

Life-Cycle Civil Integrated Management (CIM) Advancements in Preliminary Design BIM for Infrastructure

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August 2019

Final Report 2019-36



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Technical Report Documentation Page

1. Report No. MN/RC 2019-36	2.	3. Recipients Accession No.	
4. Title and Subtitle Life-Cycle Civil Integrated Management (CIM) Advancements in Preliminary Design BIM for Infrastructure		5. Report Date August 2019	
		Cell left blank intentionally	
7. Author(s) Chris Trbojevich, Richard Lovel, and Curtis Sohn		8. Performing Organization Report No.	
9. Performing Organization Name and Address SRF Consulting Group Inc. 1 Carlson Parkway North, Suite 150, Minneapolis, MN 55447-4443		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. MnDOT Contract No. 1030365	
12. Sponsoring Organization Name and Address Local Road Research Board Minnesota Department of Transportation Office of Research & Innovation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://mndot.gov/research/reports/2019/201936.pdf			
16. Abstract (Limit: 250 words) This study is an evolution of the Minnesota Local Road Research Board's sponsored research <i>Modernizing Road Construction Plans and Documentation</i> (Iowa State University, September 2016). Where previous studies provided high-level practices for transportation, this research examines advances in preliminary (0-30%) design tools and methods that bring ramifications to the larger BIM for Infrastructure project life cycle. This has been an overlooked but vital area that sets the tone for success in civil transportation projects adopting 3D information technologies. An existing traditionally delivered project in Carver County, Minnesota, is mirrored as context to explore the emerging tools and methods. Findings identify changes in functionality and process that modify work breakdown relationships, reduce silos of information, and expedite project delivery. Identified advancements will challenge engineers and draftsman to rethink their roles in the design process as organizations now have the opportunity to re-evaluate workflows and streamline project delivery methods.			
17. Document Analysis/Descriptors Modernization, Infrastructure, Planning and design, Technological innovations, Design methods		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 214	22. Price

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FINAL REPORT

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August 2019

Published by:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

This report represents the results of research conducted by the authors and does not necessarily represent the views or policies of the Local Road Research Board, the Minnesota Department of Transportation or SRF Consulting Group, Inc. This report does not contain a standard or specified technique.

The authors, the Local Road Research Board, the Minnesota Department of Transportation, and SRF Consulting Group, Inc. do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to this report.

ACKNOWLEDGMENTS

This project was funded by the Minnesota Local Roads and Research Board (LRRB). The authors would like to acknowledge the support and efforts of the LRRB technical advisory panel (TAP) for its contributions to the advancement of this study.

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Special thanks are also extended to Barritt Lovelace, Collins Engineering.

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LIST OF ABBREVIATIONS

4D = 3D Model + Schedule

5D = 3D Model + Schedule + Costs or Quantities

AEC = **Architecture Engineering Construction**

AMG = Automated Machine Guidance

BEP = BIM Execution Plan; defines project teams delivery work processes (interchangeable with BIMxp)

BIM = Building Information Modeling- a process supported by various tools and technologies involving the generation and management of digital representations of physical and functional characteristics of places. For purposes of this document BIM is used interchangeably with BIM for Infrastructure

BIMfi = BIM for Infrastructure, Building Information Modeling for Civil Transportation (FHWA)

BIMxp = BIM execution plan defines project team delivery work processes (interchangeable with BEP)

BIMpxp = BIM project execution plan (interchangeable with BIMxp)

BrIM = Bridge Information Modeling

CIM = Civil Integrated Management, synonymous with Virtual Design and Construction (VDC)

CAD = Computer-aided Design

CD = Contract Documents

CDE = **Common Data Environment** = online (intranet, cloud, or extranet) place for collecting, managing and sharing information amongst a team working on a project

CSV = Comma Separated Value File Format for Microsoft Excel Spreadsheet for Survey Layout

DWG = Autodesk Proprietary File Format for CAD Data

DGN = Bentley Proprietary File Format for CAD Data

ECW = enhanced compression wavelet format – sharpening algorithm for large image compression

GCP = Ground Control Point

GIS = Geographic Information Systems

GNSS = Global Navigation Satellite System is a satellite system used to pinpoint geographic locations worldwide and user's receivers

GPR = Ground Penetrating Radar

IFC = Industry Foundation Class, internationally accepted open and neutral file exchange format

IMX = Autodesk file interchange format used to transfer data between Infracore and Civil 3D

I-Model = Bentley proprietary file format that works as a container for multiple files

LOA = Level of Accuracy, measure that defines appropriate context of use for model elements

LOD = Level of Development (or detail), the amount of graphical detail within an information model at any given point in a project

MEP = Mechanical, Electrical, Plumbing - type of BIM design discipline typically associated with architectural BIM

PMM = Project Modeling Matrix

PS&E = Plans, Specifications, and Estimates

ROI = Return on Investment

SHP = ESRI vector file format

SME = Subject Matter Expert

UAS = Unmanned Aircraft System (commonly referred to as drone)

VDC = Virtual Design and Construction, integrated life-cycle process

WBS = Work Break-down Structure

xD = stand-in for additional CIM/BIM conventions beyond 5D. For example, a maintenance or operations model could be a 7D use.

XML = Non-Proprietary File Format for Exchanging Geometry-centric 3D data

EXECUTIVE SUMMARY

Transforming transportation project design and delivery in Minnesota to smart, paperless, 3D electronic delivery presents significant challenges that will take years to conquer. Yet the urgency is clear; the need for transportation infrastructure improvements is increasing while public funding decreases, requiring agencies to “do more with less.” Innovation is one potential answer.

The onset of intelligent 3D engineered model technology is analogous to the mylar to computer aided design and drafting (CADD) paradigm shift, only neither mylar nor CADD had intelligence, and process adaptations were not radical. Ramifications today are higher as more accurate and informed (intelligence through metadata) design methods carry information forward into an enhanced and sustainable process that includes asset management, operations and maintenance, and beyond. Notably, there are also now significant workflow changes. This report explores new preliminary design tools and *some* of these workflows. Now more than ever there is potential to reduce overall project costs in this area due to the ability to accelerate decision-making in early stages, feed downstream processes, and set the tone and schedule for later-stage project success. Collaborative design methods combined with groundbreaking tools allow examination of increased numbers of alternatives (previously cost-prohibitive) while facilitating refinement of a preferred option in a fraction of time compared to traditional methods. [Appendix F Project Benefits \(Chapter 7 Final Memorandum on Research Benefits\)](#) provides the aggregated inferred qualitative and quantitative value observed during processes related to preliminary design conducted throughout Chapters 1-7. Continued research and pilot projects *in-situ* are required to further quantify value.

