable. For example, if the 3D model is to be used strictly for stringless paving, then the model should include the proposed structural pavement surface to be constructed, including the superelevation design.

It also important to note that MDOT current guidelines in the Design Submittal Requirements already contain useful directions for creating the content of models, using standard naming conventions, and exchanging data for each phase of the project development process. *Thus, the opportunity for improvement is to define authorized uses for models during the project development process and for construction applications.*

Roles and Responsibilities

The next step is to define the roles and responsibilities for each stakeholder. Researchers recommend to define these roles and responsibilities during the scope verification phase, at which time the project delivery team starts defining the model development requirements.

The three key stakeholders in a model-centric project delivery process are the parties who create, use, and manage the model. The model author(s) are responsible for developing one or many elements of a 3D model. The model user is any party consuming information derived from the model directly or indirectly. Lastly, the BIM manager is the single point of contact for all inter-disciplinary and BIM-related issues, and is responsible for managing the collaboration and quality control processes, as well as other duties to ensure successful use of 3D models during project delivery. For example, the BIM manager is the person who would develop a Project Execution Plan (PxP), which is a model information management tool commonly used in the vertical industry to support effective execution of BIM. The PxP may be developed once the project team has been established, but before the design phase starts.

The BIM manager should work with the project delivery team to facilitate multi-disciplinary collaboration to develop the PxP, which will serve as the guide for communicating the purpose and need for the models, documenting the rights and responsibilities of stakeholders, selecting the tools to be used for collaboration and data management, describing the model development specifications, and identifying strategies for managing risk, responding to changes, and resolving any issues or discrepancies.

Model Development Specifications

LOD Specifications

The LOD specifications define the reliability of the information contained in the model in terms of design intent, certified survey accuracies for existing conditions, and allowable authorized uses. While MDOT guidelines already define the required Design Submittal Requirements for each milestone (preliminary, OEC, RID), specific LOD specifications have not yet been developed. It is recommended to consider creating LOD specifications to support specific authorized uses. Thus, defining the authorized uses may be the first exercise for MDOT to complete. Examples of authorized users include:

- Public outreach visualization.
- Estimation of quantities.
- Survey layout.
- AMG for grading and/or paving.
- Constructability reviews and clash detection.
- Construction engineering and inspection (CE&I).
- Visual inspections.
- Construction risk management (4D/5D)

While there are no LOD specifications specific for roadway models, a recent FHWA study (Maier, et al. 2017), suggests that defining LOD in terms of Model Density (MD) and Confidence Level (CL) may be more appropriate for roadway models. MD defines the resolution of model elements while CL sets a qualitative characteristic to define the accuracy of the base survey model similarly as that used for subsurface utility information. Figure 27 illustrates the relationship between MD, CL, and the use of design data models, and Table 23 summarizes the MD definitions.

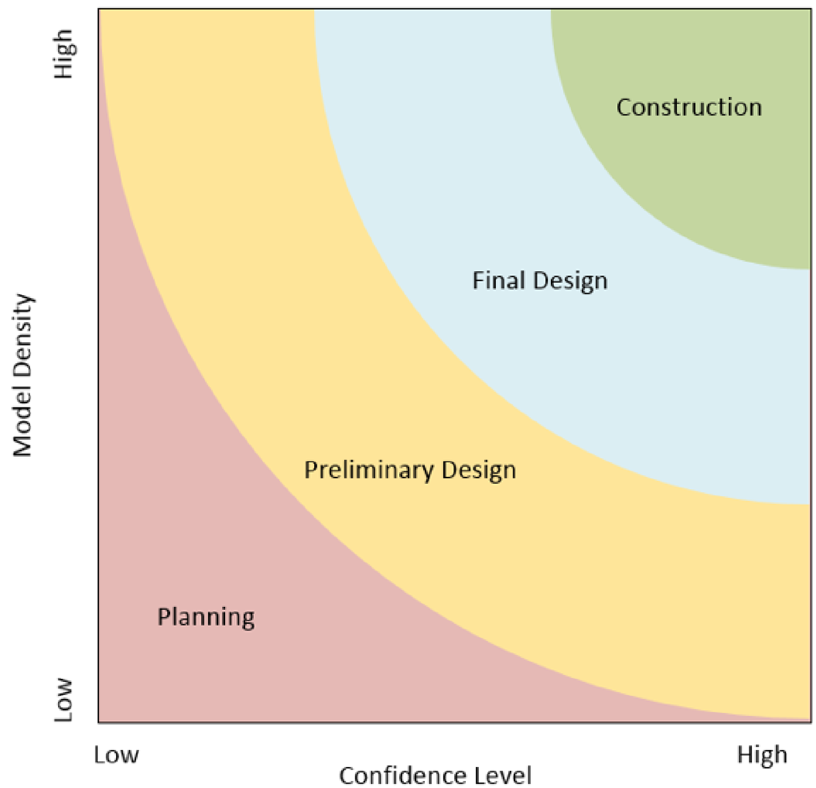


Figure 27. Relationship between MD, CL, and 3D data use. (Maier, et al. 2017)

Table 23. Definition of model density bands. (Maier, et al. 2017)

Model Density	Definition
MD-1	Data points are located at regular stations and key geometry points. Transitions such as lane widenings, gore areas, and intersections are incorporated into the 2D data only.
MD-2	Data points are located at regular stations and key geometry points. Transitions such as lane widenings, gore areas, and intersections are incorporated into the 3D data. Typical data densities are: • 25-foot point interval in tangents. • 10-foot point interval in curves. • 5-foot point interval in transitions.
MD-3	Mid-ordinate distances are small enough to support staking with GNSS or RTS. Typical data densities are: • 10-foot point interval in tangents. • 2-foot point interval in curves. • 2-foot point interval in transitions.
MD-4	Mid-ordinate distances small enough to minimize risk of material overruns. Typical data densities are: • 5-foot point interval in tangents. • 1-foot point interval in curves. • 1-foot point interval in transitions.
MD-5	Mid-ordinate distances are small enough to measure quantities within the measurement precision. Typical data densities are: • 25-foot point interval for straight or regular features. • 10-foot point interval in irregular terrain (such as borrow pits). • 5-foot point interval in curves. • Points at horizontal deflections and/or grade breaks.

However, model density alone may not be sufficient to describe what it is needed to support specific authorized uses. Other characteristics to consider when defining LOD should include the source of survey data and whether a 3D survey is desired to integrate existing conditions and proposed design model in 3D. In addition, specific components to be modeled should be defined in the LOD specifications. For example, if the authorized use of the model is for clash detection, each element to be modeled in 3D should be clearly stated.

Researchers have outlined recommendations for MDOT to consider when developing LOD guidelines or requirements. These recommendations have been outlined in Table 24 and Table 25. Thus, creating guidelines for LOD and design deliverables is better defined using MD and CL references based on the authorized uses as outlined in Table 24 and Table 25.

Table 24. LOD recommendations for roadway models.[1]

No.	Authorized Uses	Model Element Requirements
1	• Survey layout • Geometry for GIS databases	2D/3D line work representing centerline, right-of-way lines, and grade break lines modeled at MD-2.
2	• Quantity estimation • AMG for grading • Contract plan development • Construction staging • CE&I • Visualization • Traffic control simulations	Geometrically and geospatially accurate 3D elements depicted in the roadway typical section, including: existing ground, proposed pavement design, clear zone, and side slope conditions (e.g., traveled way, shoulders, and side slopes) that are modeled at MD-2. May include feature attributes such as pay items.
3	• Quantity estimation • AMG for grading and paving • Contract plan development • Construction staging • CE&I • Visualization • Traffic control simulations	Geometrically and geospatially accurate 3D elements depicted in the roadway typical section, including: existing ground, proposed pavement design, clear zone, and side slope conditions (e.g., traveled way, shoulders, and side slopes) that are modeled at MD-3 or higher. May include feature attributes such as pay items.

[1] Confidence levels should also be considered as part of LOD requirements.

Table 25. Recommendations for 3D models deliverables based on purpose and need.

