Construction-Ready Digital Terrain Models

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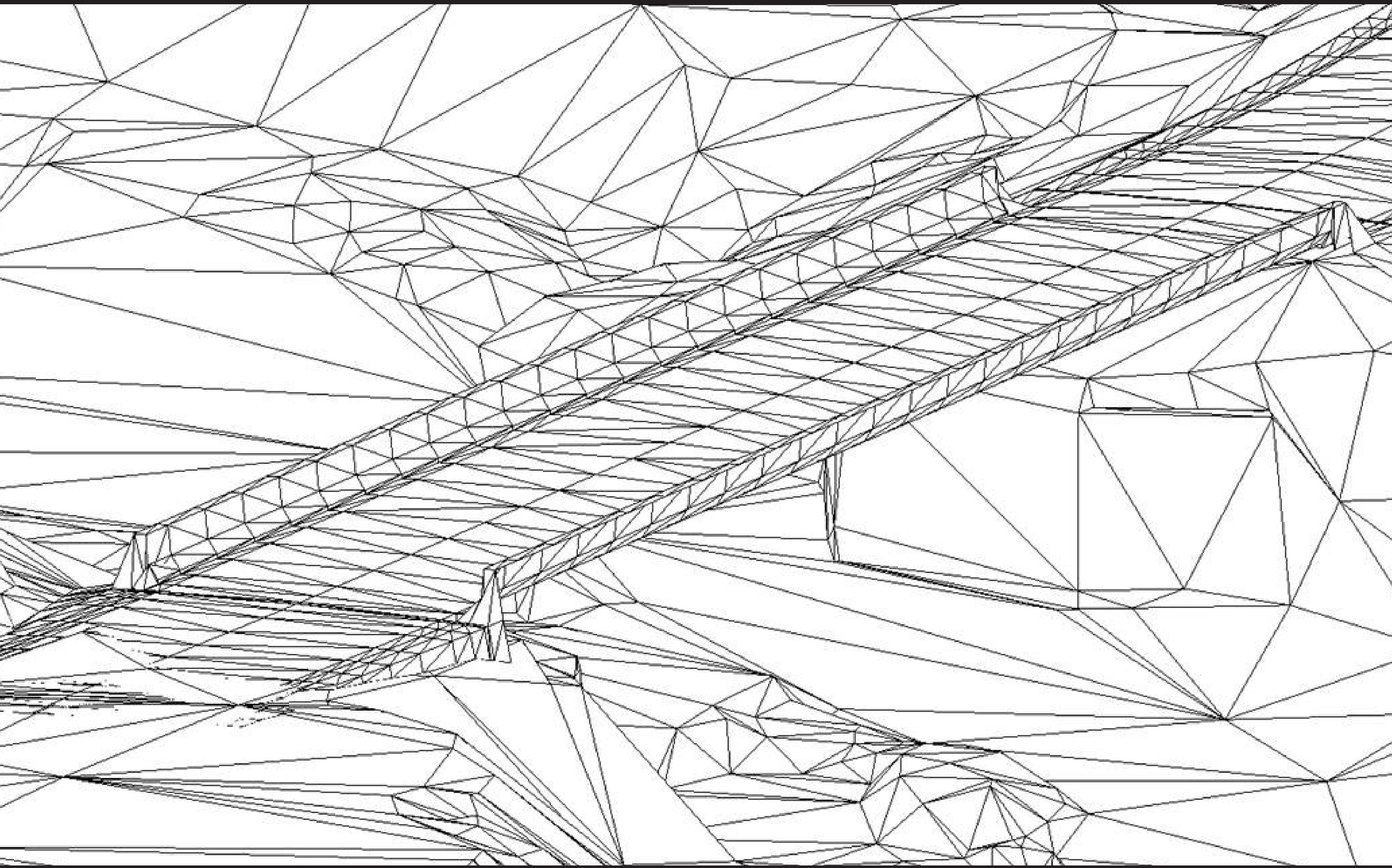

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Kentucky Transportation Center
College of Engineering, University of Kentucky, Lexington, Kentucky

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Research Report
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Construction-Ready Digital Terrain Models

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16. Abstract

Since 2009, Kentucky has made its 3D design data available as a supplemental reference to bidders through the project delivery process. This research discusses methods for ensuring electronic engineering data (EED) — and specifically the proposed digital terrain model (DTM) — support modern construction management methods at the Kentucky Transportation Cabinet (KYTC). Researchers performed a literature review, surveyed KYTC construction and design staff, engaged with Cabinet staff and industry members to understand the current state of practice, and evaluated quality-related attributes of the EED through case studies. The report presents a set of targeted recommendations for improving KYTC processes of highway design review, training and guidance for Cabinet staff, data sharing and management, professional service contract negotiations, and facilitated communication between KYTC and its industry partners.

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Executive Summary

This research discusses methods for ensuring electronic engineering data (EED) — and specifically the proposed digital terrain model (DTM) — support modern construction management methods at the Kentucky Transportation Cabinet (KYTC). Table 1 presents 15 recommendations for achieving this goal. These were developed based on a literature review, survey, interviews, and case studies. *Quick wins* are shaded gray; they can be enacted quickly and without a significant commitment of additional resources. An additional benefit of implementing quick wins is that they can facilitate the adoption of more complicated recommendations. For example, establishing more formal and consistent information exchanges with industry representatives can lay the groundwork for the more daunting task of revising production hours for design consultant contracts. Reinforcing existing CAD Standards offers the Cabinet an immediate opportunity to improve the utility of the DTM for construction. Case study findings (based on a review of project files) were consistent with sentiments expressed by construction interviewees about this topic. That is, there tends to be significant inconsistencies between project files. Breaklines and KMZ files represent simple output from the present software workflow. Requiring these additional deliverables at the end of design will increase the utility of EED for construction. At the same time, issues related to data management were a ubiquitous theme throughout the research and should not be ignored under any circumstance. Beyond using DTMs, deliberate, cohesive management of EED will help the Cabinet identify and adopt solutions to management challenges that arise throughout the life-cycle of highway infrastructure assets.

Table 1 indicates the chapter and section in which detailed information on each recommendation can be found. For instance, readers should consult Section 5.1.1 for an exploration of reinforcing existing CAD standards. Chapter 5's content is organized as follows:

5.1 Strengthen the Quality of the Electronic Engineering Data
5.2 Professional Services Contracts
5.3 Staff Training and Support
5.4 Facilitated and Continuous Information Exchange with Industry Representatives
5.5 Project Cost Implications for 3D Modeling Impacts Within KYTC

Table 1 Recommendations for Using EED to Support Modern Construction Methods

Recommendation	Section
Reinforce Existing CAD Standards	5.1.1
Mandate a Consistent Rate of Template Drop	5.1.2
Deliver Breaklines in Point File Format	5.1.2
Deliver KMZ Formatted Files of Proposed Manuscript Data	5.1.2
Review the EED Quality at Construction Contract 25% Completion	5.1.2
Implement CAD Standards Specific to Project Type	5.1.2
EED Submittals Increased Within Existing Plan Review Processes	5.2.1
Update Shelved and Aging Projects' EED to Most Current Software	5.2.2
Revise Production Hours and Descriptions to Modern Workflow	5.2.3
Train EED Reviewers	5.3.1
Establish Support for Construction Surveying	5.3.2
Train Construction Staff	5.3.3
Consistent Information Exchange with Industry Representatives	5.4
Track and Measure Case Studies for Links between EED Quality and Costs	5.5.1
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1. Introduction

When the Kentucky Transportation Cabinet (KYTC) completes a highway project design, it provides the three-dimensional (3D) design — also called Electronic Engineering Data (EED) — to contractors for informational purposes only. The EED file group includes information in many formats that is submitted collectively and labeled supplemental. One component of the EED is a digital terrain model (DTM) which represents the project's as-designed terrain.

In April 2006 KYTC introduced a policy mandating it to provide supplemental design files to bidders. The new policy was in response to requests made by contractors through the Kentucky Association of Highway Contractors. Fourteen years later, the contents and structure of supplemental design file data remain mostly inconsistent. To cope with this, contractors and KYTC construction staff have devised an array of methods to extract data from these files and make them usable. Wanting to remedy this situation, the Cabinet asked Kentucky Transportation Center (KTC) researchers to explore how DTMs might better support construction management responsibilities, for both in-house staff and contractors. To that end, we examined other practices at other state transportation agencies, administered a survey to KYTC personnel, conducted interviews with Cabinet and private industry stakeholders, and assembled case studies based on information from local staff and project data. This report summarizes our findings and advances recommendations that can be adopted by KYTC and its industry partners. Some recommendations we put forward can be implemented quickly, however, others will demand fundamental shifts in policy.

2. Literature Review

Because many engineering problems require accurate representations of the Earth's surface, solutions have been developed which efficiently transform terrain data into models that can be analyzed by computers — for example, DTMs (Miller and Laflamme 1958). DTMs are continuous representations of the ground surface generated using "a large number of selected points with known XYZ coordinates in an arbitrary coordinate field." These points are used to produce a 3D model that can be analyzed using computer algorithms. Generally, these models capture landform characteristics (e.g., elevation, slope) and terrain features (including hydrographic and transportation networks).

DTMs are constructed using data acquired via remote sensing technologies such as Lidar, 3D laser scanning, and georeferenced point clouds with high-resolution imagery. Gant and Boivin (2014) summarized the data acquisition process for generating DTMs (Figure 1). Using remote sensing technology carries several benefits, including time and cost savings, less rework, increased productivity, enhanced bidding quality, and fewer safety incidents (FHWA, 2018).