Appendix G Preliminary Design Next Steps from [Chapter 8](#) includes over 60 potential next step(s) for consideration to further research in this area. In addition, Chapter 8 offers considerations for agencies to begin their own (programmatic) BIM adoption strategy including expected outcomes. ([Section 8.7](#) provides sub-task details). Three programmatic action items from Chapter 8 for consideration are:

1. Start a small (design squad) BIM design practice.
2. Begin internal change-management efforts along with a measurable success framework.
3. Identify a suitable project and prepare to deploy BIM methods in a pilot.

The predominant takeaway for readers is that there are years of collective work ahead of the industry, especially with cultural change; local agencies need to *just get started* and begin the process.

To date (with a few exceptions around the U.S.), BIM implementations are largely *ad hoc*. Early adopters trend toward “lonely BIM,” where processes are isolated without a supporting BIM execution plan (BIMxp) or cohesive strategy throughout the project duration. Examples include creating 3D design models *only* for automated machine grading (AMG) use in construction. While a critical BIM-use activity, building 3D models for single purposes is a short-sighted, siloed approach not conducive to best practices that lead to consistent BIM return on investment (ROI). Conversely, when BIM activities are *deployed together in sequence* (BIM is a process), higher cumulative value is returned to the project, owner, and taxpayer. Preliminary design BIM use may prove critical to this equation; for certain projects,

it can accelerate a vital project stage while kick starting the single source of truth (3D model) collaboration process.

Technology alone is not a silver bullet. Potential human-factor pitfalls (besides lonely BIM) include forcing new tools into outdated legacy work practices that invite potential financial risk, increasing exposure to liability, and potentially impeding cultural acceptance within an organization. Local agencies ignoring the importance of process change could experience dramatic failures; those taking a more comprehensive approach may experience extraordinarily positive outcomes. Success of agencies will be influenced in part by:

- How broad and tiered of an approach is used to institutionalizing the technology
- How comprehensively the human change-management part of the equation is addressed
- The ability to understand process differences between traditional delivery vs. BIM methods
- Use of progress measures such as capability maturity models and key performance Indicators
- Openness to contract mechanisms most conducive to successful BIM (Construction Manager/General Contractor (CMGC) for example)

Potential action items to address change-management include educational campaigns about a new process, draft standards or materials such as BIMxp's templates. Other further next steps include investigation of work-breakdown structure relationships related to new processes and mapping information flow (geometry and metadata) throughout the entire project life cycle. Most important, agencies should simultaneously further support preliminary design BIM research as well as learn by doing via pilot projects.

In 2004, the *Journal of Information Technology in Construction* predicted we are entering the second generation of BIM development, where knowledge-based systems will augment the civil engineer's tools and capabilities. This prediction is now reality, manifested in seven significant technical innovations, which are highlighted throughout each chapter of this study and now have the potential to drive the success of *preliminary design*, positively impacting downstream processes including acceleration of schedules:

1. **Parametric Design, Data Analytics and Rapid Prototyping** (Chapter 1): collaborative workflows.
2. **Enhanced Survey Technology** (Chapter 2): *Reality Capture* using photogrammetry, LIDAR, and unmanned aerial systems (UAS); provides rapid access to increasingly accurate data for preliminary design
3. **Convergence of BIM with GIS Data and Tools** (Chapter 3): enriches the planning and conceptual design process, making GIS accessible for non-GIS professionals; as design becomes more intelligent (like GIS), the lines between these two technologies will continue to be blurred
4. **Knowledge Based Systems (KBS) and Generative Design** powered by machine learning/artificial intelligence in the cloud (Chapters 4-5): once science fiction, but becoming old news for architecture, now emerging as a mainstream automation feature for transportation designers, releasing engineers from menial repetitive tasks; requiring practitioners to rethink their roles

5. **Enhanced Visual Design Process** (Chapters 1-6): improved communication and faster preliminary design decisions leading to earlier consensus, which accelerates project schedules into the next stage of design
6. **Open Format Standards** (Chapter 6): improvement in software interoperability, usability, metadata integrity, GIS integration, and reduced dependence on proprietary systems
7. **Single Source of Truth** (Chapters 1-6): 3D model design process, reduction of siloes, increased accuracy, reduction of requests for information (RFIs), and enhanced communication and efficiencies

Although this study used new Autodesk technology in the context of preliminary design, the concepts, types of tools, and methods used, are platform agnostic in that both Bentley and Autodesk are embedding the same design technologies listed above. Notably, technologies transforming preliminary design reappear in many other project life-cycle areas.

Excuses to delay adoption are numerous including valid technical reasons; yet all technical hurdles are transient and being addressed. For example, American Association of State Highway and Transportation Officials (AASHTO) committees are developing electronic data standards (including digital signatures) and vendor software releases are on aggressive update schedules. Consultants, contractors (and several Minnesota counties) are embracing the benefits and lessons learned from progressive neighboring states, identifying pilot projects, and developing workarounds for temporary challenges. Federal (GSA) architectural design projects in the U.S. (and both architecture and transportation projects in the U.K.) mandate BIM due to efficiencies and need for sustainable infrastructure practices. The Federal Highway Administration (FHWA), AASHTO, and the Associated General Contractors (AGC) are now championing BIM and virtual design and construction (VDC) concepts. One incentive for agencies to start the process is that use of BIM methods could feasibly be a future eligibility requirement access to federal funding.

BIM provides more accurate designs with reduced risks. For designers, constructors, and owners to be successful with positive return on investment (ROI) they should shift from the traditional siloed approach to a more collaborative project management practice. Data repurposing through collaborative, sequential workflows is one central tenet of the BIM argument. The inferred value proposition for BIM is that the more instances a common 3D model (and its inherent metadata) is repurposed, the higher the potential return on investment (ROI) and the lower the total cost of ownership (TCO). Survey and preliminary design start the flow of this chain of information.