Purpose and Need of 3D Model	Final Deliverable	File Format
AMG – Grading	• Triangulated irregular network (TIN) model of the surface depicting either the proposed finished grade or subgrade (top of dirt) for the roadway traveled way and side slope conditions. • 2D line work showing all lane lines or grade breaks. • Survey control files.	DGN, TIN, and/or LandXML
AMG – Paving	• Alignments and survey control files. • 3D line strings for all lane lines or grade breaks.	DGN and/or LandXML
Constructability Reviews	• Bentley PowerGEOPAK or OpenRoads Designer (ORD) design models.	DGN
Public Outreach Visualization	• Still images and videos.	TIFF and MP4
Survey Layout	• Alignments, profiles, 3D line strings, and survey control files.	DGN and/or LandXML
Quantity Take-offs	• Alignments, surfaces, and 2D/3D line work. • PowerGEOPAK or ORD model.	DGN, TIN, and/or LandXML
Risk Construction Management	• 4D model showing sequence of construction work based on the work breakdown structure (WBS) and activities used for critical path method (CPM) progress schedules as still images and/or videos.	3D DGN, TIFF, and MP4

LOV Guidelines

Stakeholder expectations for visualization products are typically high and often defined very loosely, which creates great uncertainty for those developing the based-model and the visualization products. Therefore, it is important to specify what level of visualization is expected for different applications. The more photo-realistic and content added to the visualization, the higher the cost. The software used for 3D design has many standard tools available to the designer to do basic visualization, such as visual textures based on 3D template components and showing striping. However, to create visualization outputs, the software requires an additional level of effort to set lighting, placing cameras in the view, and rendering images. This sophisticated level of visualization is usually reserved for public outreach and communication of high profile projects. Researchers recommend aligning the LOV requirements with those recently recommended for bridges, as described in Table 26. (Brenner, et al. 2018)

Table 26. LOV guidelines.

Visual Quality	Visualization Elements	Target Audience
Photorealistic	• 3D elements are textured with materials. • Perspective view style. • Defined camera locations. • Defined lighting (locations, colors, intensities). • Rendering required to produce images and videos.	• General public.
Representative	• 3D elements are colored in solid colors. • Perspective or orthometric view style. • Defined camera locations, lighting, and rendering optional (can be use shaded view styles and screen gabs to create images).	• General public. • Non-technical stakeholders. • Technical stakeholders.
Illustrative	• 3D elements may be any color. • No cameras, lighting, or rendering needed. • Can use shaded or wireframe view styles. • Can create images with screen grabs.	• Technical stakeholders. • Project team.

An example of a photorealistic visual quality model is shown in Figure 28. A representative visual quality model does not have sophisticated renderings and textures. An example of an illustrative visual quality model is shown in Figure 29.

Figure 28. Example of photorealistic visualization quality.

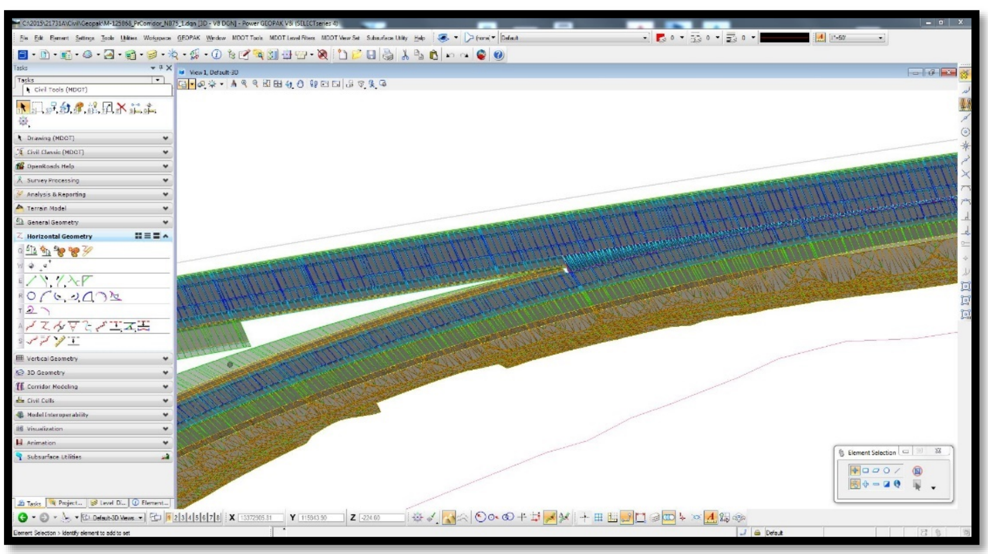


Figure 29. Example of illustrative visualization quality.

Model Documentation

Currently, MDOT uses a RID Review Checklist that lists the project manager and the model reviewers and other project information. The RID Review Checklist is also used to document the quality assurance performed on the design files for each stage of the project development phases (i.e., preliminary design, OEC, and RID). Researchers recommend to use this document as the basis for developing a standard Model Progression Specification (MPS) or Model Inventory to keep track of model elements and their certified LOD. A MPS should be part of the PxP. The Model Inventory is like the “read me” file to communicate what information is contained in the model, such as information about elements modeled, LOD and LOV specifications for each modeled element, authorized uses, name of responsible party for developing the model, certified survey quality and project combined scale factor, and any comments or notes helpful for the MPS/Model Inventory responsible party. The only difference between a MPS and a Model Inventory is that the Model Inventory is a snapshot in time for the model while the MPS documents the LOD by milestone and it is in line with the agreed upon data exchanges specified in the PxP.

An example of a model inventory for roadways is illustrated in Figure 30.

Category	Element	Sub-Element	Included?	LOD	LOV	Resp. Party	File Name	File Type	Primary Use	Secondary Uses	Notes
Proposed	Roadways	Alignments									
		Profiles									
		Proposed Finished Grade Surface									
		Alternate Surfaces									
		2D Line Work									
		3D Line Work									
	Drainage	Pipes/Culverts									
		Drop Inlets									
	Utilities	Storm Sewer									
		Sanitary Sewer									
		Water									
		Power/Electrical									
		Telephone									
		Fiber									
		Gas									
	Appurtenances	Sign Structures									
		Lighting									
		Signals									
		Conduits									
	Earthwork	Embankment									
		Excavation									
		Borrow/Waste									
	Structures	Bridges									
		Retaining Walls									
		Noise Walls									
Staging	Earthwork	Embankment									
		Excavation									
	Terrain	Terrain									
	Traffic Control										
Existing	Reference points and lines	Referrenc Points and Lines									
	Roadways	Roadways									
	Terrain	Terrain									
	Drainage	Pipes/Culverts									
		Drop Inlets									
	Utilities	Storm Sewer									
		Sanitary Sewer									
		Water									
		Power/Electrical									
		Telephone									
		Fiber									
		Gas									
	Structures	Bridges									
		Retaining/Noise Walls									
	Context	Roadways									
		Buildings									
		Landmarks									

Figure 30. Sample model inventory for roadway models.

Data Management Guidelines

MDOT has extensive published guidelines to manage data related to 3D models for each phase of the project development process. However, *the opportunity for improvement in this area is to add guidelines for managing the data post-award*. Because the current data management guidelines are specific for the RID workflow, they lack the needed instructions for contractors and construction staff to manage the construction models post-award. This was an area of improvement noted during the interviews with construction staff and contractors. ProjectWise, the common data environment (CDE) currently used by MDOT to manage files, seems to be acceptable to contractors and construction staff for submitting, accessing, and managing data files.

Model Changes During Field Operations

Currently, there is no guidance for documenting model changes that occur during field operations. However, once models become contractual, it is imperative that a protocol for documenting changes and managing versions of the files is defined, as well as the responsible party to make the adjustments to the model and schedule expectations. Unless the designer of record continues to support model changes during construction, it is important to define which changes constitute the necessity for a professional engineer to certify the model versus which changes may be certified by a non-licensed professional.

Deliverables submitted through ProjectWise should have a folder structure for the most current models, including a corresponding list of changes from version to version. Having a “historical” folder is often used to keep a complete model history of the changes pertaining to the project. Furthermore, a model inventory for post-award changes should be kept up-to-date with changes, including the reason for the changes, when the changes occurred, who updated and certified the model, and for what the model was used. This is important for resolving any discrepancies between layout, placement, and inspection.

Field staff using the 3D models can quickly verify that the work being done meets the anticipated proposed changes immediately from the field.

As-Built Model Development

During project close-out, the responsible party for recording the as-built conditions should be equipped with the necessary tools for which they have sufficient proficiency to collect the data. Additionally, the data dictionary for each model element being recorded should be established ahead of time in coordination with the asset inventory staff. Once data is collected, the data should be validated against the requirements and specifications to ensure data quality. Once the data has been validated, it can be accepted and stored in the appropriate enterprise data location.

Geographic Information Systems are commonly used to manage asset inventory, thus coordination between design, construction, and asset management is critical to ensure the proper data dictionaries are being used throughout the model development. Several GIS collection tools, such as Collector for ArcGIS, Survey 123 (also an ESRI product), and Feature Manipulation Engine (FME), can be customized to help those responsible for collecting as-built records with standard forms that easily integrate the data with the enterprise GIS database.