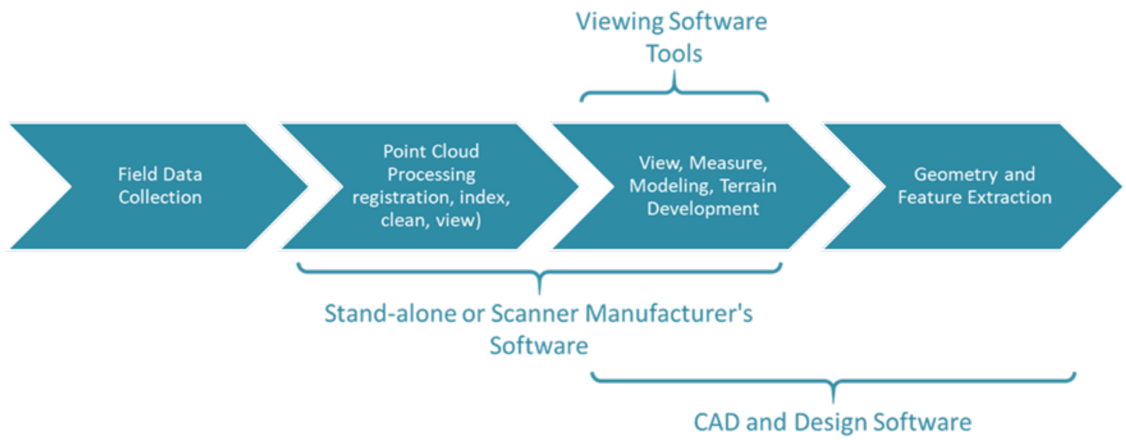

Figure 1 Point Cloud Processing Pipeline (Gant and Boivin, 2014)

Cawley et al. (2012) estimated that more than half of state departments of transportation (DOTs) were using some type of Lidar technology. Common Lidar data collection technologies include: 1) Airborne Lidar, which rely on airplanes or drones, GPS devices, and IMUs; 2) Terrestrial Mobile Systems or Mobile Laser Scanning (MLS), which leverage moving vehicles, multiple 3D scanners, positioning hardware, cameras, data acquisition systems, and computer monitors for shoulder-to-shoulder highway corridor mapping; and 3) Static Laser Scanning, where scanners and cameras are mounted on tripods to survey highway structures like bridges and tunnels.

Most researchers have found that these latest technologies outperform traditional surveying methods. Miller et al. (2012) compared MLS technology to traditional surveying on an Iowa DOT interchange project. They confirmed the accuracy, safety, and efficiency benefits of MLS. Chang et al. (2014), in conjunction with the North Carolina DOT, outlined guidance for how DOTs can determine whether Lidar can be practically used by transportation agencies; they specifically examined different aspects and performance measures for effectively deploying Lidar equipment or taking advantage of contracted services. The Utah DOT found that using existing mapping grade Lidar data for design surveys reduced costs by 24%, lowered the time needed for data collection 22%, and increased safety (Searle and Sridharan, 2014). An Alabama DOT study of MLS revealed it has considerable potential in terms of safety, time savings, level of detail, accuracy, scalability, efficiency, and quantity estimates (Russell, 2012).

Hurwitz et al. (2013) surveyed 50 DOTs, six transportation agencies, and 14 MLS service providers about the adoption of MLS. They found that a main reason why DOTs have not used MLS more widely is that they want to see more evidence of its benefits being validated through cost-benefit studies. Yin et al.'s (2014) cost-benefit analysis of Washington DOT and Caltrans projects where MLS was used showed the agencies enjoyed millions of dollars in savings as well as intangible benefits related to the environment, people, and traffic. Olsen et al. (2013) provided guidelines for using MLS in transportation applications, incorporating tasks from project planning, design, construction to operations and maintenance, and addressing data collection methods, formatting and management, storage requirements, quality assurance, and translation and formatting of derived products.

State DOTs have increasingly turned to 3D models in their construction projects. These models can help automate highway construction and are essential for maintaining stakeholder communication and coordination on large transportation projects, where multiple design, construction, and consultant teams must work together (Gilson, 2014). The shift from 2D plans to 3D plans was mainly driven by contractors using automated machine guidance (AMG) and having to reengineer 3D models from 2D plans, which is a burdensome and time-consuming task (Figure 2) (Arena, 2014). Recognizing the importance of 3D models in all phases of a highway project, including planning, design, maintenance, and operations (FHWA, 2018), contractors are now using 3D models for bid preparation (e.g., more accurate earthwork quantities), clash detection, and field inspection.

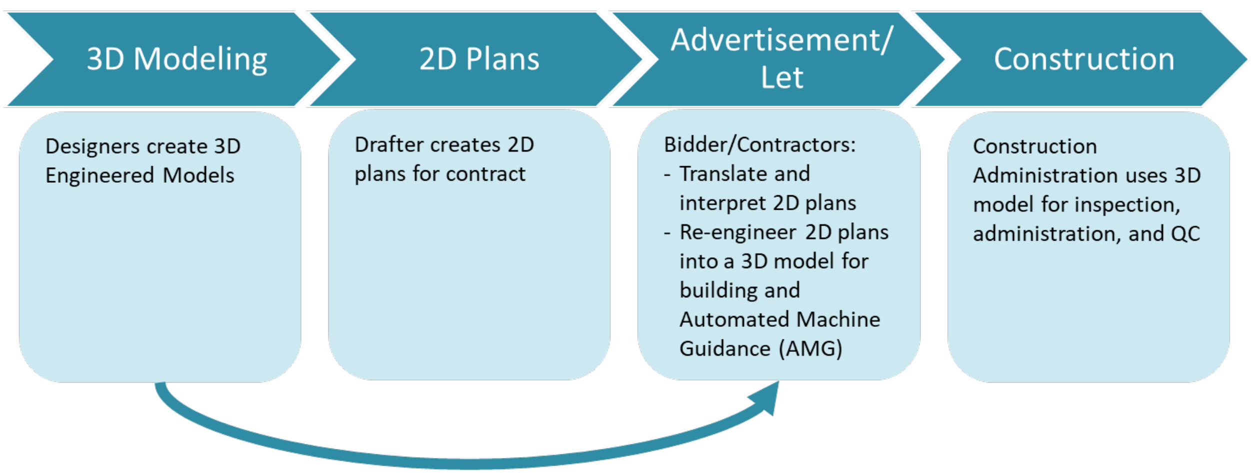

Figure 2 Comparison of 2D and 3D Design Workflows (Arena, 2014)

During the project design phase, shifting from 2D to 3D models has brought numerous challenges, such as an increase in cost and time to generate designs; a lack of standards, which results in incompatibility issues due to different modeling technologies; problems related to data management privacy and errors; the need for training expertise (especially on software); lack of guidelines and specifications for 3D designs (such as error tolerance and level of detail); issues with model validation; and contractual issues especially at the level of 2D versus 3D model deliverables (FHWA, 2018). Nonetheless, the benefits of 3D models outweigh their drawbacks. These include cost and time savings and increased productivity. Various DOTs have forged ahead with 3D modeling and aggressively moved to resolve the challenges mentioned above. For instance, the Wisconsin DOT began developing 3D design models for large projects, justifying the costs by noting that staff would gain experience which could then be applied on smaller projects. The agency has also conducted review sessions on 3D models with designers, consultants, construction professionals, and industry personnel for model validations. Elsewhere, the Iowa DOT has dedicated IT staff during the design phase to support 3D design efforts, while the Oregon DOT has established guidelines for determining the increased tolerances and level of detail required for 3D design (by surveyors, designers, and project managers), allocates extra time for 3D modeling in project schedules, and reviews and performs quality checks and assurances on digital files. Agencies handle training individually because it presents a challenge that requires significant organizational and cultural changes. DOTs have invested in pilot projects to demonstrate the advantages and benefits of 3D design, partnered with consultants and software developers, and formed leadership teams to guide transitions.

Figure 3 captures how DOT policy manuals currently treat DTMs. We compiled the figure based on an analysis of manuals from all 50 states conducted as part of an earlier research effort. All manuals mention DTMs, while most include guidance on their use (roughly 87%). Some manuals provide detailed steps and rules for developing DTMs (e.g., file naming conventions, preferred software formats, layer names, processes). Over half of the agencies lay out a full roadmap on the use of digital surface models, including standards, expectations, and instructions on the data handover from the designer to the contractor that will be used during construction. Some manuals include legal verbiage to reduce liabilities agencies might incur by suggesting the use of these files in lieu of traditional practices.

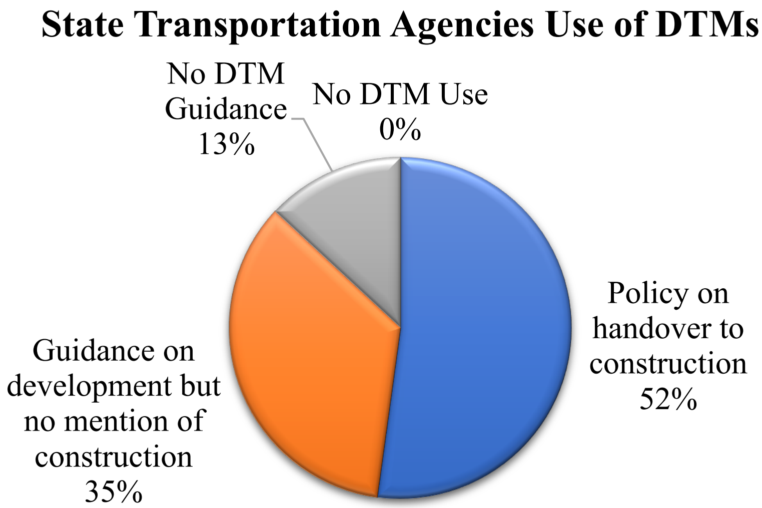

Figure 3 Use of DTMs at State Transportation Agencies

An FHWA report on the use of 3D digital design data in highway construction found that leveraging 3D data creates opportunities and challenges with respect to risk allocation, enterprise data management, workforce development, and industry-related matters (FHWA, 2017). Looking at six projects, the study found that all construction parties benefited from 3D drawings, with resident engineers and inspectors being the most impacted. Given appropriate training, resident engineers viewed 3D drawings as a safer and more efficient method for real-time verification and an easier way to measure payment quantities from post-construction drawings. Inspectors were able to document inspections in a more accurate and transparent manner as well.

As DTMs have gained momentum in the highway sector, the building sector has further advanced 3D modeling through Building Information Modeling (BIM). BIM has upended construction industry paradigms through the shift from 2D-based drawing information systems to 3D-object based information systems. BIM can also peer beyond three dimensions, with 4D (time), 5D (cost), and 6D (as-built operations) modeling as options. It establishes a shared knowledge resource for information on a facility, forming a reliable basis for decisions during its lifecycle, from inception to commission and beyond. For instance, Kong (2020) divided BIM applications into three project phases: pre-construction, construction, and post-construction. During pre-construction, BIM serves as an early collaboration platform for sharing information and using 3D models for estimating take-offs. While construction is ongoing, BIM can be used to keep track of schedules, cash flows, and work progress in real time to reduce work and overruns. In the post-construction phase, BIM improves facility operations and maintenance.