Wisconsin DOT quantified BIM ROI (for clash detection). Utah DOT studied ROI for (LIDAR/Geographic Information Systems (GIS)), and a recent construction ROI report by Michigan DOT documented value to construction. Apart from this study, published BIM research in the 0% to 30% design phase are (as of June 05, 2018) nonexistent. There are also no standardized mechanisms to evaluate ROI for projects of all sizes, especially for typical-sized (non-mega) projects. Chapter 8 (next steps) notes that the FHWA recommendations propose a need to establish standardized techniques for measurement. Significantly, 44% of all Architecture Engineering Construction (AEC) BIM users do not formally measure their ROI; another 43% measure ROI on less than 50% of their projects. The remaining 13% is thought to represent the most advanced BIM adopters who never measure ROI because they already know the value and no longer feel the need to measure.

The intent of this project's ROI was to study emerging concept design BIM for infrastructure tools and processes and unearth potential clues toward qualitative and quantitative return on investment value (up to handoff at the end of 30% design). [Appendix F Project Benefits](#) provides initial findings.

Limitations in scope and lack of pre-existing, standardized metrics to qualify value infer a need for future work in this area. Future pilot projects that study ROI should also track from survey to project as-built because there is also a need for complete project life-cycle observations to fully understand the value that BIM information and processes bring to operations, maintenance, and management of capital assets throughout their useful lifespan.

CHAPTER 1: ROLE OF PROJECT CONTROLS AND BIM PROJECT EXECUTION PLANS

1.1 SUMMARY

Many examples of Building Information Modeling (BIM) execution plans (BIMxp) and templates exist for architecture. The challenge for civil transportation projects is how to leverage and learn what is relevant (or not) from these resources to develop BIM for infrastructure execution plans. Because the architecture industry is significantly more mature in BIM use, and because much of transportation design geometry is horizontal not vertical, details available in these plans often include out-of-context information for transportation engineers. Fundamentally, however, many processes required for success are the same, regardless of project type. Development of good templates and standards is an area of future development and research. It is anticipated that templates will arrive from entities such as AASHTO, National BIM Standard (NBIMS), AGC, or FHWA, followed by state agencies; these are not expected to be available in the near term, and they will be guides at best, such as provided in this project.

This project will provide an example BIMxp template (Appendix A: Example BIMxp Template). Because the stakeholders and potential future users are from a wide variety of jurisdictions throughout Minnesota (and because every project is different), the template is intentionally generic. Yet it provides a foundation that can be customized to fit the needs of individual agencies and projects of all types and sizes. The most critical element within the BIM for infrastructure movement will be the need for pre-emptive education throughout Minnesota and a continued emphasis on additional pilot projects (as mentioned in the Executive Summary). In addition, future project federal-funding requirements could someday require use of more efficient delivery methods such as BIM. To avoid scenarios where cities and counties are caught short-handed if this happens, educational campaigns and materials such as BIMxp templates must be available for agencies in Minnesota to move forward.

1.2 TASK PURPOSE

Communicate the role of project controls and BIM execution plans for Minnesota counties and cities who plan to adopt BIM for infrastructure methods on projects.

1.3 INTRODUCTION

Project controls are defined as the data-gathering, management, and analytical processes used to predict, understand, and constructively influence the time and cost outcomes of a project or program through the communication of information in formats that assist effective management and decision making. Traditionally this occurs by use of scheduling tools, such as Microsoft Project or Primavera (P6), cost estimation systems, and other project management tools.

Today, project controls take on an even larger role when used in the context of a BIM project and combined with a BIMxp. Specifically, the schedule is the project plan used for internal communication of work expectations and timing and for external communication of project requirements and status. The BIM life cycle modifies the relationships and timing of project processes. These relationships need to be represented in the project schedule and identified in the BIMxp to ensure that BIM coordination and other activities occur when they can provide the most value to the project.

1.4 APPROACH

This project studies emerging conceptual-design BIM for infrastructure tools and processes, with the intent to determine value during the early project life-cycle phases, up to handoff at the end of 30% design. The project mirrors a traditionally delivered project with BIM goals including capturing differences, lessons learned, and pitfalls, as well as identifying the potential for both qualitative and quantitative return-on-investment (ROI) value.

This task illustrates typical sequential steps of a small BIM for infrastructure project (up to 30% design handoff). These steps are shown on page 10 in [Table 1: BIM Uses](#). The relationships of individual BIM uses in this table also correlate to the P6 schedule ([Appendix B: Traditional vs. BIM WBS](#)) by Activity ID. Understanding dependencies and relationships to achieve milestones in the life-cycle chain of information is critical when planning a BIM for infrastructure projects.

While this project studies the 0-30% portion of the project life cycle, Figure 1.1 illustrates the entire life cycle, showing that the early phases of projects have more potential for positive impact on project value and ROI in later phases. Unfortunately, a common trend observed for civil projects is the tendency to embrace 3D modeling with no focus on leveraging multiple 3D model uses (BIM). The current trend is not BIM, only 3D modeling. When the model is only leveraged for one or two BIM uses, it is considered piecemeal (lonely BIM), representing a break in the life-cycle flow of information while failing to obtain maximum value.