Special Provision for 3D Models

Researchers recommend that the department use a project special provision to indicate the use of 3D models as contractual or non-contractual elements. The sample special provision provided herein should be reviewed by MDOT’s legal team, as the researchers are not qualified to provide legal advice. The researchers recommend the following contract language for consideration:

Consultant Requirements

The Michigan Department of Transportation plans to use 3D engineered models for design authoring and development of contract plans, contractor use of automated machine guidance (AMG) for grading and paving, and construction inspection and verification. Contract Plans for Highway Construction shall *continue to be produced electronically in accordance with the Department requirements. The consultant shall work closely with the Department to develop a Project Execution Plan (PxP) to define authorized uses of specific engineering data; roles and responsibilities for different tasks; specifications for survey accuracies to meet model development requirements and authorized uses; protocols for data management, validation, and information exchanges; requirements for collaboration tools; and strategies for managing risks.*

Contractor Requirements

The Michigan Department of Transportation plans to use 3D engineered models for design authoring and development of contract plans, contractor use of automated machine guidance (AMG) for grading and paving, and construction inspection and verification. The Department shall authorize the engineering digital data files distributed with the contract plans as specified in the Contract Model Inventory.

The contractor shall comply with the Department Construction Specifications and contract requirements. The governing ranking in case of any discrepancies between the engineering digital data and the contract plans is:

1. *All proposal material except those listed in subsections 104.06.B through 104.06.F.*
2. *Special provisions.*
3. *Supplemental specifications.*
4. *Model.*
5. *Project plan and drawings.*
6. *Standard plans.*
7. *Standard Specifications.*

Upon contract award, the contractor shall participate in a pre-construction meeting with Department staff and consultants to develop a Project Execution Plan (PxP) to define roles and responsibilities, as well as protocols for validating and documenting any field changes to the models and manage data files.

Design-Builder Requirements

The Michigan Department of Transportation plans to use 3D engineered models for design authoring and development of contract plans, multi-disciplinary collaboration, contractor use of automated machine guidance (AMG) for grading and paving, and construction inspection and verification. The design-builder shall perform all tasks necessary to prepare and maintain 3D engineered models and animations, and 4D schedule simulations in accordance with contract requirements.

Recommendations for Establishing Lean Processes for Contract Deliverables

As more emphasis is placed on the development of the model rather than the plan sheets, it is expected the project delivery process will become more streamlined and, therefore, more efficient. While the efficiencies will not result in faster delivery times, the more streamlined model-centric design will allow design staff to produce better quality plans within the already demanding schedules. The five principles (Lean Enterprise Institute. 2000-2018) for lean processes, as illustrated in Figure 31, should be leveraged to improve project delivery of roadway projects.

Figure 31. The five principles of a lean process.

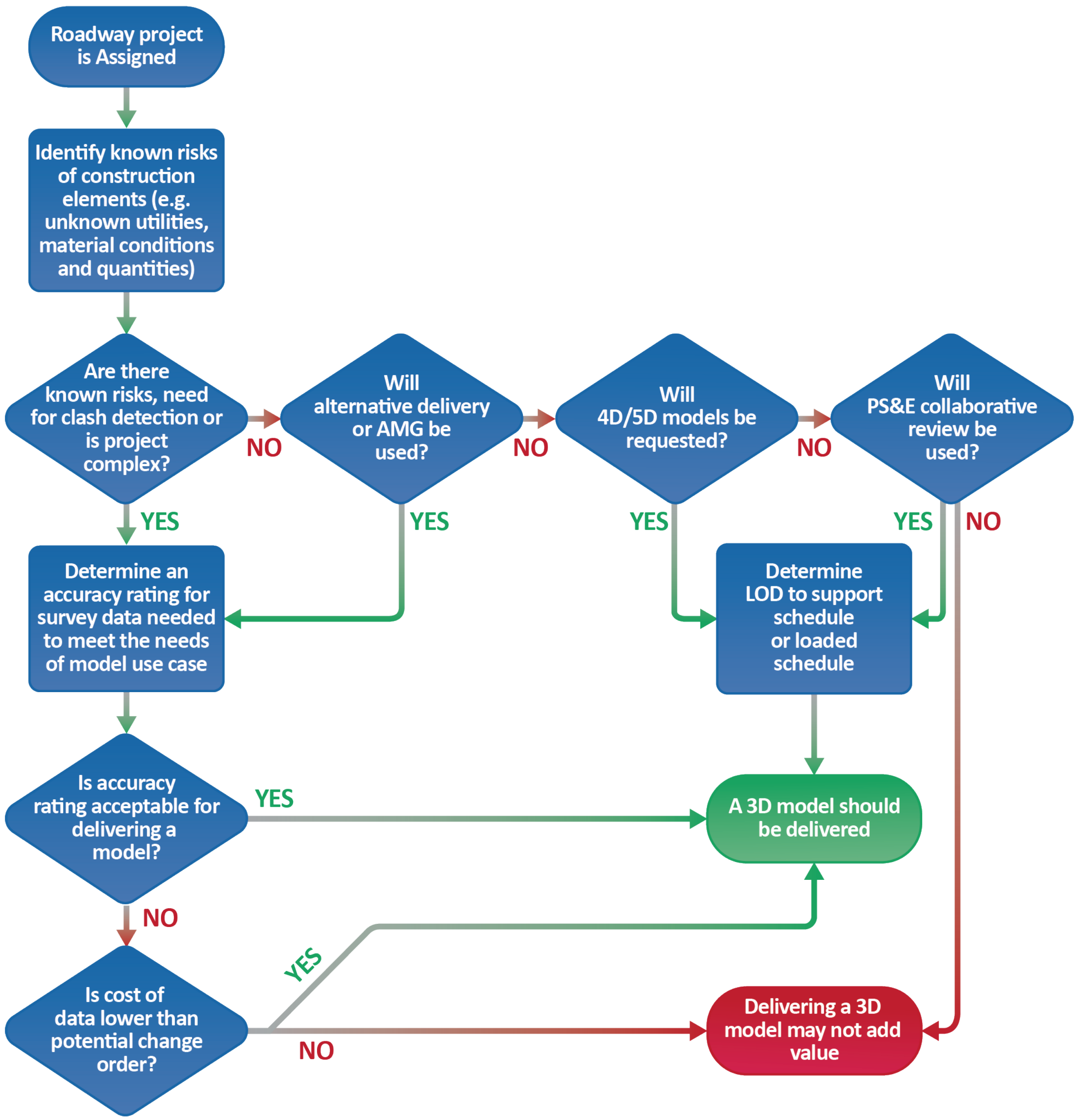
The first step is to identify the value of the model being developed from the downstream stakeholder perspective. The authorized use should be used to determine the downstream stakeholder. Next, it is critical to map the processes for each area of the project delivery to identify how information is exchanged between the various disciplines. Try to identify steps that currently require paper documentation that could be eliminated with direct digital data exchanges. Then, create workflows that optimize the model-centric software to create a sequence of steps that flow smoothly between data exchanges. This will require a multi-disciplinary team that works together to achieve a common goal. In addition, it may be beneficial to work with Bentley to identify areas in which the software can automate and reduce unnecessary steps currently being performed. Once the new workflows have been implemented, work with other disciplines to continue to find ways to optimize the use of digital data throughout project delivery, and ultimately for asset inventory.

For example, for models authorized to be used for survey layout and AMG grading and paving, the only files currently used by the contractor are listed in Table 27. What is the value of all other files currently being required? However, if clash detection is the authorized use, then the files necessary to conduct a clash detection review should be provided.

Table 27. RID files being currently used by Michigan contractors.

Alignment and Modeling Files	Design and Survey Files
A-XXXXXX_LandXML_Geometry.xml	D-XXXXXX_Const.dgn
M-XXXXXX_PrCorridor.dgn	D-XXXXXX_Drain.dgn
M-XXXXXX_PrLineString_Surf.dgn	D-XXXXXX_Topo.dgn
M-XXXXXX_PrLineString_SubSurf.dgn	U-XXXXXX_Utility.dgn
M-XXXXXX_PrTriangle.dgn	U-XXXXXX_Sanitary.dgn
M-XXXXXX_LandXML_PrSurf.xml	U-XXXXXX_Water.dgn
M-XXXXXX_LandXML_PrSubSurf.xml	S-XXXXXX_ControlPts.txt
M-XXXXXX_LandXML_PrTriangle.xml	S-XXXXXX_Survey_Info_Sheet.doc
	S-XXXXXX_ExTriangle.xml
	S-XXXXXX_Survey_3D.dgn

Decision Making Flowchart for Establishing Contractual Requirements for 3D Models.