Widely acknowledged as a successful innovation in the construction industry, BIM has been studied by construction researchers to identify its short- and long-term benefits. In 2012, McGraw-Hill Construction surveyed construction professionals to identify the short- and long-term benefits of using BIM (Figure 4). The study also highlighted the business benefits of major construction project stakeholders, especially the impact of BIM on architects, engineers, contractors, and owners. An international survey conducted by Olawumi and Chan (2019) verified previous findings of how BIM facilitates efficiency and process, performance and knowledge, sustainable building, technical aspects, finances, and legal-related matters. Most of the survey respondents felt that BIM enhances overall project quality as well as productivity and efficiency.

Short-Term Benefits	Long-Term Benefits
➢ Reduced document errors and omissions	➢ Maintain repeated business
➢ Market new business	➢ Reduced project duration
➢ Reduced rework	➢ Increased profit
➢ Offer new services	➢ Reduced construction cost
➢ Reduced cycle time of specific workflows	➢ Fewer claims and litigation
➢ Staff recruitment and retention	

Figure 4 Short- and Long-Term Benefits of BIM

3. KYTC Survey and Interviews

3.1 Survey Results

We distributed a survey to 125 KYTC construction and design staff to understand their attitudes toward DTMs. The survey generated 45 responses. Of these, 34 people (evenly split between design and construction) indicated whether they prefer using a DTM. Among these staff, 65% prefer using a DTM, 26% do not, and 9% are neutral (Figure 5).

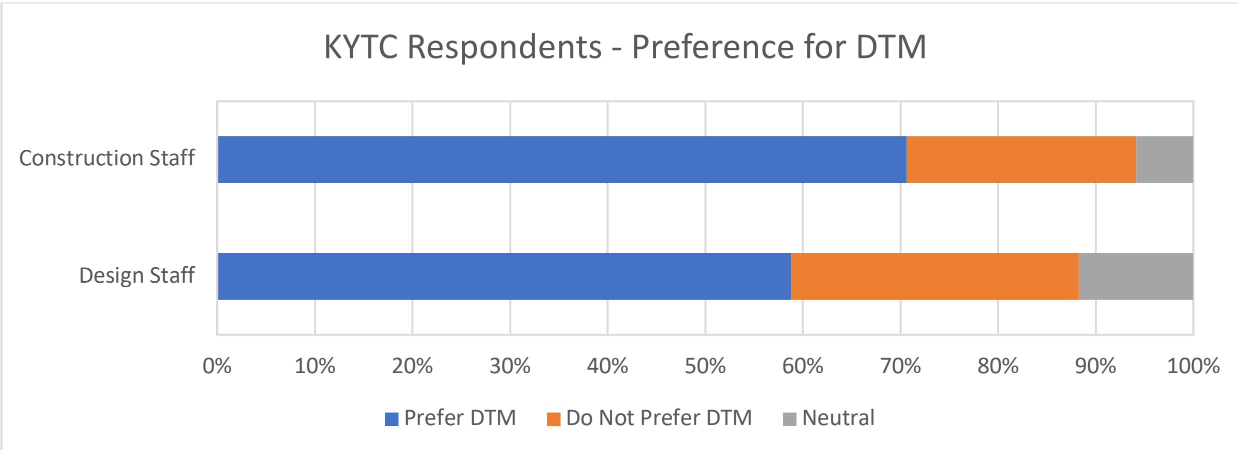

Figure 5 Staff DTM Preferences

3.1.1 KYTC Design Staff

Fifty-one percent of designers prefer using DTMs while 29% do not. Staff favorable toward DTMs noted that since a project begins with a DTM it is sensible to conclude with one. Respondents said DTMs facilitate the construction phase, foster easier comparisons between the 3D design models and the contractor's 3D model, and provide better control over the project. Nonetheless, designers observed that the current design process lacks the standards necessary to implement DTMs. The Cabinet's survey equipment also is not ready to handle construction staking or inspection using very large files. Designers who are not inclined toward DTMs believe that the models are not always accurate, not continually updated, and that contractors prefer using their own 3D models without referring to the DTMs produced by KYTC. One respondent also noted that when working with construction, cross sections are more important during operations than the DTM.

3.1.2 KYTC Construction Staff

Among construction staff respondents, 71% prefer the use of DTMs while 23% do not. Those in favor of DTMs believe they cut down on the use of paper and are easier to get information and calculate data from compared to paper plans. One respondent highlighted that a primary benefit of DTMs is visualization. Respondents identified several challenges associated with DTMs, including lack of training and the need for new technology, especially for inspectors. Respondents who do not prefer DTMs expressed different concerns. They believe that the Cabinet-supplied DTM is not accurate enough, which leads to claims for additional compensation from contractors. Some respondents said they prefer a model that they have created to edit and update. Another said they obtain information from plans profiles and cross sections instead of models.

3.2 Interviews

Members of the Study Advisory Committee had previously attempted to engage their construction contractors in discussions about the EED. However, the conversations in these settings yielded little actionable information. Seeing the limitations of talking with stakeholders in meetings where many people are present, we decided to conduct one-on-one interviews for this project. Our team spoke with 27 construction and design stakeholders from across KYTC and industry. Several interviewee appointments were to follow-up on survey responses. All participants were told their anonymity would be preserved; however, several interviewees offered their expertise should the Cabinet need it. Figure 3 shows the composition of the interviewee groups.

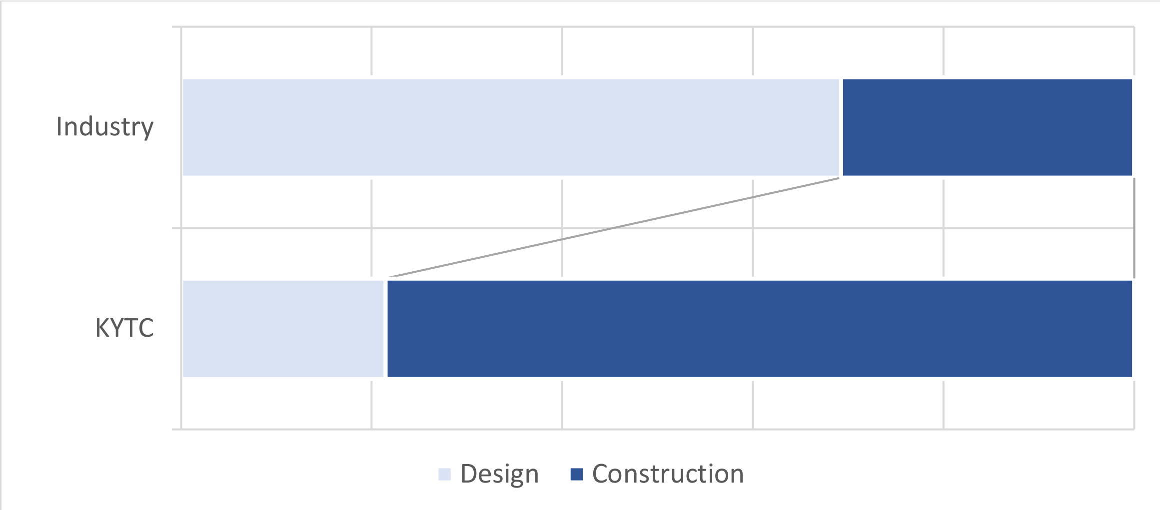

Figure 6 Interviewee Groups

We drafted separate interview questions for construction and design job groups (see below). Conversations with design staff focused on opportunities to improve the quality of the supplemental file content and procedural issues associated with changing the required design deliverables. We began each interview with the following question: *Does your office support a workflow that allows for full development of the proposed design in a 3D model (DTM format)?* The interviewee's answer to this question guided the remainder of the interview. On the construction side, the interviewee's level of experience dictated what questions we posed. The next section contains our lists of interview questions.

3.2.1 Interview Questions

Design Interview

1. Does your office support a workflow that allows for full development of the proposed design in a 3D model (DTM format)?

<u>If NO, the following questions apply:</u>

2. Does your office have plans to implement a workflow for creation of 3D model information?

3. How is your office planning to meet the requirements of the newest KYTC CAD Standards[1] and move toward the use of OpenRoads Designer[2] (ORD)?

4. What barriers do you perceive to your office taking full advantage of current software in designing projects? How do training costs affect the implementation of software updates? Do staff have support (internal or external) to improve their modeling skills? Are the hardware requirements of newer software any issue? How can KYTC help?

5. What feedback, if any, from KYTC construction staff or contractors, have you received related to your projects and the digital information products (supplemental files) supplied at letting?

6. How does your office field questions received during or after the construction letting process about your plans? How do you resolve any issues?

[1] CAD: Computer Aided Drafting
[2] OpenRoads Designer is a Bentley Systems, Inc. product endorsed by KYTC CAD Standards for Highway Design.

If YES, the following questions apply:

7. Are there any projects for which your office performed 3D modeling that you'd like to talk about?

8. What do you consider a successful modeling effort on a project? How does that differ for various types of projects?

9. Has your office ever been asked to revive a project that was shelved AND update it for a newer software version? How did you go about doing so? Did the KYTC project manager support the effort with a contract modification? If so, was the upgrade worth the delay and cost? Why or why not?

10. Has your office ever had a KYTC project for which the project manager scoped full 3D modeling as a tradeoff for production hours spent on detailing cross sections?

11. About how long ago did designers in your office begin moving toward taking advantage of the 3D modeling capabilities of InRoads[3] or other software? Did office management see potential with the innovation or was it disregarded? Who championed usage? Was the 3D model primarily seen as an internal Quality Control tool or a marketing tool for attracting and retaining customers?

12. How does your office share data between designers during the 3D modeling process to ensure that the most relevant version is preserved?

13. Does your office "cut the model loose" at a point within the development of the design deliverables so that PDF versions of the information become the working version of the most current plans? Why?

14. How long would you estimate it takes for an individual designer to become proficient enough to "successfully" model within InRoads?

15. Describe the workflow your office follows when you first receive a new KYTC project for Design.

16. Do you believe that workflow and 3D model development should vary, depending on the type of project? Please explain.

17. What elements do you spend additional effort to develop within a proposed DTM (such as various grades, initial and final terrains, relevant utilities, primary alignment, etc.)?

18. Describe what equipment you use (both office and field) to develop and utilize DTMs.

19. What level of detail, information and accuracy of DTMs do you think is needed for administration of construction projects?

20. What terrain or project features make the preparation/usage of DTMs more difficult? Do you approach the area within the limits of proposed pavement differently than the slopes and ditches?

21. Does it make sense for different type projects to have varying level of detail? Such as rural, urban, widening, reconstruction, new construction, etc.

22. What training/knowledge/hardware deficiencies exist regarding the use of DTMs by KYTC design staff as they manage consultant contracts?

23. Some states are moving to using the 3D model as the contract document rather than paper (PDF) versions of the plan set. What issues do you see with this movement?