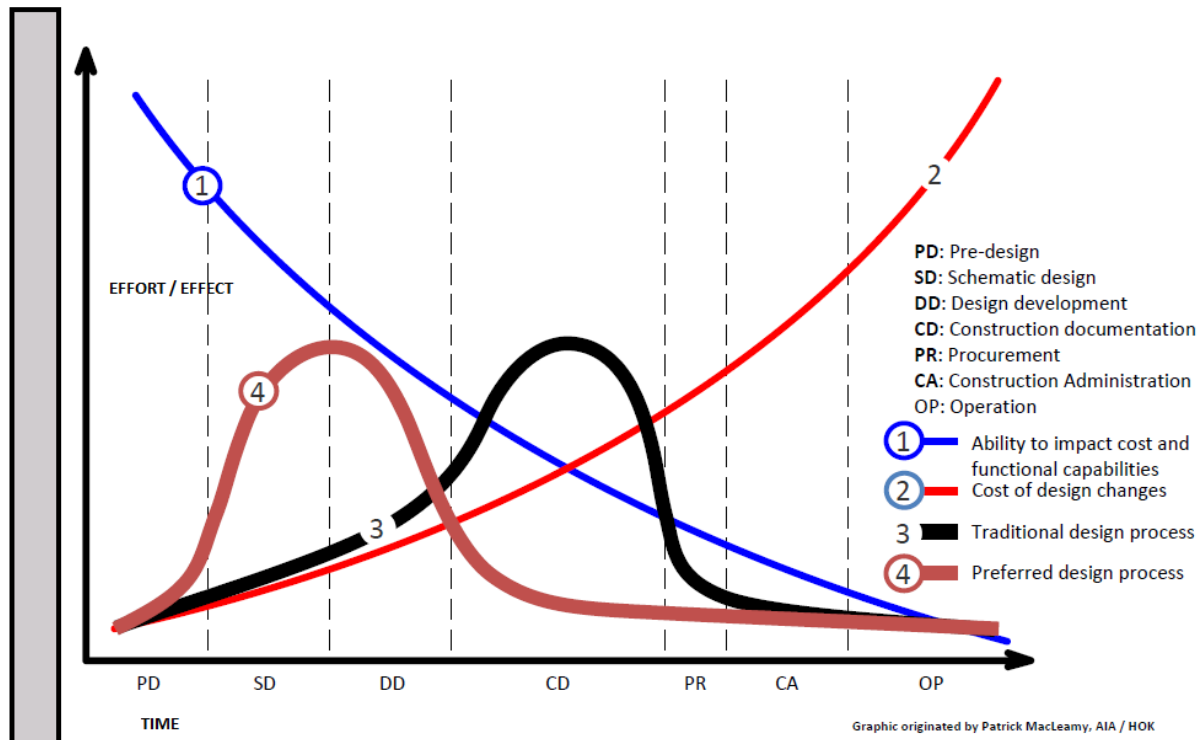


Figure 1-1: The MacLeamy Curve (2004) — impact of design changes on cost and relationship to phase
 (Source: www.division4triclinium.blogspot.com)

Figure 1 illustrates the premise for this research. The *current* (U.S.) transportation industry trend is to deploy singular 3D model uses in later stages of projects, such as designing in 3D only with the intent to hand off to automated machine-controlled grading (AMG). While this approach may provide occasional value, breaking the information chain (both metadata and geometry flow) reduces ROI potential. Furthermore, the inferred value of BIM is cumulative via multiple BIM uses leveraged throughout a project. Therefore, while piecemeal BIM use can provide value, it also introduces potential risk and conflicts with the overall value argument implied by data repurposing concepts and models that grow in intelligence. Cultural adoption of new BIM workflow needs addressed as lonely BIM perpetuates the old inefficient workflow and cultural siloes (unless used as a steppingstone to fuller life-cycle practices).

This traditional Marsh Lake Road project presents an opportunity for collaborative research that directly contrasts and compares traditional process, delivery tools, and methods with emerging BIM processes in preliminary project design steps. Most important, identification of workflow best practices conducive to incrementally feeding sequential, upstream steps of the life cycle has begun.

Data repurposing through collaborative and sequential workflows is one of the central tenets of the BIM argument. In other words, the inferred value proposition for (BIM for infrastructure) is that the more instances a common 3D model (and its inherent metadata) is repurposed, the higher the potential ROI and the lower the total cost of ownership (TCO) of the technology.

The scope of this project intentionally ends at the handoff to 30% design because the early design areas have the most potential to bring value to a project (reiterated in Figure 1.1 “ability to impact” curve).

1.5 METHODOLOGY

For the purposes of this pilot project, a P6 schedule was developed that integrates BIM activities. Within this schedule lie key BIM process relationships and milestones. Regardless of the scheduling technology used, every BIM project should have BIM activities, relationships, and corresponding milestones in its schedule. Note: while introducing new milestones, some will correspond with the timing of traditional process milestones.

To recognize the benefits of the BIM process, we modeled a project schedule using traditional project delivery methods and then modeled the project with BIM activities added to Scoping and Preliminary Design. This allows for a comparison between the traditional and BIM timelines. While there are additional BIM activities that occur during Final Design and Construction (with corresponding benefits), we have limited our comparison to Preliminary activities in this pilot project.

Other assumptions and considerations include:

- The same start date was used for both schedules.
- Specific dates were not analyzed but rather time savings were reviewed as periods of time.
- Due to the timing difference between the project’s traditional design and this project, we did not update the schedules with actual progress.

Findings based on the planning-level schedules (even with additional BIM activities within the Scoping and Preliminary Design process) show that the project can be completed approximately two months earlier than using traditional project methods.

1.6 PURPOSE OF THE BIM EXECUTION PLAN (BIMXP)

Civil Integrated Management (CIM) for Departments of Transportation, NCHRP Volume 1: Guidebook (2016) states “Neither the benefits nor the costs and management risks associated with adoption of CIM are as yet well understood.”¹

To help combat this, the purpose of a BIMxp is to provide a critical project management and QC document to establish the roles, responsibilities, and ground rules that optimize value of technology implementation on a project. In the simplest terms, a BIMxp provides mitigation of risk (risk as referred

¹ This statement should be qualified as “Neither the benefits nor costs and management risks associated with adoption in the Transportation Engineering industry are as yet well understood” (the benefits are clearly established and documented by the architecture and construction industry). McKinsey construction industry report from 2017: The European Construction Industry Federation predicts that the wider adoption of BIM will unlock 15-25% savings to the global infrastructure market by 2025.

to in the 2016 NCHRP report) when adopting new technology on a project. This document shall be considered a companion to the project management plan and roll directly into the project QC management plan as a pre-cursor to success for any BIM project.² The project controls schedule then incorporates critical dependencies, relationships, and milestones of the BIM-related activities, to ensure the life-cycle data-reuse elements and collaboration protocols stay on track.

The primary goal is to gain value from BIM processes in cost and time savings through accelerated schedule, more accurate designs, fewer RFI's, and more efficient use of taxpayers' dollars. Note that while requisite steps happening during design may reap benefits (such as faster decision making and reduction of schedule), the predominant payback for the owner shows up during construction due to more competitive bids, reduced number of RFI's, and accelerated construction.