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Appendix A: Contractor Surveys Summary

MDOT Request for Input: RID 3D Models.

This survey is being distributed by WSP, a consulting firm hired by the Michigan Department of Transportation to conduct a study to gather information that can be used in making future changes to the policies, specification and requirements for 3D models and Reference Information Documents (RID). We appreciate your participation. To keep responses anonymous, please send your completed surveys using one of the following methods:

BY MAIL:
Alexa Mitchell
(Confidential Information)
350 W. Washington St
Suite 300
Tempe, AZ 85281

BY FTP UPLOAD:
Scan completed survey and upload to:
WSP ftp website using the public upload option.
The system will ask for email recipient, please enter: Alexa.Mitchell@wsp.com

Study Objectives

1. Collect information to quantify the understanding of the usage, benefits and savings to calculate the return on investment (ROI) that has resulted from Reference Information Documents (RID) with and/or without 3D models to inform future decision making with policies and uses of digital deliverables as well as justifying the past level of investment.

2. Use input provided by the industry to make improvements to current processes, maximize usefulness of digital data, streamline workflows, and advance digital project delivery to construction.

Background

MDOT has been supplying electronic information to construction for several years as information only.

MDOT is now engaging industry through the Digital Design Working Group (DDWG) and through this study as they prepare to provide digital data as part of the contract. Additionally, MDOT has already identified multiple projects as PILOTS that will utilize the results of this study. Your input is extremely valuable in achieving the goals of the study.

Please return survey no later than October 27, 2017.

Beginning of Survey

1. What size would you consider your organization?

ANSWER CHOICES	RESPONSES
Small size contractor	0
Medium size contractor	4
Large size contractor	5

2. How do you use the current MDOT RID with 3D models? (select all that apply)

ANSWER CHOICES	RESPONSES
a. Nothing from the RID 3D model is used	1
b. RID 3D model files are referenced to identify inconsistencies between the design and the plans	6
c. RID 3D model files are referenced to validate our own independently created models	4
d. RID 3D model files are directly used to prepare AMG files	3
e. Other	3

3. How often do the contract plans match the RID documents? (select one option)

ANSWER CHOICES	RESPONSES
a. Always	0
b. Most of the time	4
c. Some of the time	4
d. Almost never	0
e. Never	0

4. On average, how has the number of design related construction issues changed since MDOT started the 3D model RID process? Note: Do not include projects with special circumstances. (select one option)

ANSWER CHOICES	RESPONSES
a. Have not noticed any change at all	2
b. We have noticed significantly more issues	0
c. There are less issues identified in construction	3
d. Significantly less issues in construction	1
e. Other	2

For questions 5-9, please help us understand how beneficial are the current RID 3D model files MDOT provides suggestions

5. How beneficial are 3D line strings? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	1
b. Beneficial	5
c. Essential	3

6. How beneficial are the LandXML files of alignments and profiles? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	1
b. Beneficial	2
c. Essential	5

7. How beneficial are the LandXML files of digital terrain models (surfaces)? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	1
b. Beneficial	1
c. Essential	6

8. How beneficial are the Microstation files? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	3
b. Beneficial	3
c. Essential	2

For questions 9-12, please help us understand the importance of 3D model files if they were contractual.

9. How beneficial are 3D line strings? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	0
b. Beneficial	1
c. Essential	8

10. How beneficial are the LandXML files of alignments and profiles? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	0
b. Beneficial	1
c. Essential	7

11. How beneficial are the LandXML files of digital terrain models? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	1
b. Beneficial	0
c. Essential	7

12. How beneficial are the Microstation files? (select one option)

ANSWER CHOICES	RESPONSES
a. Unnecessary	3
b. Beneficial	2
c. Essential	3

13. How would you document model requirement revisions (RID or contractual)? (select one option)

ANSWER CHOICES	RESPONSES
a. No documentation needed because models would not be updated	0
b. Document only changes previously defined in the contract or specifications as major or significant	1
c. Document changes to the models as they take place	7
d. Other	0

14. What plan-sheets could be eliminated if 3D models were made contractual instead of RID? (multiple choices) (select all that apply)

ANSWER CHOICES	RESPONSES
a. Typicals	1
b. Special Details	0
c. Horizontal alignment sheets could be simplified/eliminated	8
d. Plan View Construction Sheets	2
e. Profile Sheets	2
f. Other(s):	2

15. How do you use the RID 3D models? (select all that apply)

ANSWER CHOICES	RESPONSES
a. Do not use the RID 3D models at all	2
b. Use the RID 3D model pre-bid for estimating purposes	7
c. Use the RID 3D model post-bid to create a new model for AMG construction	7
d. Use the RID 3D model pre-bid and/or post-award for visualizing schedules	3
e. Use the RID 3D model post-award for safety reviews	2
f. Use the RID 3D model post-award for determining storage locations	4
g. Use the RID 3D model post-award to determine earthwork quantities	7
h. Other	0

16. What software packages do you use for preparing AMG field ready files? (select all that apply)

ANSWER CHOICES	RESPONSES
a. Microstation/Geopak	1
b. AutoCAD/Civil 3D	3
c. Trimble Business Center	7
d. Topcon Magnet	1
e. Agtek	2
f. Leica	1
g. Not sure, I subcontract this task	0
h. Other: Carlson	3

17. For what activities, do you use 3D models and AMG? (select all that apply)

ANSWER CHOICES	RESPONSES
a. None	0
b. For Grading	8
c. For Trimming	6
d. For Paving	4
e. Other	0

18. What information should be included for an AMG model? (select all that apply)

ANSWER CHOICES	RESPONSES
a. Finished surface from edge of paved shoulder to edge of paved shoulder	4
b. Finished surface for entire surface including side slope conditions (earthwork)	5
c. Finished surface and all layers of materials below from EOS to EOS (no side slopes)	3
d. Finished surface and all layers of materials below including side slopes	4
e. Finished surface, all layers below, all earthworks, and all additional improvements including storm sewer, etc.	6

19. What feedback do you receive from MDOT on the models you submit for AMG use? (select on option)

ANSWER CHOICES	RESPONSES
a. None/We don’t use models or AMG	1
b. We do not request feedback	2
c. We use designer’s RID files	0
d. Very Limited	2
e. Moderate comments	1
f. Thorough review and comments	0

20. What equipment or tools do you use to support 3D models and AMG? (Select all that apply)

ANSWER CHOICES	RESPONSES
a. None (we do not use 3D models/AMG)	0
b. We rely on subcontractors as our service providers for this task	1
c. Computers with spreadsheet capacity only	3
d. CADD/Design Software (Microstation/AutoCAD/Civil3D)	7
e. Surveying Equipment	6
f. Other	0

21. What is a typical cost in terms of percent of overall contract value for the review/validation/creation of a 3D model used for AMG? (Select one option)

ANSWER CHOICES	RESPONSES
a. 0%. We don't use 3D models or AMG	0
b. 0-0.5%	1
c. 0.5% - 1%	5
d. 1% - 3%	2
e. More than 3%	0

22. How do grade-checkers on site perform QC on AMG projects? (select all that apply).

ANSWER CHOICES	RESPONSES
a. We rely strictly on subcontractors for this task	0
b. We have a combination of in-house staff with surveying equipment and subcontractors	3
c. We use laser levels	4
d. We use GPS	8
e. We use total stations	6
f. Other	0

23. What model information do you require the designer of record to deliver on Design Build projects? (select all that apply)

ANSWER CHOICES	RESPONSES
a. Have not worked on a design-build project	1
b. Surfaces (LandXML files, etc.)	7
c. 3D line strings	7
d. COGO (points, alignments and profiles)	4
e. Surfaces, 3D line strings and/or COGO	5
f. Other	0

Appendix B: Design Firm Surveys Summary

MDOT Request for Input: RID and Digital Plan Development Process

1. What size would you consider your organization?

Answered: 17 Skipped: 0

ANSWER CHOICES	RESPONSES
Small size consultant	35.29% (6)
Medium size consultant	41.18% (7)
Large size consultant	23.53% (4)
Total Respondents: 17	

2. How familiar are you with MDOT's RID documents?

Answered: 17 Skipped: 0

ANSWER CHOICES	RESPONSES
No experience	0.00% (0)
Heard of it, but no project experience	11.76% (2)
Performed 1-2 projects	29.41% (5)
Multiple projects/extensive experience	58.82% (10)
Total Respondents: 17	