24. Where do you expect 3D model information and digital plan data usage to go in the next 5 years?

[3] InRoads is a Bentley Systems, Inc. software endorsed by KYTC CAD Standards for Highway Design.

Construction Interview

1. Please describe the process your office follows when you first receive electronic design data for a new project. How do you assess the reliability of the files provided?

2. Do you create your own DTM or surface files from the PDF plans? What level of confidence would you need in order to be comfortable in relying on the digital files produced during the design process?

3. Please describe what equipment you have (both office and field) to utilize DTMs.
   a. What is the format (software) of you DTMs and why is this format used?
   b. What technology are you primarily using to create DTMs? (software & field equipment)
   c. Are certain formats or vendor software unusable by your office?
   d. What are the biggest difficulties you face regarding survey equipment?
   e. What would be the ideal equipment for each KYTC Section Office to maximize productivity utilizing digital design information?

4. What specific elements are you looking for in digital design information (such as various grades, initial and final terrains, breaklines[4], relevant utilities, primary alignment, etc.)?

5. What level of detail, information and accuracy is needed for administration of construction projects, using the digital data? What experience have you had with KYTC staff usage of the digital project information?

6. Does it make sense for different type projects to have varying level of detail or accuracy? (Such as rural, urban, widening, reconstruction, new construction, etc.)

7. What training/knowledge deficiencies exist regarding the use of DTMs?

8. What are the biggest roadblocks to a "perfect world" DTM workflow in the KYTC Section Office?

3.3 Interview Findings

All of the interviewees said they rely on the EED to conduct essential work tasks. However, construction and design industry stakeholders put it to different uses. Design consultants are proficient in developing and evaluating proposed DTM details. While all of the consultants have had formal training to help them use related software, their counterparts in construction have not. Many designers have learned to use modeling an effective quality control tool — even if only for internal purposes. External designers commented that their Cabinet clients are mostly uninterested in this information. None of the designers we spoke with have had a KYTC project scope that included an emphasis on a fully developed model. Contractors said they use the EED to plan their work and to identify conflicts.

Upon the software/hardware becoming available, contractors recognized the potential value of using DTMs and the EED. Currently, they are comfortable using the data to evaluate projects before they break ground and to manage projects through completion. While contractors often check the proposed DTM before letting, only one contractor stated that the EED assists in bid preparation, principally because of the inconsistencies in files offered to bidders.

Throughout our conversations, designers said they are willing to fulfill any Cabinet requests and provide construction with anything its staff needs. But for this to happen, designers need to receive clear information on what those needs are. This sentiment was expressed by all consultant designers, not just those more versed in modeling methods. More simply put, industry stakeholders want KYTC to clearly articulate its expectations through policy or some other means.

[4] Interviewees' vernacular varied, with related terms including polylines and feature lines. The triangulation of a DTM will not cross breaklines.

No proficient users of model data we spoke with had ever calculated return on investment (ROI) for creating surface data. These users intrinsically understood the value of creating surface data, and their internal leadership committed resources to overcoming the associated learning curve. Construction stakeholders agreed that spending additional design funds to increase modeling detail is always an efficient use of project dollars. However, these assertions were based on intuition, not a formal ROI analysis.

Everyone believed that a poorly modeled project tends to lead to negative outcomes (e.g., increased costs in the form of change orders and delays), but only those who work directly with the model information in digital form offered specifics about what they find useful in software-generated data. When asked what information they would rely on, *assuming the quality of the digital plans improved*, KYTC construction staff with experience using the EED were explicit about their needs. Construction industry stakeholders were likely to have worked with a model, whether it was of their own creation or the designer's, and as a result, they offered similarly detailed answers. The remainder of this section summarizes interview findings (see Appendix A for full details).

3.3.1 Training, Support, and Technology

Training is an urgent priority, especially for KYTC Construction staff, as well as construction-specific survey support (and equipment support). Because design and construction require different survey functions, the current approach of offering combined support is ineffective — the standard industry practice is to offer tailored services to construction and design users. Construction staff with a level of proficiency comparable to designers stand out among their peers. Most falling into this category are largely self-taught, citing You Tube, trial-and-error, and peer exchanges as valuable resources for learning about their equipment. Some staff rely on equipment and services they pay for themselves (e.g., tablet or desktop computers, cellular data access).

The Cabinet's only source of explicit surveying support is housed within the Division of Design. And yet performing surveys for field verification on active construction sites requires an entirely different skillset and lexicon. Interviewees remarked upon the absence of incentives or centralized guidance for learning and applying available technologies. This has compelled construction staff to individually learn how to use the EED during construction inspection. When challenges arise, which can occur during initial project setup, staff get frustrated and eventually give up on the task. In a previous study, Van Dyke et al. (2018) documented challenges related to survey equipment, staffing, training and support, and quality issues within the supplemental data files. Many of our interviewees echoed the pressure points catalogued in that report.

Interviewees said that staff who are responsible for monitoring supplemental files submitted for final design will benefit from targeted training. Other recommendations included boosting internet speeds at Section Offices, exploring the use of drones for construction project inspection, and if possible, increase staffing levels as lack of personnel contributes to low morale.

3.3.2 EED Needs in Construction

Since the supplemental file information became a required deliverable of the project development process, contractors have grown proficient in making the EED work for them, whether they produce it themselves, receive it from KYTC at letting, or generate a product that combines their materials and the Cabinet's.

Contractors highlighted data most valuable to their work. A primary focus was on breaklines (e.g., polylines, feature lines). As breaklines offer significant value for staking highway construction projects and AMG, contractors are eager to see improvements in their consistency and accuracy. Having breaklines as point-files that exhibit standardized point distribution was a common recommendation. The point frequency should be attuned to the project type and complexities of the centerline alignment and included in the supplemental file group. A number of contractors said that while improving the quality of this information will increase design costs, these will be offset by time and monetary savings realized during construction. One contractor interviewee offered quite candidly, "The best money spent is in engineering."

Contractors also proposed that effort spent creating proposed DTMs would be better spent creating improved breaklines. While no one mentioned pavement anomalies, several interviewees noted widespread inaccuracies in roadway slopes. This is the consequence of common design workflow practices, which focus the most attention on areas within the pavement limits. Embankment and excavation slopes are often viewed as a secondary concern, resulting in inaccurate disturb limits. Interviewees felt that, in general, all elements within the edge of pavement (EOP) are well represented in the electronic data provided in supplemental files at letting. Beyond the pavement edge, however, 3D modeling is less trustworthy than information found in cross sections and PDF plans. In particular, slopes do no match up those documented in PDF plans and are laden with errors. Tie-in points at intersections and approach roads are also common trouble spots. It's important to recognize that these quality issues are the product not only of the modeling effort, but of outdated and erroneous existing ground survey information — another noted issue with the EED.

Interviewees hoped to see additional modeling focused on construction phasing, maintenance of traffic, intersection radii, and safety concerns. Increasingly, construction staff use KMZ files with handheld devices. KYTC staff could use these files on their tablets or cellphones. Thus, interviewees recommended that the Cabinet include this information within the supplemental file group. Other suggestions put forward by contractors include:

- Studying yardage calculations policy (average end area) to determine if other methods would be more accurate and whether policy should be updated
- Packaging cross sections in a single DGN file
- Benching presplit lines should be individual breaklines
- Reference files should be always available for reattachment to the manuscript file.
- Updating digital plan data to reflect late-stage design changes.
- Improving subgrade model of the median for divided highway projects.
- Create PDF files as vector files, instead of rasters.

During our conversations it became apparent that construction staff and design staff use quite different terminology. For example, construction staff referred to polylines and data lines. Design staff, on the other hand, described these same elements as breaklines and feature lines. As these elements are typically longitudinal and represent changes in the cross section, they are central to grading and paving operations. Interviewees who are proficient in working with proposed DTMs were less concerned about final surface data than with making sure the component breaklines are consistently reliable.

After training, the most common recommendation advanced by interviewees was for KYTC to provide Construction with breaklines (e.g., polylines, data lines, feature lines) that are:

- Fully developed and continuous in a 3D format,
- Accurate to a measure required within the contract, and
- Consistent with the plans of record (PDF plans and cross sections.)

Construction staff placed a greater emphasis on these lines than on the proposed DTM. One contractor we spoke with mentioned they prefer triangulating their own surfaces as it lets them control the frequency of the point drops along each breakline and the manner in which points are triangulated. This person said they would rather have good breakline information even without a proposed surface, because this enables management of variations between equipment function and software capacities. Focusing on breaklines — rather than finished surface details — is one solution that attends to individual contractor fleets and each KYTC surveyor's equipment. With respect to DTM accuracy, interviewees pegged their suggestions directly to the tolerances required in KYTC's *Standard Specifications for Road and Bridge Construction*.

3.3.3 Cross-Division Recommendations

Designers pointed out that KYTC needs to update the design contract production hour descriptions and recommendations it uses when preparing professional service contracts. This information simply no longer relates to the workflow of modern design. It pertains to older design processes of drafting cross sections and plans by hand. Two construction interviewees commented that they want to see all projects adopt the same high level of modeling effort, while others thought the modeling effort should be tailored to project categories. Access to accurate survey control and existing ground terrain modeling when preparing designs is also critical. Interviewees encouraged KYTC to provide the means to update existing ground data — despite the cost — because problems often arise when a design project ages. Stakeholders said the Cabinet should also update the model during construction — which can eventually yield accurate digital as-builts. Interviewees wanted to see facilitated and regular conversation between design and construction — in the form of a focus group or committee where all industry partners (e.g., KAHC, ACEC, and KYTC) are represented.

3.3.4 The Model as a Tool

The model is an excellent tool for teaching and mentoring, a great means of engaging the public, and a clear opportunity for quality control and clash detection before construction, as several interviewees noted. Consultants take advantage of these opportunities during model development more often than their KYTC Project Development colleagues.

3.3.5 Existing DTM Use and Quality, Coordinate Control Data

Additional field verification of existing ground and statewide Lidar is needed to ensure plan detail accuracy. As the case study in the next chapter demonstrates, correct data are needed to ensure the accuracy of bid item quantities and right of way requirements. Some interviewees felt that statewide Lidar is an underutilized data source.

4. Case Studies

We developed an initial list of candidate projects for our case studies based on the following sources:

- Recommendations from the SAC, Division of Construction staff, and interviewees
- Construction projects having change orders between 25% less to 25% more than the original bid item quantity.
  - Selections were made from a list of all projects between 2010 and February 2020 having earthwork bid items. The list included active and inactive construction projects and did not include change orders in pending status.