Use of BIM technology on projects using traditional siloed transportation-design processes without a BIMxp can bring value in certain instances. Inappropriate use in this context can also be costly; some using this approach will completely fail in execution. This is easily avoided if minor adjustments to process, enhanced collaboration, transparency, and communication protocols are embraced. Entrenched culture and the "we have always done it this way" mindset is one risk to projects using BIM because this sabotages the collaborative communication process and workflows. To combat this, project owners must commit to working a new process and take the responsibility to ensure that the project design team, all sub-consultants, and contractors are actively buying-in to the BIMxp and associated processes.

The civil engineering industry in the United States (U.S.) is still in incubation mode when it comes to BIM for infrastructure projects. Change however, is constant and (in some jurisdictions) rapid. More and more states are adopting Civil Information Management (CIM) or BIM for Infrastructure.³ Many civil mega-projects around the country are using full BIM life-cycle processes. Jurisdictions of all shapes and sizes realize that this trend is on their doorstep and are beginning to prepare. Florida, Utah, Iowa, Michigan, Wisconsin, New York, Oregon, are State agency examples of early-adopter agencies leading the way in this area. Locally at least two Minnesota Counties have also started the process.

² The State of Minnesota BIM guidelines (which only exist for buildings and architects using Autodesk REVIT) refer to this plan as BIM Implementation Plan, or BIP).

³ While FHWA originally coined the acronym CIM to differentiate civil works from the architecture industry, FHWA is now supporting the adoption of BIM for Infrastructure, by TRB Committee J45454.

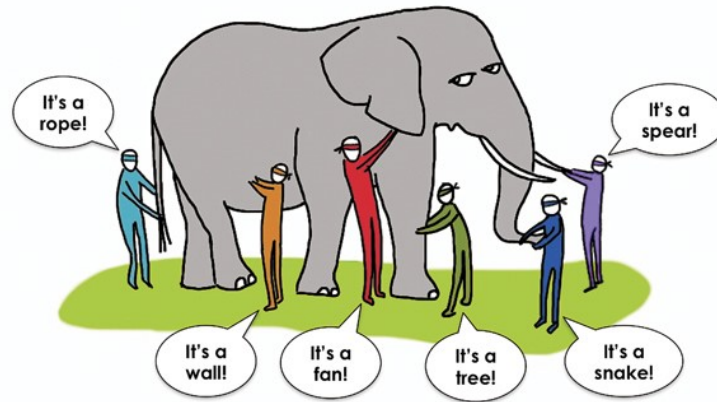


Figure 1-2: BIM can mean different things to different professionals.

From an overall architecture/engineering/construction (AEC) perspective in the U.S., architects led the way with adoption, followed by the construction industry, and finally, transportation design engineering. To be clear, water/wastewater engineers embraced BIM well prior to bridge, roadway, or municipal transportation engineers, as the water/wastewater discipline is closer to their architectural brethren in that they are deal predominantly with facilities that include mechanical, electrical, and plumbing (MEP) trade disciplines.

In the U.S. transportation industry, there are few civil BIMxp examples available in the public domain. The State of Minnesota has a [BIM guidance document](https://mn.gov/admin/assets/RECS-CS-BIM-Guideline_tcm36-208266.pdf) (2014)⁴ authored for State project facility building architecture specifically targeted for designing with Autodesk REVIT (Figure 1.3). This document therefore does not address transportation. National BIM standards also target architecture with some recent civil works additions (predominantly civil BIM [ontologies](https://bimdictionary.com/en/bim-ontology/1/)⁵). Despite the lack of BIMxp templates for transportation in the public domain this is not always a negative, as each transportation project is unique with differing issues and complexities. No single recipe exists; rather it will be an iterative learning process where value found should be documented as recommended best practices for potential inclusion in future BIMxp's. Likewise, pitfalls encountered, and other lessons learned should be noted for future avoidance. In addition, each jurisdiction may have unique standards and protocols that must be incorporated into any given project.

⁴ https://mn.gov/admin/assets/RECS-CS-BIM-Guideline_tcm36-208266.pdf

⁵ <https://bimdictionary.com/en/bim-ontology/1/>

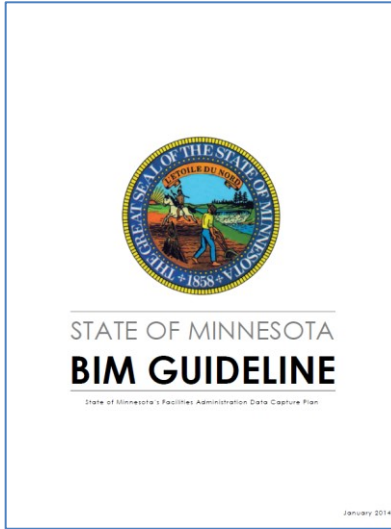


Figure 1-3: State of Minnesota BIM Guideline.

Once a template is developed and completed, the BIMxp then provides the recipe for successful BIM/CIM adoption and deployment on a project (to mitigate and resolve the statement posed by the 2016 DOT Guidebook). The BIM Project Execution Planning Procedure, shown in Figure 1.4, is a four-step procedure for developing an execution plan for a project and the foundation of the [BIM Project Execution Planning Guide](#).⁶