3. What model information do you deliver on Design Build projects? (Select all that apply)

Answered: 17 Skipped: 0

ANWSER CHOICES	RESPONSES
Have not worked on a design-build project	41.18% (7)
Surfaces	29.41% (5)
3D line strings	35.29% (6)
COGO (points, alignments and profiles)	41.18% (7)
Surfaces, 3D line strings and/or COGO	47.06% (8)
Other (please specify)	17.65% (3)
Total Respondents: 17	

#	OTHER (PLEASE SPECIFY)	DATE
1	Geotechnical information	11/14/2017 4:50 PM
2	MDOT design surveys require that the 3D drawing basically be dumbed down and segregated into each of the above. This alone is a huge redundancy.	11/10/2017 3:06 PM
3	None at this time	11/10/2017 10:11 AM

4. On design-build projects, what file formats are delivered? (select all that apply)
Answered: 16 Skipped: 1

ANWSER CHOICES	RESPONSES
MicroStation (DGN) and/or GEOPAK	87.50% (14)
Bentley i-model	6.25% (1)
LandXML	56.25% (9)
Other (please specify)	25.00% (4)
Total Respondents: 16	

#	OTHER (PLEASE SPECIFY)	DATE
1	Have not worked on design-build	11/15/2017 4:01 PM
2	Geotechnical information	11/14/2017 4:50 PM
3	DWG	11/13/2017 10:51 AM
4	Civil3DE .dwg is the industry's norm	11/10/2017 3:06 PM

5. What is the percent of designers in your firm with 3D modeling expert level skills?
Answered: 17 Skipped: 0

ANWSER CHOICES	RESPONSES
Less than 10%	58.82% (10)
Between 10% and 25%	29.41% (5)
Between 25% and 50%	0.00% (0)
Over 50%	11.76% (2)
Total Respondents: 17	

6. What skill level designer typically develops your 3D models?
Answered: 17 Skipped: 0

ANWSER CHOICES	RESPONSES
Entry level designers (less than 1 year)	5.88% (1)
Intermediate designers (less than 5 years)	35.29% (6)
Senior designers (more than 5 years)	58.82% (10)
Total Respondents: 17	

7. What are your perceived concerns regarding submitting/referencing RID? (select all that apply)

Answered: 16 Skipped: 1

ANWSER CHOICES	RESPONSES
Parallel and duplicate effort takes more time to finish the contract plans	43.75% (7)
Accelerated timelines do not allow thorough review	43.75% (7)
Milestones are based on plan production, not 3D design	50.00% (8)
Not properly defining the authorized uses for specific elements of the 3D model	25.00% (4)
Do not have enough information to form an opinion	43.75% (7)
Other (please specify)	25.00% (4)
Total Respondents: 16	

#	OTHER (PLEASE SPECIFY)	DATE
1	Recently on a few occasions, we have been asked by MDOT to review contractor's models to compart the to the RID. We do not get paid to do that. We have done it as a favor so far, but if it will continues to happen, it needs to be planned	11/15/2017 4:01 PM
2	No comments, feedback or review from MDOT on 3D models turned in with milestone RID documents. If you want models to be accepted as contractual you should also perform reviews on the model files.	11/11/2017 8:43 AM
3	Shouldn't we focus our energy on developing good proposed surface models that contractor surveyors can stake and not get bogged down in all the various underground layers, pipes, underdrain, etc.	11/10/2017 10:53 AM
4	No concerns	11/10/2017 9:32 AM

8. What items in the RID take the longest amount of time to develop?
Answered: 16 Skipped: 1

ANWSER CHOICES	RESPONSES
Proposed finished grade surface	18.75% (3)
Alternate surfaces (e.g. subgrade)	12.50% (2)
3D line strings	6.25% (1)
Drainage networks and structures	31.25% (5)
Utilities	6.25% (1)
Cross Sections	6.25% (1)
Other (please specify)	18.75% (3)
Total Respondents: 16	

#	OTHER (PLEASE SPECIFY)	DATE
1	Unique areas where roadway geometry is not simple	11/15/2017 4:01 PM
2	Not sure	11/14/2017 4:50 PM
3	Most items are developed along the way. The time is just to organizing and cleaning them up to be presented.	11/10/2017 9:32 AM

9. How have you used or would you use 3D models you design? (select all that apply)
Answered: 17 Skipped: 0

ANWSER CHOICES	RESPONSES
To review my own design and identify errors	58.82% (10)
To collaborate with the project development team	41.18% (7)
To perform constructability reviews with MDOT construction staff	29.41% (5)
Other (please specify)	23.53% (4)
Total Respondents: 17	

#	OTHER (PLEASE SPECIFY)	DATE
1	Pull earthwork & subbase quantities. Evaluate right-of-way impacts. Establish slope stake line	11/15/2017 4:01 PM
2	Not sure	11/14/2017 4:50 PM
3	Earthwork quantities and ditching/grading.	11/11/2017 8:43 AM
4	Construction layout	11/10/2017 3:06 PM

10. How have you used or would you use a 3D model to calculate plan quantities? (select all that apply)

Answered: 17 Skipped: 0

ANSWER CHOICES	RESPONSES
I do not use 3D models for quantities	17.65% (3)
To calculate volume pay item types	76.47% (13)
To calculate square area pay item types	17.65% (3)
To calculate linear pay item types	17.65% (3)
Other (please specify)	5.88% (1)
Total Respondents: 17	

#	OTHER (PLEASE SPECIFY)	DATE
1	Not sure	11/14/2017 4:50 PM

11. How do you use the 3D model to collaborate with the project delivery team during the design process? (select all that apply)

Answered: 15 Skipped: 2

ANSWER CHOICES	RESPONSES
Drainage Design	60.00% (9)
Quantity Calculations	33.33% (5)
Detail Grade Development	66.67% (10)
Under Clearance	60.00% (9)
Other (please specify)	20.00% (3)
Total Respondents: 15	

#	OTHER (PLEASE SPECIFY)	DATE
1	Do not use for collaboration	11/15/2017 4:22 PM
2	Not sure	11/14/2017 4:50 PM
3	Not using any 3D models at this time so I cannot answer	11/10/2017 10:11 AM

12. What tools do you use for collaborating with the project delivery team? (select all that apply)

Answered: 16 Skipped: 1

ANSWER CHOICES	RESPONSES
Do not use any collaboration tools	31.25% (5)
Bluebeam to review PDFs	50.00% (8)
OpenRoads Navigator to review models	12.50% (2)
WebEx or Skype to review models and/or PDFs	50.00% (8)
Other (please specify)	6.25% (1)
Total Respondents: 16	

#	OTHER (PLEASE SPECIFY)	DATE
1	Bluebeam not by choice. It is expensive and unnecessary	11/21/2017 9:34 AM

13. Once construction has started, how often do you receive requests for information from the field?
Answered: 17 Skipped: 0

ANSWER CHOICES	RESPONSES
Never	11.76% (2)
Very seldom	35.29 (6)
Sometimes	41.18% (7)
Often	11.76% (2)
Total Respondents: 17	

14. What is the most common RFI received?
Answered: 17 Skipped: 0

ANSWER CHOICES	RESPONSES
Detail Grades	70.59% (12)
Superelevation	0.00% (0)
Earthwork	23.53% (4)
Other (please specify)	5.88% (1)
Total Respondents: 17	

#	OTHER (PLEASE SPECIFY)	DATE
1	Utility related items	11/10/2017 9:19 AM

15. What is your process for QA or independent review of the 3D model before during the design phase?
Answered: 16 Skipped: 1

ANSWER CHOICES	RESPONSES
There is no QA review before advertisement	25.00% (4)
Peer design review	62.50% (10)
MDOT constructability review	12.50% (2)
Total Respondents: 16	

16. Which of the following elements would you authorize as a contractual item assuming level of development is established? (select all that apply)
Answered: 16 Skipped: 1

ANSWER CHOICES	RESPONSES
Alignments and profiles	87.50% (14)
Proposed finish grade surface	50.00% (8)
Proposed 3D line string features	43.75% (7)
Total Respondents: 16	

17. Which of the following elements would you authorize as a contractual item without establishing the expected level of development? (select all that apply)

Answered: 10 Skipped: 7

ANSWER CHOICES	RESPONSES
Alignments and profiles	100.00% (10)
Proposed finish grade surface	20.00% (2)
Proposed 3D line string features	40.00% (4)
Total Respondents: 10	

18. What is the typical cost in terms of percent of design contract/preliminary engineering to produce 3D models and RID?