After compiling the initial list, we excluded projects which had any of the following characteristics:

- Not awarded (i.e., had not moved from design into construction phase)
- Highway Safety Improvement Program-type projects
- Projects with paid quantities less than 10,000 cubic yards of either roadway excavation or embankment in place (as of February 2020)
- Projects let to construction before 2014
- Bridge replacement projects
- Projects moved to construction through an expedited funding source (e.g., Transportation Investment Generating Economic Recovery (TIGER), Appalachian Parkway Development (APD))

The case studies we identified encompass sizeable roadway design projects that follow conventional delivery paths and were located in 12 counties. In-house KYTC designers and eight consultant engineering companies developed the projects. The longest span between initial design funding authorization and letting was 26 years; the shortest period was five years. Our team used workstations in the Cabinet's Central Office to examine supplemental folder data. In doing so, we replicated the methods available to a project manager reviewing consultant or in-house designer data. Nonetheless, hardware and software problems slowed our reviews. For example, one day of scheduled file review was cancelled after KYTC's Bentley ProjectWise server malfunctioned. On another day, we could not review any data due to the supplemental project files being corrupted. If we had not obtained assistance from the Cabinet's CAD staff, compatibility issues between older files and newer versions of Bentley InRoads and OpenRoads Designer would have frustrated the case study review process.

All of the projects we reviewed adopted the 3.xx series CAD Standards (none used the latest 4.xx series, which was issued in October 2019). The District Transportation Engineer Branch Manager for Project Development decides when the EED must be updated as a result of the issuance of new standards. Depending on the circumstances, under this policy a project may be submitted for construction letting with supplemental files that are incomplete and outdated. KYTC's *Final Plan Submittal Form* (revised March 9, 2015) indicates what files must be included in the supplemental file folder for projects submitted to Plan Processing ahead of construction letting. These include:

- DGN Files
- 3D Mapping Files (.dgn files)
- 3D Proposed Manuscript (.dgn files)
- Existing Ground Digital Terrain Data (.dtm and .xml files)
- Coordinate Control Data (.asc files)
- Alignment Geometry (.alg and .xml files)
- Earthwork Calculations (Excel file)
- Superelevation Report (.xml file)
- Proposed Model (.dtm and .xml files)
- Template Library (.tml or .itl file)
- Roadway Library (.rwl or .lrd file)

Supplemental file folder content varied significantly (Figures 4 and 5). For example, the folder depicted in Figure 4 is clearly missing much of the required EED, while the folder in Figure 5 contains more data but is still incomplete — it lacks a 3D Proposed Manuscript or DTM. Coordinate Control Data is often provided in .csv format, as in Figure 5. This has become the more preferred format, though the *Final Plan Submittal Form* hasn't been updated to reflect this.

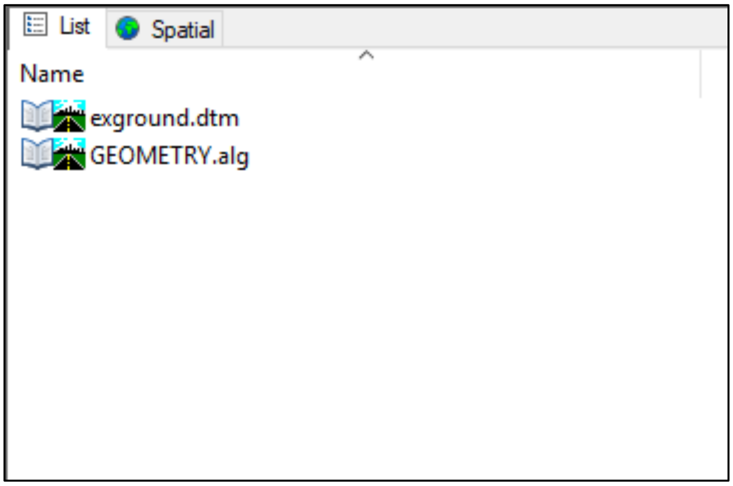

Figure 7 Supplemental File Folder Example 1

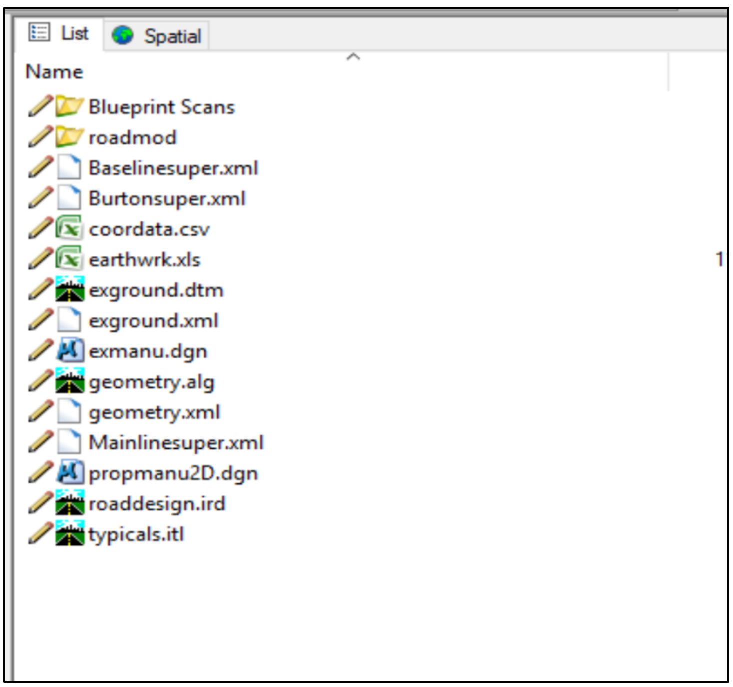

Figure 8 Supplemental File Folder Example 2

We checked each project file for 11 digital design attributes. The first five attributes are listed and described in Table 1 and correspond directly to the 3.xx series CAD Standards requirements:

Table 2 Design Attributes in 3.xx CAD Standards

Design Attribute	Description
3D Proposed Manuscript (.dgn)	• A 3D MicroStation file; it is expected to include the graphics that represent the entire project.
Proposed Model File (DTM and XML formats)	• A proposed DTM includes the terrain of the proposed design, including breaklines. This information can be exported from InRoads in XML format.

Alignment Geometry Provided (.alg and XML formats)	• ALG files are developed using InRoads and can be exported in XML format.
Coordinate Control Data Provided (.csv or .asc format)	• File format varies depending on which CAD Standards memo and *Final Plan Submittal* form apply.
Adherence to CAD Standards for Line Styles, Colors, and Levels	• Graphics in the DGN files should display according to specified line styles, colors, and levels, depending on the features represented. • The case study illustrated in Figure 8 has graphics that do not match required standards.

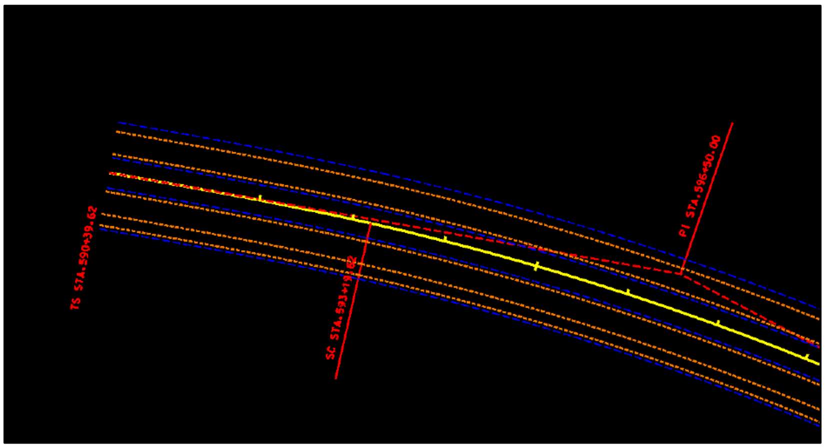

Figure 9 Project with Graphics that Do Not Adhere to Standards

Of the five required attributes in Table 1, only the alignment geometry files were found in the supplemental folders of every project. Two-thirds of the projects had a Proposed DTM, while 3/4 included a 3D Proposed Manuscript and adhered to CAD Standard formatting of Line Styles, Colors, and Levels. Just seven of the projects had coordinate control data files in the required format. While it is possible that contractors and KYTC construction staff received missing information directly from the designer rather than through the bidding procedures — a frequent post-award occurrence according to some interviewees —when these required elements of the EED are missing significant value is lost, especially to Cabinet processes that rely on this information in the future.

The next two attributes we looked at pertain to design workflow practices for a project's DTM and indicate whether or not a proposed DTM was updated through late stage design work. Designers create a proposed DTM by pushing the template through the project corridor during preliminary design, before the horizontal and vertical alignments are finalized. In some cases, a proposed DTM is abandoned and cross sections are edited graphically when further design changes are necessary. Many seasoned designers continue this practice out of habit because they adopted it to navigate the shortcomings of early CAD software. Contractors and construction personnel refer this practice as designers *cutting the model loose* when they encounter inconsistencies between PDF plans and the EED. The point at which the model is abandoned varies, but the ubiquity of this practice can be seen by evaluating the perimeter of the terrain data.

First, we looked at whether the exterior perimeter of proposed DTM is within proposed and existing right of way (ROW). We observed this to be the case in just half of the 12 project folders. When the exterior perimeter of the proposed terrain pushes beyond the available ROW, many potential issues are handed off to construction. If it is not possible to steepen slopes, it may be necessary to revise the ROW. And if slopes are steepened, additional guardrail may be required and/or slope stability compromised. These changes will result in delays and higher costs.

Additionally, environmental clearances related to disturb limits might be jeopardized. Although this attribute is not a direct requirement of CAD Standards, it directly correlates with the quality of the final roadway plans. Figures 7 and 8, respectively, present two examples where surface details lie beyond the ROW line (solid blue) and temporary easement line (dashed blue).