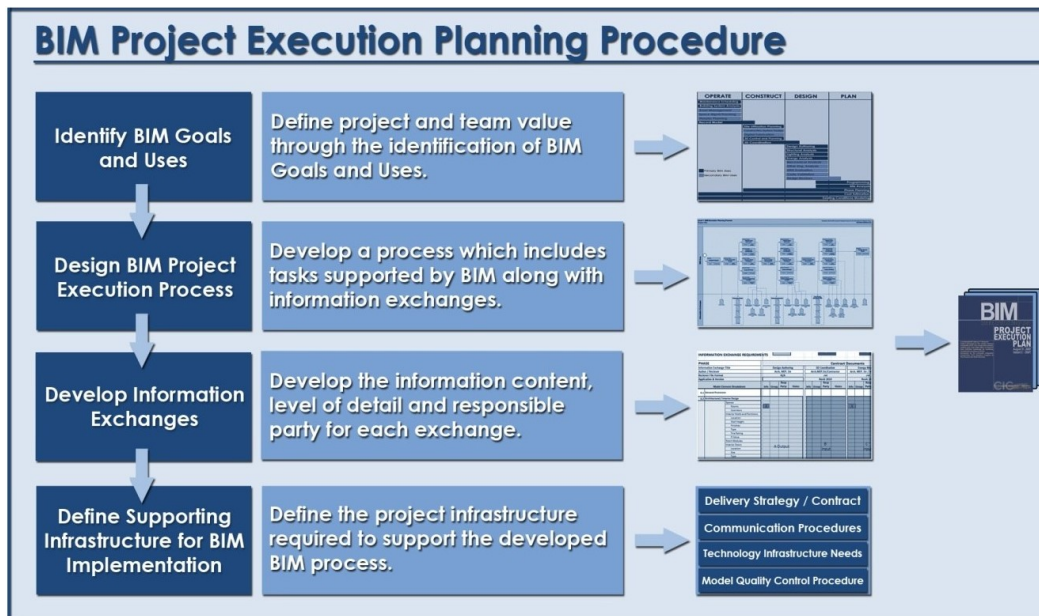


Figure 1-4: BIMxp Planning Procedure. (Source: Penn State BIM Project Execution Planning Guide)

⁶ https://www.nationalbimstandard.org/files/NBIMS-US_V3_5.3_BIM_PxP_Guide.pdf

The steps and sub-steps include:

1. Identify BIM Goals and Uses
 - a. Goals
 - b. Uses
2. Design BIM Project Execution Process
 - a. Work Break-down Structure (WBS)
 - b. Project collaboration plan
 - c. Project roles/responsibilities
3. Develop Information Exchanges
 - a. Model origin
 - b. Model coordinate system
 - c. Model Level of Detail (LOD)
 - d. Standard exchange format
 - e. Standard collaboration software
4. Define Supporting Infrastructure for BIM Implementation
 - a. Recommended hardware
 - b. Storage
 - c. Backup solution

1.7 COMPONENTS OF A BIMXP

1.7.1 BIM Goals

BIM goals for projects are set early in the project and form the basis for the rest of the BIMxp document. They set the tone for the project and therefore should be done at an early kick-off meeting, soon after notice to proceed (NTP). Examples of BIM goals include:

1. Sample BIM goal: The intent and primary goal of utilizing BIM in this project is to add efficiency in the design and construction at all phases of the project. This shall be accomplished by coordinating trades effectively so that they identify coordination issues in the design early, to mitigate issues in the field and aid the owner, major stakeholders, and the tax-paying public in visualizing their project. This will also increase productivity and reduce cost by minimizing the number of RFIs and time-consuming change orders and aid in pre-fabrication by avoiding delays in the schedule.
2. Sample BIM goal: It is the intent to capture weekly workplan information in models and leverage this to assist with overall project management.
3. Sample BIM goal: BIM implementation shall allow for a final deliverable of an as-built model issued to the owner for use in operations, maintenance, and asset management.

For this research pilot project, the BIM goals may read like this:

1. This project will communicate fundamental concepts of BIM for Infrastructure so cities and counties can understand the importance of project controls and BIMxp's for a successful BIM for Infrastructure project.
2. This project shall demonstrate the principles of re-purposing 3D models and data re-use from survey through 30% design to create efficiencies and reduce data and disciplinary siloes.
3. This project shall embrace BIM collaboration and a single source of truth 3D model to demonstrate at minimum a six-week reduction in schedule over a traditionally delivered design project, while simultaneously providing a more mature model to the 30-60% design stage.

1.7.2 BIM Goal Identification

Flexibility is key as the National BIM Standards Organization (NBIMS⁷) notes: "The goal for developing this structured procedure is to stimulate planning and direct communication by the project team during the early phases of a project. The team leading the planning process should include members from all the organizations with a significant role in the project. Since there is no single best method for BIM implementation on every project, each team must effectively design a tailored execution strategy by understanding the project goals, the project characteristics, and the capabilities of the team members."

A BIMxp is a needs assessment and project planning guide document rolled into one process that:

- a) Defines work break-down structure (WBS) to leverage the 3D engineering model for repeated use throughout the project life cycle.
- b) Addresses key functional requirements including (but not limited to) standardization of assembly codes, naming conventions, interoperability, and functionality of systems.
- c) Establishes visualization and collaboration protocols.
- d) Provides model LOD requirements for each step and deliverable of the project.

In IT jargon, these are called Functional Requirements. For a project using BIM, these requirements define the activities and standards necessary to successfully utilize (and optimize) BIM on a project.

⁷ Jurisdictionally in the United States, National BIM Standards (NBIMS-US), an initiative of the National Institute of Building Sciences, building SMARTalliance, provides standards for the architecture industry, and more recently, additions for civil works.

1.7.3 BIM Uses

BIM model uses = value. Model uses for this 0-30% design project are illustrated in Table 1. However, in a full project life-cycle scenario, the BIM use list would be expected to grow with additional uses such as:

- Sub-surface 3D Utility Engineering (Level A&B SUE)
- Hard Clash (geometry clash) detection
- Quantity Take-off (more mature than 0-30% automated quantities)
- 4D simulation (for management of traffic, logistics, safety, alternative concepts)
- 5D cost-loaded simulation
- Automated Machine Grading (AMG)
- As-built into O&M/Asset Management