Answered: 16 Skipped: 1

ANSWER CHOICES	RESPONSES
0%, we have not noticed any changes.	0.00% (0)
Less than 3%	6.25% (1)
Less than 5%	18.75% (3)
Less than 10%	43.75% (7)
Other (please specify)	31.25% (5)
Total Respondents: 16	

#	OTHER (PLEASE SPECIFY)	DATE
1	20%	11/21/2017 9:34 AM
2	~10%	11/15/2017 4:22 PM
3	I started working around the time 3D models/RID were being pushed. I've noticed there is usually not enough budget to get the model to the level of completeness MDOT would like. For that reason, I think the difference in effort required is more than people expect. I can't put a percentage on it since I didn't work before we had to develop RID files	11/15/2017 4:01 PM
4	Not sure	11/14/2017 4:50 PM
5	Not sure	11/10/2017 10:11 AM

19. What plan-sheets (or plan-sheet details) could be eliminated if 3D models were made contractual instead of RID? (select all that apply)

Answered: 13 Skipped: 4

ANSWER CHOICES	RESPONSES
Typicals	15.38% (2)
Special Details	0.00% (0)
Geometric Details (Horizontal Alignment)	53.85% (7)
Plan (Removal and Construction)	15.38% (2)
Profile	46.15% (6)
Other (please specify)	53.58% (7)
Total Respondents: 13	

#	OTHER (PLEASE SPECIFY)	DATE
1	None. Some of the prime contractors would be ok with this on large jobs, but many subs and smaller local contractors need sheets to complete the work	11/21/2017 9:34 AM
2	Detail grades	11/15/2017 4:01 PM
3	Not sure	11/14/2017 4:50 PM
4	These would all still be needed	11/11/2017 8:43 AM
5	If I am a designer, I have to first understand the legal contracts behind the 3D model before making a determination as to which plan sheets can be eliminated. it is a very difficult question to answer at this time.	11/10/2017 10:11 AM
6	Since we are not building the project this is tough to answer. If industry said they could estimate/build the project without certain sheets/details, I don't think designers would have an issue eliminating any sheets.	11/10/2017 9:32 AM
7	Grading details	11/10/2017 9:19 AM

20. What risk assessment practices would you use without a model to identify high-risk design elements? (select all that apply)

Answered: 13 Skipped: 4

ANSWER CHOICES	RESPONSES
There is no risk assessment performed	7.69% (1)
Request higher level of survey for drainage structures	38.46% (5)
Work with surveyor to check profile elevation at bridge clearances	69.23% (9)
Work with surveyor to check profile elevation at tie-in points	69.23% (9)
Work with construction staff	53.85% (7)
Total Respondents: 13	

21. Would you be willing to participate on a follow-up phone interview?

Answered: 0 Skipped: 17

Appendix C: Construction Staff Interview Guide and Notes

MDOT Request for Input: RID and Digital Plan Development Process.

Overview of Research Project

WSP was hired by the Michigan Department of Transportation to conduct a study to gather information that can be used in making future changes to the policies, specification and requirements for 3D models and Reference Information Documents (RID). The focus of this phase of the research is to obtain input from contractors, design consultants, and MDOT construction staff regarding the current and/or future use of 3D models as RID, and any suggestions for improvement of the current digital plan development process. You were recommended as candidates to participate in this effort, and we are reaching out to set up several phone interviews.

Study Objectives

1. Collect information to quantify the understanding of the usage, benefits and savings to calculate the return on investment (ROI) that has resulted from Reference Information Documents (RID) with and/or without 3D models to inform future decision making with policies and uses of digital (model) deliverables as well as justifying the past level of investment.

2. Use input provided by the industry to make improvements to current processes, maximize usefulness of digital data, streamline workflows, and advance digital project delivery to construction.

Background

MDOT has been supplying RID files since 2012. The process started by sharing 2D CADD files, such as plan and profile geometry, and PDF files of the cross sections. As the design software evolved, they started adding more information to the RID. In March of 2015, MDOT started delivering 3D models as part of the RID. MDOT is now engaging industry through the Digital Design Working Group (DDWG) and through this study as they prepare to advance their goal in providing digital data as part of the contract. Additionally, MDOT has already identified multiple projects as PILOTS that will utilize the results of this study. Your input is extremely valuable in achieving the goals of the study.

Interview Questions: MDOT Construction Staff

1. What is your title and responsibilities?

a. Construction engineer. Oversight of projects for respective areas.
b. Transportation Tech 11. Lead worker, construction inspection overseeing contractor activities on projects in respective area (Muskegon TSC). Office got GPS and total station within the last two years, and has been engaged doing QA and quantity measurements as part of responsibilities.
c. Senior Tech inspector grade 12 (Cadillac TSC). Last couple of years he has picked up on AMG verification on contractor staking.
d. Assistant Engineer. Has design background and has been in construction since 2009. He is a project engineer and assistant construction engineer.
e. Inspectors, tech 10. Both interviewees serve as leads for AMG projects.
f. Designers use Geopak/MicroStation to create the models, but only released as RID when project is advertised as AMG. There is a requirement for review on the construction by MDOT, but that happens on a need by need basis. In this office, they are not using RID 3D models, but rather the model the contractor creates from RID.
g. Models are checked by a independent consultant. If any issues come up, independent consultant notifies MDOT. Once model is checked it is loaded to GPS for subgrade and total station for stone grade and pavement to check within tolerances. Building layers on top of those models to collect all the data so that thickness of all layers may be seen. Interviewee indicated not sure what to do with all the data after the project. Too many changes in software, and 3D model industry is moving so quickly that more guidance is needed. Should we be gathering as-built/utilities?

2. What is the size of your staff? (engineers interview only)

a. Size of group fluctuates significantly, but the base staff is 12 (combination of techs and engineers). There is significant resource sharing between TSC on big jobs. Only has worked on one project, which was $100 million and construction staff to support that effort was up to 30 people.
b. 8 construction techs, 15 construction engineers, 4-6 co-op students on a $20 million construction program.
c. Typically, 8 people in the staff, local agency staff engineer, and assistant construction engineers. Up to $40 million, we had 1-co-op hired each summer, as needed staking and as needed testing. Centralization of region is diminishing the competency.

3. What training do inspectors typically receive?

a. There are certain competencies we like to maintain, which include surveying skills, industry certifications and general construction background.
b. Training available for new inspectors include: plans reading class, industry certifications, survey training. However, the modern survey technology is more of an informal training that our Lansing office provides on a one-on-one basis.

c. Industry certifications are based on widely used programs such as colleges (e.g. Farris State University and Michigan Tech), and industry classes (e.g. concrete), survey training is informal provided by Lansing staff.
d. Receive all certifications, densities, concrete, aggregate sampling, office type training, soil erosion and sedimentation training, survey 1 & 2 (but training is not offered that much anymore). They are trying to set-up training last winter, but due to resources changing positions, it was not scheduled. Lansing has very good support staff that construction relies on. It is working well, most of us are hands-on-learning, but still lacking Geopak skills/knowledge.
e. For survey, recently the design support unit has started a few different modules, starting up with basic surveying, new equipment and how to access models and load them onto the equipment. This training is available to inspectors every winter. It depends on the supervisor who goes to the training to bring it back. Not a whole lot of training on the computer (looking at the models in Geopak) in the office. The training available online is too in-depth for inspectors.
f. For survey, there is no formal training in 3D model/AMG projects, use of the GPS equipment. Typically, it is peer-to-peer training. We have new personnel in Lansing that are working on this type of training and are always available to train us.
g. There is Geopak/MicroStation online training through the Bentley LEARN subscription. Previously (about 2 years ago), Lansing Central Division tried to start a formal training but due to personnel changes, it took a back seat. I hear they are still working on it.
h. Lansing survey based on availability, whenever they are able to come down. Generally, they only come down when a project is about to start because that is when it is needed. I picked it up quickly, and so I just took the lead to train others (consultants, co-ops). It would be nice to capture utilities for future use. Biggest issue that we have right now is that we don't k now what to do with the data we have. We can cut sheets and enter information into ProjectWise, but what about all the valuable data that we have in our inspector daily reports, and the utilities we capture for elevations (e.g. for the inverts, pipe elevations, etc.). But because we do not have any guidance, we don't know what to do with it. I took a modern survey course in Lansing, but there has been nothing since that training. Lansing is just one division taking care of an entire state and they are doing the best they can.
i. Data just sits there, other design surveys use the same equipment we do, and they have an unbelievable amount of data that doesn't gets transferred to other areas, what about as-builts? It looks like there may be a disconnect between phases of project delivery. There is no process in place to handle and manage data.
j. Additional people are needed for the data collection because we (inspectors/techs) do not have enough time to do both inspection and data collection work. But when we do capture the data, we just don't know what to do with it. We can't take inspectors away from grabbing the data and do something with it.