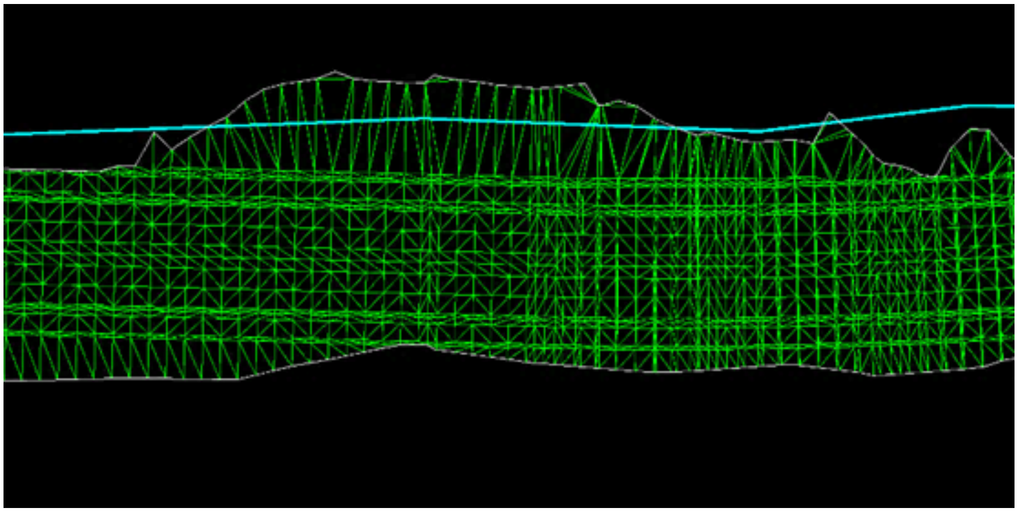

Figure 10 Surface Details Lie Beyond the ROW Line

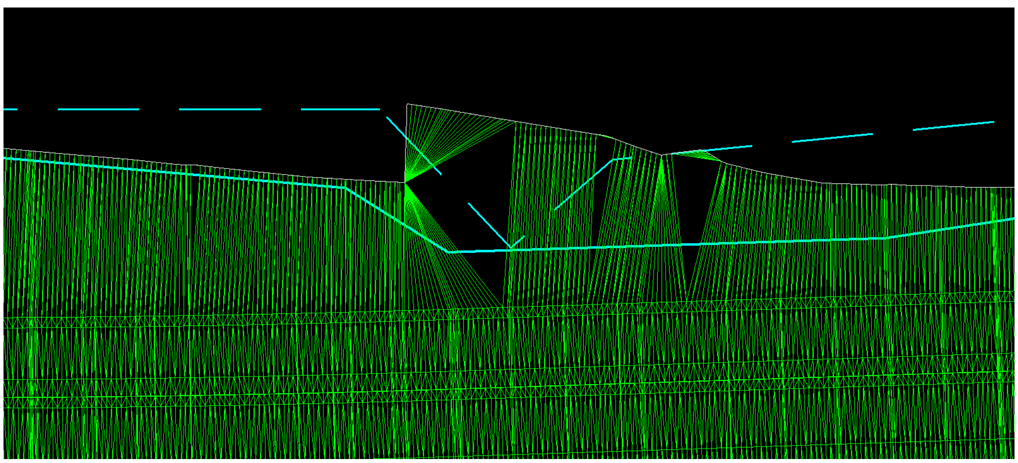

Figure 11 Surface Details Lie Beyond the Temporary Easement Line

Second, we examined if the exterior boundary of proposed DTM file matches surface triangulation. This gets at the issue of whether the provided DTM is the most up-to-date version and has remained current as plan details underwent revisions. Eight of the 12 project folders exhibited this conflict. Figure 9 illustrates a case in which the proposed surface perimeter does not match the proposed DTM graphic file in the supplemental folder. Note the considerable discrepancy between the DTM's true perimeter and the graphic file — as well as irregular and exceedingly closely spaced template drops.

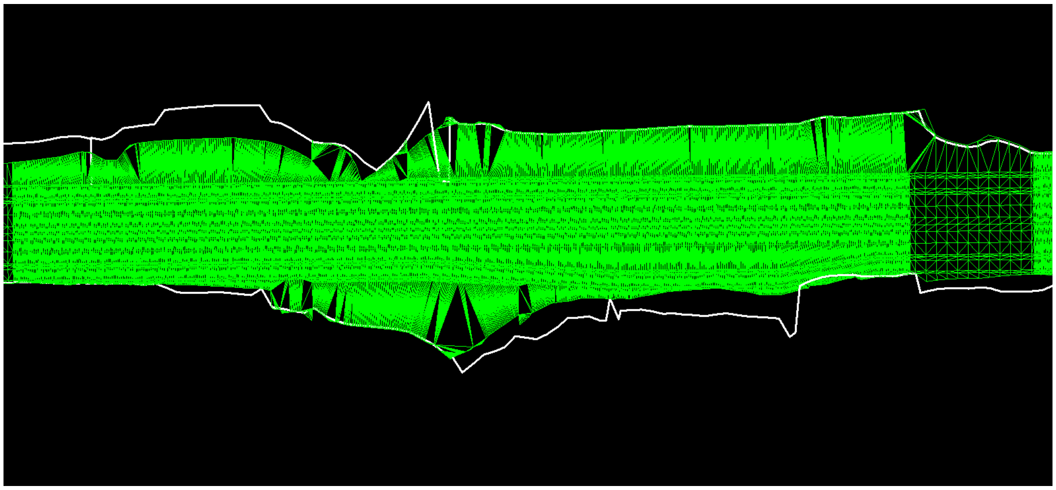

Figure 12 Proposed Surface Perimeters Misaligned with DTM

The last four attributes we looked for in project folders relate to the overall quality and level of detail in project data. First, we investigated if slopes triangulated uniformly at transitions and at tie-downs. Triangulation of a surface relates to the density of the point spacing along the breaklines or features which define the surface. The triangulation of the proposed surface in Figures 9, 10, and 11 exhibit problematic irregularities and gaps. Just 25% of the case studies developed consistent triangulation structure within their data.

Next we looked at whether there were consistent template drops that increase for pavement transitions (e.g., superelevation transitions). Too-frequent and irregular template drops are a common design practice. Designers may use closely spaced template drops to home in on a suspected problem in the existing DTM information. Each template drop generates triangulation points available along the breaklines. Additional points in transitions are needed to ensure the design intent is constructed properly (e.g., complicated intersections) but points spaced too closely can produce unnecessarily large file sizes. One-half of the projects had consistent template drops. Spacing within the projects ranged from 0.02 to 50 feet. Figure 12 offers an example of a project with irregular (and exceedingly dense) template drops. The proposed DTM also exceeds the limits of available ROW and the triangulation contains gaps.

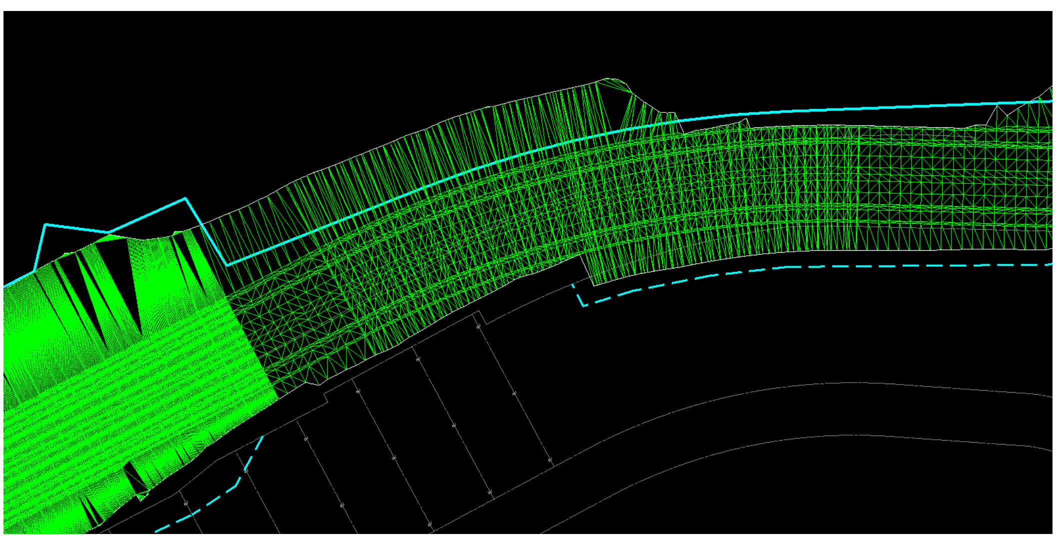

Figure 13 Irregular Template Drops and DTM that Stretches Beyond Available ROW

Next we looked at whether the proposed drainage was modeled and unbroken. Two projects included ditches and drainage structures in the proposed DTM. One benefit of this increased detail is that designers can check slope transitions around headwalls, ensuring consistent slope. Finally, we examined whether pavement (e.g., centerline, lane lines, and EOP) features were modeled and unbroken. Feature lines should tie into one another at radii. The designer merges alignment features within the pavement limits, which establishes a clear design intent for transitions rather than leaving the construction staff to develop them in the field. Five of the projects executed this successfully and provided the information in the EED.

Table 2 summarizes the findings of our case study review, listing the number of folders which possessed each of the attributes we were interested in.

Table 3 Case Study Statistics

Attribute	Number of Compliant Folders
Inclusion of Alignment Geometry	12
Inclusion of 3D Proposed Manuscript	9
Inclusion of Proposed Model File	8
Inclusion of Coordinate Control Data	7
Adherence to CAD Standards for Line Styles, Colors, and Levels	9
Exterior Perimeter of Proposed DTM Within Proposed and Existing ROW	6
Exterior Boundary of Proposed DTM File Matches Surface Triangulation	4
Slopes Triangulate Uniformly at Transitions and Tie-Downs	4
Consistent Template Drops Increase for Pavement Transitions	6
Proposed Drainage Modeled and Unbroken	2
Pavement Features Modeled and Unbroken	5

In our digital data samples we did not uncover a correlation between the CAD Standard in effect when the design was initiated (i.e., the CAD Standard prescribed in the Professional Services contract) and whether the model was up-to-date according to the latest software functionality. Division of Professional Services staff observed that, as of February 18, 2020, they had never processed contract modifications for the purpose of updating plans to meet the latest CAD Standards. This issue appeared irrelevant for the project files we reviewed. In fact, two the most comprehensively modeled projects also had the oldest design contracts, with initial notices to proceed issued in 1998[5].

Contrasting projects with similar design ages further attests to the fact that design age is unrelated to the EED's overall quality. Design age is the time between initial design funding authorization and construction letting. One of our interviewees — a contractor — endorsed one project that began in 1998 as a modeling success. But another project whose design was also initiated in 1998 was identified by another as sorely lacking important model detail for earthwork. Figure 13 plots design age against the quality of the supplemental file data. Design age is on the y-axis, and the x-axis denotes the number attributes met (i.e., the number of features or characteristics we looked for during our reviews that a project folder possessed). The more attributes a folder contains, the higher the quality of project data. We find considerable variability in quality levels across all design ages. As an example, we looked at two projects which each had a design age of 19 years; the quality of their supplemental files differed from one another quite significantly.