Table 1: BIM Uses on Pilot Project

BIM USE	Involved Parties	Relationship	P6 ID	Data	Benefits
Existing Conditions Modeling- (Reality Capture Survey)	Owner Design Consultant Survey UAS Contractor	Feeds as built conditions to down-stream activities	A1400 A1410	↓	Rapidly provides accurate 3D base map and field conditions
Planning/GIS/Environmental (Simulated Project Scoping)	Planners/GIS Analysts, ROW	Dependent upon Reality Capture data, upgrades to as-built model		↓	Design input model gets more feature rich info 3D Planning environment with sense of place
3D Conceptual design (simulated alternatives analysis)	Owner Design Consultant Major Stakeholders	Dependent upon previously enhanced base model Collaboration Step	A1630	↓	Incorporates GIS and other ancillary info into one source of truth (model) Optioneering (facilitates affordable 3D review of more options than normal)
3D Decision Support System (DSS) (Computative Alternatives Analysis) – (simulated Corridor Route Optimization)	Owner Design Consultant ROW	Dependent upon previous model Collaboration Step	A1240	↓	Cloud process auto -computes optimum route(s) (based on inputs)
Internal Design Intent Review(simulated)	Owner Design Consultant Major Stakeholders	Feeds estimation Dependent upon previous model Collaboration Step	A1620	↓	Rapid consensus, transparency, design is in real-world 3D context
Volume/Cost Estimation - Semi-automated Profile Optimization	Design Consultant Estimator	Dependent upon previous model	A1660	↓	Rapid prelim volumes and cost available for each alternative. Cloud profile optimization delivers optimum profile
Preferred Alternative	Owner Design Consultant Major Stakeholders	Collaboration Step	A1690	↓	
Public Engagement Visualizations (simulated)	Owner Design Consultant Major Stakeholders Public	Collaboration Step	A1620	↓	Rapid consensus and transparency, model re-use

1.8 WORK BREAKDOWN STRUCTURE

Changes to the work breakdown structure (WBS) for BIM project process scenarios were identified in the modified P6 Schedule ([Appendix B Traditional vs. BIM WBS](#)). Both traditional and BIM WBS are illustrated in this modified schedule to contrast and compare the differences. Inferences were made for time savings in key BIM activities versus traditional methods that are a direct result of UAS reality capture, increased collaboration, semi-automated processes, faster consensus and decision-making, integrated GIS, and workflow silo reduction. In this project example P6, 45 working days are shown as being reduced from schedule due to use of BIM process.

1.9 PROJECT COLLABORATION PLAN

The project collaboration plans tie directly into the project schedule. BIM coordination meetings should be held on a regular basis once conceptual design has started. Depending on project duration and phase, after the BIMxp is completed and the project is underway in a typical scenario there will be weekly or bi-monthly coordination meetings held on Mondays. The Friday before a Monday meeting, disciplinary leads submit their model work to the BIM manager who aggregates them into the master model (the *digital twin*⁸). In some cases, the BIM Manager would run clash detection on the model on this Friday. The following Monday, the project team would gather to review the previous week's progress and plan to resolve clash (if any).

The BIM manager facilitates these meetings. The model may be displayed in Bentley or Autodesk "middleware" collaboration software.

Other key elements of the collaboration plan include:

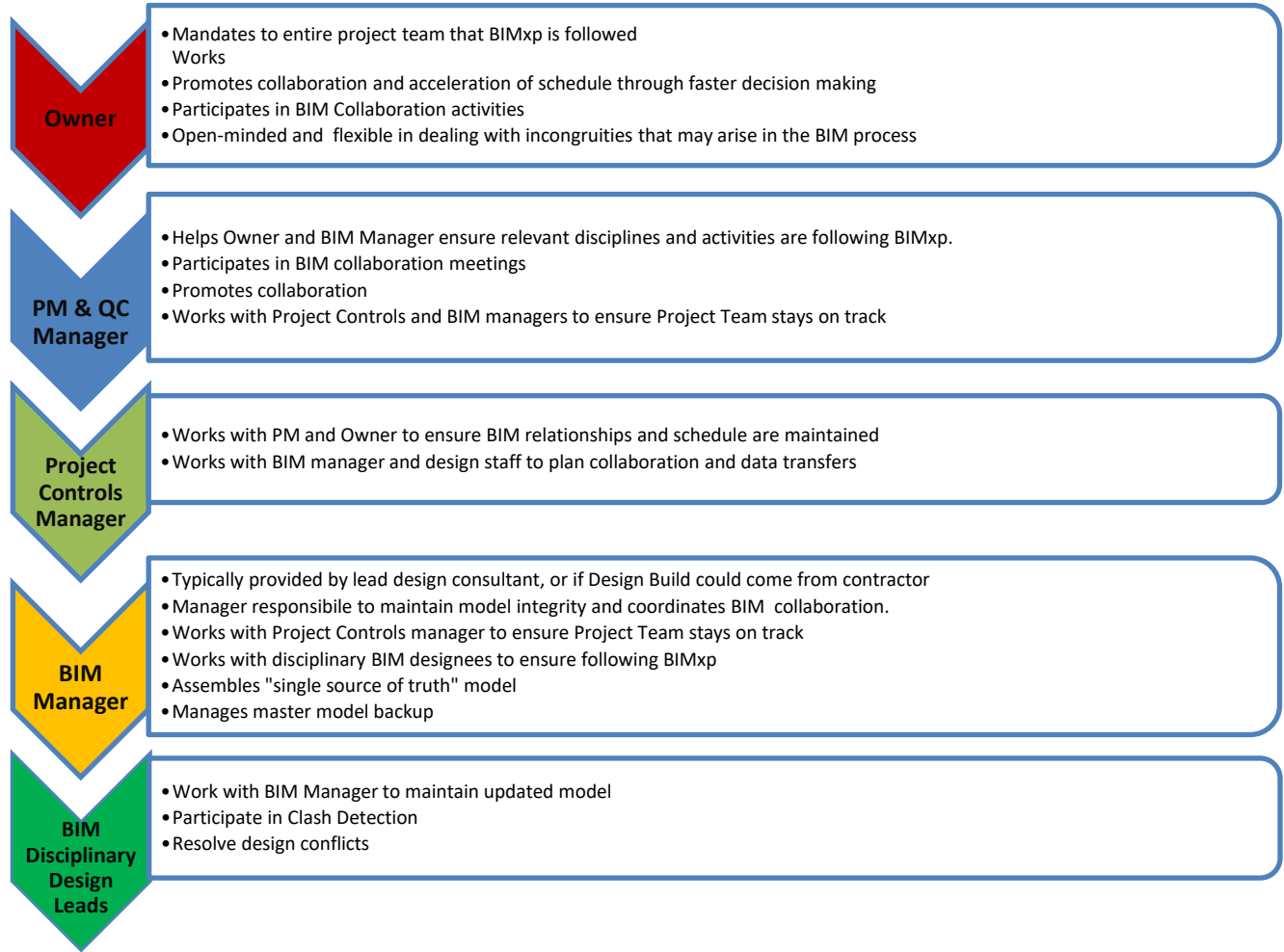
- Design intent visualizations (internal rough concept models)
- Preferred alternative visualization (upgraded model)
- Public outreach visualization (upgraded renderings, VR or animations)
- Project simulation (Traffic or 4D, 5D)

1.10 PROJECT ROLES AND RESPONSIBILITIES

The project scope determines which of the roles are required on a project. Not all roles are required for all projects. However, there should always be a BIM Manager for the prime designer of record and ideally, a BIM Manager for the constructor. Additional BIM model coordinators may manage the various discipline models on a project to ensure interoperability between technologies used on the project, perform model updates and versioning, and facilitate clash or quantity generation. Table 2 (next page) illustrates high-level examples of BIM Roles and Responsibilities.