4. How often are the construction and specifications updated?

a. It seems that in the old days, the spec book was produced every 6 years or so, but have always had errata type changes as needed. With digital specifications (all digital by

2020), revisions are issued as needed. Also, the construction manual wiki is updated in real-time. Construction field services updates the wiki.

5. Do you feel construction is keeping up with digital design methods, and why?

a. Not really. It's all very technical stuff. Especially the design software (Geopak) that is used is hard to keep up. Need to have some better support to keep with 3D model reviews, uploading surfaces/models to data collectors. It doesn't make sense to have one guy in the office go learn it on their own and become the lone support for the entire office.
b. Need some more formal training for regular activities to check models and load them to collectors, and processing information. Need more guidance or simply resources available to ask questions and provide general/specific support. Booking grades, measuring quantities, locating utilities, digital information could be useful in the future. Data is sitting unprocessed, unchecked and not QA. We have no ability to do this during the life of the project and it becomes a winter activity.

6. How would you describe your knowledge or experience with the CADD products?

a. Very little experience, or knowledge. Have been in those products but do not know how to use. But there is a guy in the office that knows more. I don't know what to do with the information we collect in the field, so we would like some training on that. Open to taking more formal training on Geopak. It sounds like MDOT has more formal training available for surveying/Geopak, but it just is uncommon for inspectors to take part.
b. My experience is good in Geopak pulling the files from the RID and installing them on the data collector, but not everyone in the office can do that).
c. Started working with MicroStation fairly early in my career (about 10 years ago). During the winter I try to learn/pick up my skills, log jobs, typical cross sections for log jobs. Most recently, in our office we are moving towards big collection in the field for rovers for measurements and payment calculations, area calculations, sidewalks, pavement removal, things of that nature. Oddball areas, slope restoration irregular areas. Collect data with rover, then export out of data collector and bring it in Geopak. We started with SS2 a couple of years ago, and now onto SS4. It has different terrains or surfaces. Starting to learn how to use standard coding system for survey features. But in construction, we hadn't and have started implementing those codes for our own pick up work. We have submitted DGN for the calculation for area pavements, even though FHWA doesn't accept it.
d. A few people in the area can use the software. I use Bentley LEARN during the winter to take online courses, but we are so busy that it is difficult.
e. The 296 project is piloting a project sheet (3D PDF) of the job versus having individual plan sheets. They are preparing for a new big job in the Metro region. For this job, they are only dealing with 1 plan sheet rather than multiple sheets. Using PDF files is very unique, and a new direction for MDOT. The future is all going to be 3D.
f. We want/need symbology for line weights, levels for construction items like surfaces, and other sub surface items. We want our own coding system for things that haven't

come up in survey yet. Lansing support can get the line weights correct so they can start importing that in there. They don't have many techs that can pull this into Geopak. They basically just take snap shots of the controls and attach to the IDRS.

g. Everything is changing. This new PDF 3D single sheet is different. We have projects that do not have AMG provision so the RID are limited. We may get an alignment file available with DGN alignment but not the LandXML format. This is valuable information for all projects not just AMG.
h. There are a lot of things in terms of technology (GPS/total stations, MicroStation/Geopak) that you only do once so it is necessary to have a dedicated person in the office.

7. How familiar are you with MDOT's 3D model RID?

a. Familiar with them
b. Use alignments, have not used surfaces. Use alignments for location and layout. Hasn't used RID documents DTMs. Have not done earthwork quantities yet, but have used it for square yard items (agg-based pavement removal). Nothing on the volumetric pay item type. Use of RID and models, but not as familiar with the process. From the model, we can use the alignments for layout and verifying locations. Use model for spot checking elevations against the plans.

8. How has the implementation of digital design (3D design) as RID affected your staff?

a. It cuts out the stakes, reduced the need for that activity, reduces staffing needs, but we had been doing contractor staking for a long time.
b. It has put us behind in our competencies. We need to build more competencies and get better with using equipment. Still need to build competency with building models (we are behind from where we used to be with our competencies). Must rely on contractor staking contracts, so now have to spend more time checking with survey staff.

9. What design information do you receive prior to the start of the project construction?

a. Receive plan-sheets, alignments, often asked to review plans through the design phase. All the RID are in the ProjectWise and I have access to those files.
b. I have an iPad assigned where I can access plan sheets as PDFs through ProjectWise.
c. Use ProjectWise on the iPads. Never have used anything else (e.g. Bentley Navigator).
d. Surface, 3D lines, alignments and profiles out of the RID as well as cross sections and plan sheets, which are posted in ProjectWise. We use the model the contractor provides. We never have used a subconsultant to check the model.
e. Alignments (DGN and LandXML), we are using the 3D surfaces from the contractors so we don't typically look at the RID files.
f. We are not receiving LandXML 3D surfaces, they seem to be only available in DGN format for the contractor to grab.
g. We sometimes have to ask to convert files from the contractor to LandXML so we can upload them to our data collectors. Contractor builds the model, and the subconsultant (independent) checks the model and compares it to the RID/plans.

h. 3D PDF single file is a pilot right now. We have all the layers right in this PDF, drainage construction, alignments, signing, permanent marking. It is easier for design to use it right at the beginning stages only (30%).
i. Challenges: how are we going to use such a big file. We cannot open it with the tablet in the field. Issues with multi-layer big files. Simply the iPad will not pick it up. Even with the laptops, sometimes, it takes a long time in ProjectWise and then you have to go back and turn off levels. They just need to come up with a way to divide the plan sheets.
j. Change management is always a big challenge, but I do like the main objectives and terminology moving forward.

10. If design provided you with 3D models, how would you use them?

a. Use GPS to store locations of storm sewers and curbs for as-built information. Can export out of the data collector, but not sure what to do with it. There is another guy in the office who handles the data after Blair collects the information.
b. Use it for locating items and verifying as-built conditions, but not using it for measuring earthwork. When we don't have the contractor's model before the job starts, we use the MDOT RID model and files to do layout.
c. We use the cross sections before the pre-construction meeting and before the project.
d. One of our minor frustrations is that the modeling process doesn't work well in the field sometimes. Our process to do QA is still very paper-based (specs and construction manual), so we still print the graphics form the screen onto a piece of paper so we can see actual graphics to locate the limits of paving surfaces, etc. Also, when we do not get a PDF of the cross sections it is challenging for us in the field to check work.
e. When we import the 3D strings to the data collector, they all look the same (using Leica software) and there are so many that is confusing to know what is what, so that's why we still like to have the paper version of the drawings that show the colors. 3D PDFs will not work for importing data into the data collector.

11. What is the standard equipment for your construction inspectors?

a. Total stations and GPS rover, data collectors.
b. In one of the offices there are 5 GPS and 1 Total station setups.
c. Almost 1 piece of equipment for all our inspectors. Also, equipment is available through TSC sharing and through as needed staking contracts (Mt. Pleasant).

12. Are they trained to use the equipment formally or informally?

a. There used to be an agreement with Leica for training related to any new equipment purchase.

13. Do consultant inspectors bring other technology as standard equipment? If so, what is it that technology?

a. Total stations and GPS rovers.
b. All consultants are required to bring their own equipment.

14. In your opinion, what is the ideal combination of equipment and training for inspectors?

a. In general, if we had total stations and GPS rover for at least each project that is AMG, that would be ideal. Also, would like to see more guidance expertise, ideally resource dedicated to certain regions. They feel that having trained expert assistance within the region would be more helpful than just a guidance document. One region has requested this resource and waiting to see what will be approved.

15. Do you have a dedicated survey construction crew on site (internal staff or consultant) to help inspectors collect data for measuring quantities?

a. Not anymore. Design surveys are assigned to each region for survey support.
b. How long does an inspector usually wait to get quantity measurements from a surveyor?
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d. In the Metro area, there is no waiting because we use contractors to do staking layout, or troubleshoot. Internal staff has final field measurements for progress reports.

16. We understand that iPads are issued to all inspectors. What applications are installed that would help you verify as-built conditions using digital information, such as GPS locations of installed features?

a. None
b. We can take pictures with GPS location, but other than that, there is nothing we can use.
c. I have Avanza maps, but I have not used it in any projects. I can get my coordinates that way.
d. Maintenance is using ArcGIS Collector.

17. Who is responsible for creating the as-built records?

e. If contractor sis taking the job, then contractor does the as-builts.
a. If Engineer is staking job, t hen the MDOT project office does.
b. Process today is to mark-up PDF plan sheets after the project is finished.