[5] The first CAD Standards memo was issued by KYTC on June 16, 1999.

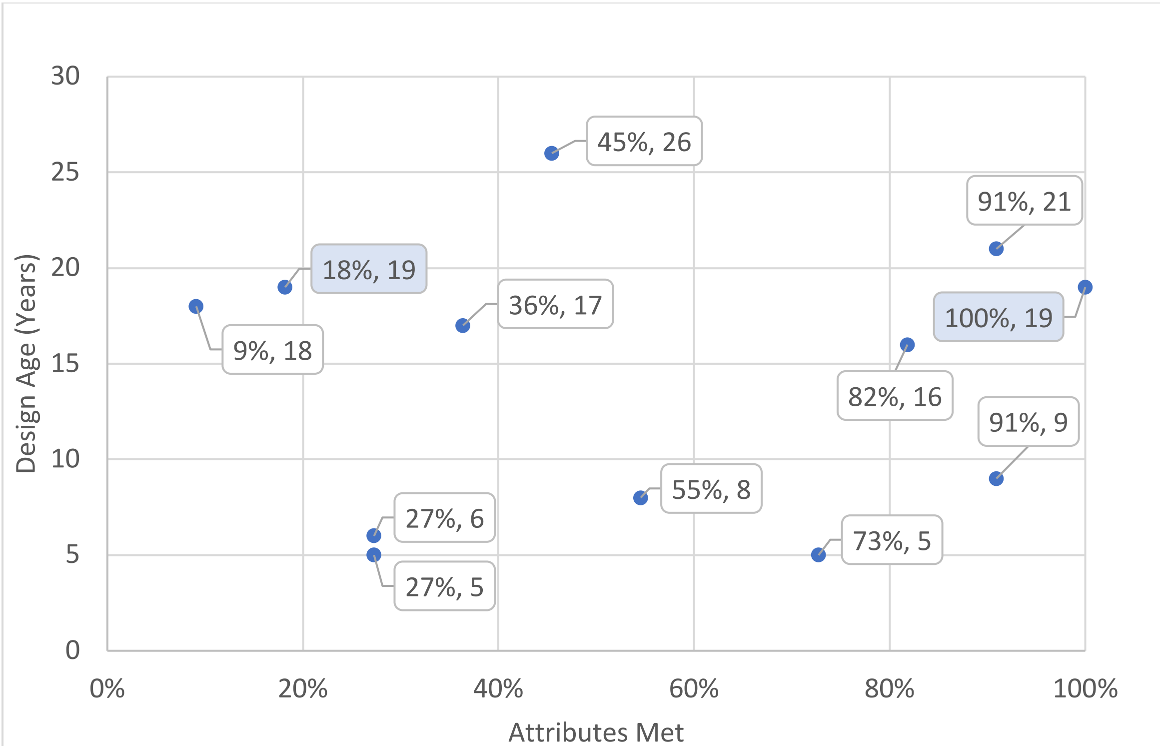

Figure 14 Relationship Between Design Age and Supplemental File Data Quality

5. Recommendations

We recognize that no discussion of DTMs is complete without considering the entirety of the EED and that no discussion of the EED is complete without the management, sharing, and consumption of these data. Routine sharing, managing, and interrogation of the EED supports modern project management through all phases of project delivery. For example, the designers we interviewed have successfully used DTMs to conduct in-house quality control, train staff, and resolve conflicts. And in construction the EED offers many field verification solutions to KYTC and contractor staff, in addition to machine guidance of equipment. Our team believes that improved internal usage of the EED offers KYTC the potential to solve management challenges throughout the life-cycle of highway infrastructure assets. But the focus of this research remains on *improving the utility of the proposed DTM for construction management*. Based on the findings of our literature, survey, interviews, and case studies, we developed the suggestions catalogued below.

5.1 Recommendation 1 — Strengthen the Quality of the Electronic Engineering Data

5.1.1 Reinforce Existing CAD Standards.

While KYTC CAD Standards are intended to ensure consistency among design project deliverables, we noted disparities in their application during both the interviews and in the case studies. Case studies revealed that portions of the CAD Standards are disregarded. If KYTC were to re-emphasize the requirements already in place for the EED, a dramatic quality improvement could be realized. In turn, KYTC Construction would find more consistent utility in the information presented to it. To improve the review of EED submittals, KYTC can leverage a combination of the following resources:

- The Project Team
    - Throughout project development, the project team should incorporate the EED review into existing review processes, especially for existing milestones. Project Development staff are equipped with EED-compatible hardware and software. Strengthening the EED review and placing it under direct control of the Project Manager and Project Team is a straightforward solution that makes efficient use of existing resources and expertise.
- District Survey Staff
    - Location crew (design survey) or construction survey personnel could be redirected to review the EED prior to final plan submittal. This could afford KYTC an important review of the coordinate control data, an area of particular weakness noted in our case studies. With requisite support (e.g., peer exchanges and training) these staff would be able to verify the EED's consistency as well as the compatibility of file formatting with surveying equipment. Construction staff throughout the state will have the opportunity expand their surveying skill set.
- Quality Assurance Branch (QAB)
    - Located in Central Office Highway Design and charged with improving the design of projects, the QAB Branch could provide another layer of review for EED deliverables in coordination with District staff.
- Plan Processing Branch
    - As a continued function of the Highway Design Branch's responsibilities for ensuring that plan submittals comply with KYTC requirements for the Divisions of Highway Design and Construction Procurement, this branch offers another logical solution for strengthening the EED review prior to letting.
- Resources external to KYTC could perform the EED quality control review.

5.1.2 Introduce Additional CAD Standards Requirements and Review Processes.

KYTC should consider adding specific design deliverable requirements to improve the utility of supplemental files. Possibilities include:

- **Mandate a consistent (but not overly dense) rate of template drop.** A rate of 10 feet between template drops was recommended by multiple interviewees. This dovetails with standardized 20- and 50-foot cross-section spacing — two of the most commonly prescribed spacings. Using 5-foot spacings may be appropriate through transitions. Additionally, KYTC may consider different template drop spacings for conceptual and final design phases. Other states, such as Maryland[6], have adopted similar guidance.

- **Deliver breaklines in point file format.** Along with requiring consistently spaced template drops, KYTC could offer breakline information in a point file (e.g., ASCII) format as exported information from the design software. KYTC Construction and industry contractors are equipped to use information in this format, and breaklines are of particular use for AMG.
- **Deliver KMZ formatted files of proposed manuscript data.** Including KMZ file data (similar to GIS shapefiles) with the design deliverables is a quick and simple means of boosting their utility for construction. KYTC Construction staff increasingly have access to mobile devices which let them retrieve and display spatially explicit project details through mapping software. Using this format with handheld devices does not match the accuracy of survey equipment, but the accessibility of KMZ files still offers massive value to site personnel. KYTC should consider that this information is useful beyond construction and design as well (e.g., KMZ files for ROW users).
- **Review the EED when the construction contract is 25% or less complete.** This allows the contractor to mobilize for and implement the initial stages of work, yielding feedback related to the digital plan information that is explicit and timely. Construction contracts are often not paid out (i.e., completed) for many years as the result of waiting on materials certifications and approvals. By the time a post-construction review is conducted, the issues identified may be irrelevant and outdated to the software currently in use. Even if a full review (e.g., a meeting) is not conducted, reporting should be issued to the design project manager after construction has begun.
- **CAD Standards for each type of project undertaken.** Design interviewees with modeling expertise stated that the variability between projects translates into difficulty scoping the work in finite detail. Although this area carries risk for consultants, innovation has traditionally been rewarded (e.g., a consultant who employs updated technology may improve their efficiency and therefore profitability). Increased guidance and flexible CAD Standards might offer a framework around which the scope and production hours can be varied as the project manager sees fit. This reduces the risk undertaken by the consultant designer and ensures the construction staff will have the EED best suited to the work.

5.2 Recommendation 2 — Professional Services Contracts

5.2.1 Coordinate intermediate file data submittals with the existing plan review processes. KYTC should consider requiring formal EED submissions at four points: 1) Phase I completion, 2) When a project is shelved, 3) When ROW plans are submitted, and 4) When project-specific milestones occur (e.g., preserving data files used for public involvement). KYTC receiving these files will aid the quality review process and safeguard against problems that can occur if a consulting firm is bought out, key personnel change, and/or it closes its Kentucky offices.

5.2.2 Provide the means for shelved and aging projects' EED to be updated to match current software. KYTC should implement a policy to ensure aging projects are updated to be compatible with modern software. The case studies and interviews revealed that some consultants update their projects, but as of March 2020 no consultants have seen contract modifications that address the additional burden work this work imposes[7].

Interviewees with design expertise noted a greater disparity between all previous versions of the Bentley products KYTC uses and the OpenRoads Designer (ORD) version. Furthermore, it is inevitable that software updates will be issued to address glitches in the ORD software. Until designers can interact with the software seamlessly, production rates will fluctuate. Currently, practitioners are in the earlier stages of the learning curve and training courses in Kentucky for designers are underway.

5.2.3 Revise production hours and descriptions to relate more closely to the modern workflow. Interviewees agreed that Professional Services contracts for lump sum agreements do not capture where production hours are needed for the modern design workflow through a 3D modeling process. Production hour ranges, categories, descriptions, and items need to be modernized so that contract terms match the work being performed. Project managers should have access to guidance and training when updates are released. Robust communication between

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[6] Maryland Department of Transportation. "3D Engineered Models Guidance" January 2019, page 14.
[7] Professional Services staff initiated review of their first such contract modification in early April 2020. The modification would provide for updating the EED to the ORD version of Bentley software.

KYTC and the American Council of Engineering Companies (ACEC) will facilitate these major revisions to the structure within consultant contracts.

With respect to the proposed roadway modeling effort, current production hour descriptions establish the following preliminary design expectations: “Create, review, modify and finalize the proposed roadway model for each roadway and alternative, including creating the required cut/fill to create the roadway model. Includes depiction of critical cross sections, as discussed in the Predesign Conference.” The guidance also states: “This would include the various iterations and adjustments required to complete an alternative due to earthwork balancing, intersection sight distance and alignment refinement.” The description for the final design reads: “Modify the preliminary roadway model or generate a new roadway model incorporating the proposed design into the initial roadway model, including cut/fill slopes, roadside ditches, etc. as necessary to define ditches and disturbed limits and enable the generation of cross-sections for all roadways.” Furthermore, “The extent and degree of accuracy of the ‘final’ roadway model is to correspond with the required guidelines of electronic deliverables. This effort of work is to be discussed at the Predesign Conference.”

Standard production hour descriptions contain few details on what modeling expectations the project manager has for the design consultant. The contract line item for existing ground DTM data collection includes minor details about collecting and verifying terrain data. Contract negotiation minutes can include additional details and CAD Standards offer guidance. Increased focus on uniformity is warranted to mitigate increasing concerns about liability for the parties involved.

One promising strategy is to align the level of modeling effort with the proposed project type. For example, the project manager for a rehabilitation project or HSIP project may be comfortable with minimal modeling work outside the edge of pavement (EOP). Reconstruction projects (i.e., those that involve extensive roadway excavation and embankment) would require accurate existing ground information and proposed surface modeling. KYTC could offer project managers a decision-making matrix for choosing the appropriate modeling scope and techniques. While most designers believe it is appropriate to vary the level of modeling effort based on project context, some construction personnel disagreed. They were not receptive to having varying model types for different projects and said every project — without exception — ought to have a full proposed model.

Another method for managing variable modeling needs for KYTC is the of Level of Reliance (LOR) concept. LOR is analogous to KYTC labeling utility information with Quality Levels A-D to convey the accuracy of source data. Embracing the LOR concept will increase communication. The LOR for the EED should be initially scoped as the design contract is undertaken, and the resulting LOR should be clearly noted in the bid documents at letting. Members of the consultant community who do not support advancements in the use of 3D modeling at DOTs for construction projects sometimes cite legal concerns about intellectual property. The LOR concept has been used within the building industry to address this perceived risk. The concept should also be attended to in coordination with the ACEC. The Michigan DOT is working with industry partners to define Level of Development (LOD) for its digital design components. Its LOD concept will create distinctions within the EED (i.e., prescribed LOD for alignments may differ from proposed DTMs). LOD Designation is further explained in FHWA’s TechBrief “Utilizing 3D Digital Data in Highway Construction”, FHWA-HIF-17-031.

5.3 Recommendation 3 — Staff Training and Support

5.3.1 Train reviewers of the EED. Regardless of the method(s) KYTC uses to strengthen the EED review, training will be necessary to ensure that reviewers are consistent in how they assess EED quality. (KYTC should look at making the same training available to estimating staff to facilitate their pricing efforts). Modeling proficiency need not be a prerequisite for trainees or reviewers; they just need to understand how the roadway features present graphically. Our case studies provide a starting point for good and bad examples of the quality attributes. Successful training should build on those concepts and allow for continual input from industry (design and construction) experts, so that quality criteria remain relevant through software innovations.

5.3.2 Establish support for construction staff using the EED and surveying equipment. If KYTC wants to maintain in-house construction survey expertise, it should explore offering staff incentives to build their knowledge and remain at the agency. Developing a list of job duties for a separate survey division is one step that merits further investigation — these staff could conduct quality control for model information. Survey experts in construction and design are well-positioned to step in as a core group for the Cabinet's EED review. Another potentially viable option given widespread staffing issues is establishing regional surveying crews/expertise. In lieu of these options, the Cabinet needs to examine options for outsourcing construction surveying needs[8].

5.3.3 Train construction staff. KYTC project development staff can readily access support and training, however, the same cannot be said for construction staff, who contend with lack of support, equipment, bandwidth, peer exchange, and incentives. External support and training offer the potential for mitigating uncertainty as new innovations come online.

5.4 Recommendation 4 — Facilitated and Continuous Information Exchange with Industry Representatives

KYTC should establish a joint committee or working group with focus on the EED and Professional Services contracts. Pushing an initiative like this forward will entail facilitated conversations between consultants (ACEC), contractors (Kentucky Association of Highway Contractors), KYTC, and software suppliers. It is critical for KYTC to support open dialogue between these groups as they each have expertise related to every recommendation in this report.

5.5 Recommendation 5 — Project Cost Implications for 3D Modeling Impacts Within KYTC

5.5.1 Track select case study projects through construction completion to measure relationship between change orders and EED quality. KYTC could obtain preliminary return on investment (ROI) data from this effort. A Florida study found that making cross-slope adjustments through milling lowered contract time, reduced overall risk for the contractor and owner, and eliminated overbuilding of pavement[9]. For projects with 3D-only plan sets, the Utah DOT has estimated ROI based on differences in bid prices from the engineer's estimate. Before shifting to full 3D plans, one option for measuring ROI is using historical change order data to evaluate the actual sources of delay and cost, which will require SiteManager access for some projects.

5.5.2 Evaluate earthwork yardage discrepancies that arise from using the average end area method. A more consistent model can take advantage of software features for calculating quantities, including specific quantities for different material types. Interviewees highlighted yardage calculations. KYTC's policy of using average-end area method volume calculations should be revisited in light of software capabilities. For example, KYTC could compare existing, proposed, and as-built surface details for completed projects with marked changes in volume or tonnage from the original plan quantity. Comparative data can be used to evaluate when poor modeling was responsible for changes in volumes or tonnages. The case studies presented in the last chapter could be the target of further investigation.

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[8] These recommendations reinforce the findings of "Optimizing Available Surveying Technology to Streamline Project Delivery" SPR 17-544-1F.
[9] "Automated Machine Guidance with Use of 3D Models" FHWA TechBrief 13-055

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Appendix A

INTERVIEWEE RECOMMENDATIONS	SOURCE				TOTALS		
(K=KYTC, I=Industry, D=Design, C=Construction)	KC	KD	ID	IC	D	C	BOTH
TRAINING FOR END USERS (CONSTRUCTION)	8		1	2	1	10	11
PROVIDE CONSISTENT AND ACCURATE BREAKLINES	6			2	0	8	8
CONSTRUCTION SPECIFIC SURVEY SUPPORT FOR KYTC CONSTRUCTION STAFF, *INCLUDING* EQUIPMENT SUPPORT	8				0	8	8
MORALE AND STAFFING LEVELS IS A RELATED/INTEGRAL ISSUE	6				0	6	6
INCREASE MODELING EFFORT ON CONSTRUCTION PHASING, MOT, AND SAFETY	2		1	3	1	5	6
INCREASED MODELING AT ALL TIE-INS/TIE-DOWNS	4			1	0	5	5
TRAINING FOR DESIGNERS, INCLUDING TRAINING FOR DESIGN DATA REVIEWERS	3	2	2	1	4	4	8
SURVEY CONTROL AND EXISTING GROUND MUST BE ACCURATE, PROVIDE FOR UPDATES (EVEN AT A COST) WHEN A PROJECT AGES IN DESIGN PHASE	2	2	2	2	4	4	8
ESTABLISH A MEANS FOR CHANGES TO THE DESIGN AND TO UPDATE THE MODEL DURING CONSTRUCTION, INCLUDING AS-BUILTS	4				0	4	4
INCREASE MODELING EFFORT TAKEN AT RADII AND APPROACH ROADS	3			1	0	4	4
USE DRONES FOR CONSTRUCTION INSPECTION	2			1	0	3	3
SCOPE MODELING EFFORT SPECIFIC TO EACH PROJECT	2	1	4	1	5	3	8
SPEND MODELING EFFORT ON INTERSECTIONS	2			1	0	3	3
KYTC MODELING GUIDANCE FORMALIZED (CAD STANDARDS, MEMOS, UPDATES)	1	3	4	1	7	2	9
FACILITATED AND REGULAR CONVERSATION BETWEEN DESIGN AND CONSTRUCTION - OR FOCUS GROUP REPRESENTING (KAHC, ACEC, KYTC)	2		2		2	2	4
INCREASED KYTC QUALITY CHECK OF DESIGN MODEL FILES, SUBMITTALS		1		2	1	2	3
MORE/CONTINUED DEVELOPMENT OF KMZ FILES				2	0	2	2
BREAKLINES AS POINT FILES (aka"data-lines, feature lines…")				2	0	2	2
MORE ACCURATE SLOPE INFORMATION				2	0	2	2
SAME MODELING EFFORT FOR EVERY PROJECT	2				0	2	2
IMPROVE INTERNET DATA SPEED AT SECTION OFFICES	2				0	2	2

MODEL AS A TOOL FOR QUALITY CONTROL AND CLASH DETECTION (before construction)	2		2		2	2	4
STUDY WHETHER AVERAGE END AREA OR USING SURFACES IS BEST METHOD, DEVELOP UPDATED POLICY			1	1	1	1	2
INCREASED DATA SHARING			1	1	1	1	2
INVOLVE CONSTRUCTION IN THE PRE-DESIGN SCOPING PROCESS	1				0	1	1
CROSS SECTIONS ALL IN A SINGLE DGN FILE				1	0	1	1
PRESPLIT AS A MODELED BREAKLINE - FOR LENGTHS, AVERAGE HEIGHT ANALYSIS				1	0	1	1
MAKE SURE REFERENCE FILES ARE AVAILABLE FOR REATTACHMENT				1	0	1	1
STATEWIDE LIDAR AS A VALUABLE TOOL				1	0	1	1
MORE ACCURATE DISTURB LIMITS				1	0	1	1
UPDATE DIGITAL PLAN DATA TO REFLECT LATE STAGE DESIGN CHANGES				1	0	1	1
IMPROVE SUBGRADE MODEL IN MEDIAN OF DIVIDED HIGHWAY PROJECTS				1	0	1	1
CREATE PDF FILES AS VECTOR FILES, INSTEAD OF RASTORS				1	0	1	1
MANDATE BREAKLINE POINT DISTRIBUTION - CONSISTENT ACCORDING TO PROJECT TYPE OR ALIGNMENT CHARACTERISTICS (e.g. 10 feet in tangents as a specific request)				1	0	1	1
SPEND MODELING EFFORT ON BREAKLINES, NOT TRIANGULATION				1	0	1	1
REVISE PRODUCTION HOUR RECOMMENDATIONS RELATED TO MODELING AND WORKFLOW (right-size to project and schedule)		3	5		8	0	8
FIND A WAY TO INDICATE THE LEVEL OF RELIANCE THAT THE USER SHOULD PLACE ON THE MODEL DATA (e.g. include caveat related to any geotechnical data that is represented)		2	1		3	0	3
STATEWIDE LIDAR IS UNRELIABLE DATA - MORE FIELD VERIFICATION OF EXISTING GROUND IS NECESSARY			2		2	0	2
MODEL AS A TOOL FOR TEACHING AND MENTORING			1		1	0	1
MODEL AS A TOOL FOR ENGAGING THE PUBLIC			1		1	0	1