18. How are those as-built plan sheets used later? Does maintenance use information to append to asset inventory?

a. Not sure.

19. How are you involved in the constructability review during the design phase?

a. We receive files to view during plan review, but not early enough. We review grades at interchanges.
b. Working on a new Omissions Errors and Comments (OEC) process, which is changing a bit.
c. Unless we request the digital data, we do not see it prior to award.
d. Haven't had models to review during the design process, just plans. Data received from design prior to starting a project includes:

e. Plan-sheets, PDFs
f. OEC set of plans for review
g. RID posted in ProjectWise after letting, along with letting plans and proposal.
h. Engineers are involved in the design phase depending on the time of the year. We are asked to participate at 60% completion to do a plan review and at 90% completion for OEC. Design engineer will invite everyone and have the documents in ProjectWise ahead of tme for people to review. Meetings happen at TSC, which sometimes can be very far away, so it is difficult to participate in these meetings. Sometimes, you must be on the grade checking the contractor on other projects, so sometimes, we can't participate - even when it is a virtual meeting.
i. We used to have a process we called "Grade Inspection (GI)" check, in which the design team would get into a van and go check their preliminary design against existing conditions. MDOT has gotten away from doing this, although some may still do it. It is a detriment to the process if not being done on a regular basis. Also, with the 6-month letting schedule, sometimes those GI reviews take place during the winter when it is not appropriate time to do those field verifications because there is too much snow on the ground. So, sometimes we become victims of our own procedures.
j. Currently, the 696 project is the first time we've been involved in the 30% plans. We compile comments to the designers.
k. Typically, there is always someone, some tech in the office that is able to review the plans at the request of the engineers, and bring those comments back to design, but not sure at what point in the design process that is.
l. Technician comments to the engineer and vice-versa are hand written on the paper plans. We use the redline pens for design process (digital pen is being phased out), and moving to cloud-based Bluebeam system to do these.
m. Inspectors will be asked to provide their input/feedback at the TSC level, and then the engineers at the region level.

20. Have you even used surface to surface comparison for calculating earthwork quantities? If yes, how did you use it? If no, would you be willing to learn and use this method instead of the cross-section method?

a. Yes, currently usi8ng surface to surface, but can still use cross section method if needed.
b. I have not, but when we had design in the office, they would do it for us.
c. We are familiar with the concept, but it is not an approved method to use yet by our specs so we cannot accept it. The specs require to use cross section method to compute earthwork quantities. Contractors wanted us to do surface to surface comparison about 15 years ago, and so we've known about it for quite some time. Policies have not been updated to keep up with modern AMG methods.
d. We verify the measurements based on the cross sections and grade lines today.
e. Do not have big earthwork projects so have not been able to try it.
f. Also, a workflow to verify surface to surface should be developed for us to use so we feel comfortable with the process.
g. We typically stay away from volumes because of time constraints. Measurements are right now linear or square areas.

21. What do you think construction needs to be able to use the 3D models design or the contractor produces to verify field conditions and measure quantities? (e.g. new policy and processes, how-to's, equipment).

a. No change in resolution, if anything it is even a little slower dealing with the technology and being able to view things, and get answers back from the designers. Where before we would have just gone right to the plans and been able to interpret stuff more easily and quickly.
b. We can identify issues earlier though.
c. When you are out on the grade and things aren't matching up or making sense, you know right away, but it might take a little bit longer to resolve. You need that extra reassurance of checking 3-5 times because staff still new to using this equipment.
d. Resolution is not quicker, but identifying the issues is quicker.
e. Identifying issues on AMG is earlier because the contractor is building the model for the project. But resolving issues takes the same amount of time as it always has.
f. We use the plans to identify issues and we use the RID to look for other sources, but it doesn't give us any advantages in terms of identifying issues earlier.
g. Depending on the problem, if it is complex it will take longer, but in general we can make decisions quicker because of the models (based on standards).
h. Design surveys are not as good quality as they used to be, we typically run into issues with the existing conditions being different than shown in the plans.
i. Change orders happen because we are not spending enough time to detail our surveys (e.g. 24 pipe is needed versus an 18" pipe shown in the plans, length of curb & gutter is not accurate and now we have to pay for extra length of curb. Sometimes we get surveys with driveways missing altogether. We are seeing this getting worse. We think we had better surveys 5 years ago. Designers are not getting out in the field to do field checks, etc.

22. What tools do you have to perform real-time verification and quantity measurements on AMG projects?

a. GPS rovers, data collectors, digital levels, total stations, iPad and a laptop. Connect using my phone as a hot spot, or MiFi Verizon. To log on to the network, I will use the VPN. Fast connection, probably faster than our office.
b. Leica equipment: 2 data collectors, 1 robotic total station, 1 GPS head and rover. We have the capability of getting on the CORS network or run it off the base.
c. We got upgraded about 2 years ago. We just now have modems on our data collectors so we tie to the CORS often. Anything needing higher tolerances than GPS can provide, we'll use the robotic total stations. Still have older survey instruments, and do not have any digital levels.

23. What tools are used to perform QA grade certifications for FHWA audit requirements on AMG projects?

a. GPS for sand grade, checking fill slopes, etc. Curb grades and final pavement gravel and pavement are checked with total stations. Stakes are not used on AMG projects, but

MDOT can make the contractor put them if needed. Staff has equipment to check in real-time. Use GPS for subgrade, total station for sand, stone, and pavement. Laser level for all subgrade, auto level for sand, stone and pavement.

b. GPS equipment is used for QA grade checks.

24. What challenges do you face when the contractor uses AMG and 3D models on a project?

a. Getting a model that is good for verification that we can trust.
b. Keeping control and track of changes that re made to the model for verification.
c. Biggest challenge is that QA is not apples to apples in terms of references. It doesn't work to run off the CORS network when contractor sets up their own bases. If the contractor is setting their own base and using their own localized coordinate systems, we should be using the same thing. Usually we have control issues.
d. Changes to the model are being handled well on both the AMG projects I've worked on. The file naming convention has a data in it so it is easy to track. Contractors put their files in ProjectWise. Contractor model is only AMG surface model.
e. Mostly timing issues: getting contractor's TIN loaded into ProjectWise on time. Contractor sometimes will use AMG to their own benefit. When there are no stakes or little stakes on the ground, and the inspector does not have a rover, it is difficult for them to know where they ar. The biggest challenge is the timeline between the contractor notifying grades to be checked and the next activity. They tried to rush MDOT, and it takes time to set up equipment to shoot grades on larger projects. Expectations for timelines for the contractor should be added to the AMG specs.
f. Inspectors need to have roves available if we are going to be successful. The rovers doesn't even need to be top of the line. If MDOT is not conducting this real-time verification task, then nobody else is doing it. There is no survey crew in construction. This office is okay without it, but other offices with younger inspectors will need the equipment available.

25. What is an acceptable percent variation between plan and actual measured quantities?

a. None. MDOT pays based on actual measured quantities.

26. Have you noticed more or fewer change orders since MDOT implemented 3D models for RID, or less redesign work?

a. Same.
b. I don't think I have noticed any changes.
c. Overall, have not observed any real changes.
d. Communication between contractor and inspector on site (for any discrepancies) and being able to catch things ahead of time while still in the field is much more improved.

27. Have you noticed safety improvements?

a. For doing QA jobs is safer because it is only one person that is exposed to heavy equipment. You can let the grader get ahead of you to do your checks with automation.
b. Looking at the screen can be a distraction to keep you from watching your surroundings.

28. Have you noticed shorter construction completion times?

a. AMG seems to speed up the grading activities. Saves time for grade checkers on the contractor side.
b. 3D models allow staff to keep up with the aggressive rushed schedules that have become the norm.
c. Can't say for sure, but in general with AMG, the contractor can get a lot more done in a shorter amount of time.
d. Speed of the project is faster. Work can be expedited with this technology, but have not noticed any safety improvements.
e. It helps with communication. The inspector is more likely to receive word of an issue from the contractor because of the change to check grade.

29. Have you noticed fewer claims?

a. No

30. Have you noticed less quantity deviations?

a. Not huge differences, but depends on how the designer calculated their estimates.

31. Does MDOT have a well-defined critical path methods (CPM) schedule policy for different types of projects?

a. Have specifications that tie to generic CPM schedule, but is not defined well enough to tie to a 3D model and only required on big jobs.

32. Have you ever been involved in a project in which the contractor delivers a 4D or 5D model? If so, what was the process for receiving and using those models?

a. No, but there may be discussions to pilot the use of 4D models.