⁸ https://en.wikipedia.org/wiki/Digital_twin

Table 2: High-level example BIM roles and responsibilities for a typical transportation project.



1.11 INFORMATION EXCHANGE

1.11.1 Exchange Formats

Exchange format protocols will address primary file types such as 3D DGN or DWG (compatible with BIM) but could also use BIM-only specific exchange formats such as .dgn db, .imx, .rvt, and emerging open source formats for interoperability such as Industry Foundation Classes (.ifc).

1.11.2 Collaboration Software

Historically collaboration software was solely dependent upon the project design platform being used. Nowadays, improvements in file format interoperability opens the door for other collaboration solutions. Collaboration and BIM use facilitation tools such as Autodesk Navisworks or Bentley Navigator are considered middleware software. Other robust middleware project management and collaboration

software suites in use by civil construction and architecture firms include Tekla (Trimble), InEight (Kiewit subsidiary), Solibri, and [Viasys VDC](#)⁹ (now Topcon MAGNET previously deployed by the Wisconsin Department of Transportation on The Zoo Interchange). The ubiquitous Bluebeam could also fall into this category of products allowing digital redline markup and cloud sharing capabilities for extended staff. For Bentley projects, Navigator, LumenRT, and Synchro4D (recently acquired by Bentley) could be used in conjunction with ProjectWise. For the purposes of this project the following Autodesk collaboration software would be considered:

- Infracore – concept design alternatives
- Navisworks – clash detection, redline
- BIM360 – file sharing
- Glue – redline

1.12 LEVEL OF DETAIL (LOD) REQUIREMENTS

In the simplest of terms, LOD means modeling to the correct level of detail for the correct BIM use.



Figure 1-5: LOD Phase Relationships.

LOD is synonymous with model “level of development” and typically expressed on a sliding scale from 100-500. Generally, BIM uses leveraged in early project stages require lower level of detail as illustrated in Figure 1.6.

LOD requirements for BIM projects is one concept that can be adopted almost verbatim from the architecture industry. For example, from www.BIMforum.org: The Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process. Slight variants would be made for context of civil transportation works, but application of the underlying concept remains the same.

⁹ <https://www.viasys.com/blog/improved-collaboration-with-bimcim-models-wisconsin-dot/>

The intent of the specification is to help explain the LOD framework and standardize its use so that it becomes more useful as a communication tool. It does not prescribe what Levels of Development are to be reached at what point in a project but leaves the specification of the model progression to the user of this document. To accomplish the document’s intent, its primary objectives are:

- To help teams, including owners, to specify BIM deliverables and to get a clear picture of what will be included in a BIM deliverable
- To help design managers explain to their teams the information and detail that needs to be provided at various points in the design process
- To provide a standard that can be referenced by contracts and BIM execution plans

It should be noted that this specification does not replace a project BIMxp (or BEP), rather it provides a means of defining models for specific information exchanges, milestones in a design work plan, and deliverables for specific functions.

Table 3 and Figures 1.7 - 1.8 provide further explanation of the level of detail concept. It should be noted that definitions applied to this information were developed and refined in the architecture industry. LOD is specified in BIMxp prior to beginning modeling. Over-modeling for BIM uses may be more common than under-modeling. Since over-modeling is a potential waste of project funds due to changes or decisions on alternatives, it is important to clarify LOD early in the process with all disciplines who submit 3D components of the master model.

Table 3: LOD Definitions

Level of Detail	Definition
100:	A Conceptual Model where parameters like area, height, volume, location and orientation are defined.
200:	An Approximate Geometry Model where elements are modeled with approximate quantities, size, shape, location and orientation.
300:	Precise Geometry Modeling and shop drawings where elements are defined with specific assemblies, precise quantity, size, shape, location and orientation.
350:	Includes Model Detail and element that represent how building elements interface with various systems and other building elements with graphics and written definitions.
400:	Model elements are modeled as Specific Assemblies with Complete Fabrication, assembly, and detailing information in addition to precise quantity, size, shape, location and orientation.
500:	As-Built elements are modeled as constructed assemblies for maintenance and operations.


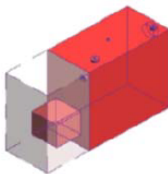
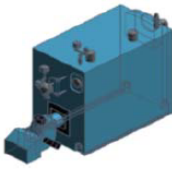
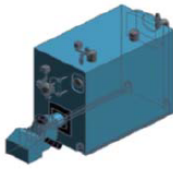

LOD 100 Conceptual	LOD 200 Approximate geometry	LOD 300 Precise geometry	LOD 400 Fabrication	LOD 500 As-built
				
The Model Element may be graphically represented in the Model with a symbol or other generic representation , but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square metre, etc.) can be derived from other Model Elements.	The Model Element is graphically represented in the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation .	The Model Element is graphically represented in the Model as a specific system, object, or assembly accurate in terms of quantity, size, shape, location, and orientation .	The Model Element is graphically represented in the Model as a specific system, object, or assembly that is accurate in terms of quantity, size, shape, location, and orientation with detailing, fabrication, assembly, and installation information .	The Model Element is a field verified representation accurate in terms of size, shape, location, quantity, and orientation.
	Non-graphic information may also be attached to the Model Element.	Non-graphic information may also be attached to the Model Element.	Non-graphic information may also be attached to the Model Element.	Non-graphic information may also be attached to the Model Element.

Figure 1-6: LOD by Phase with definitions.

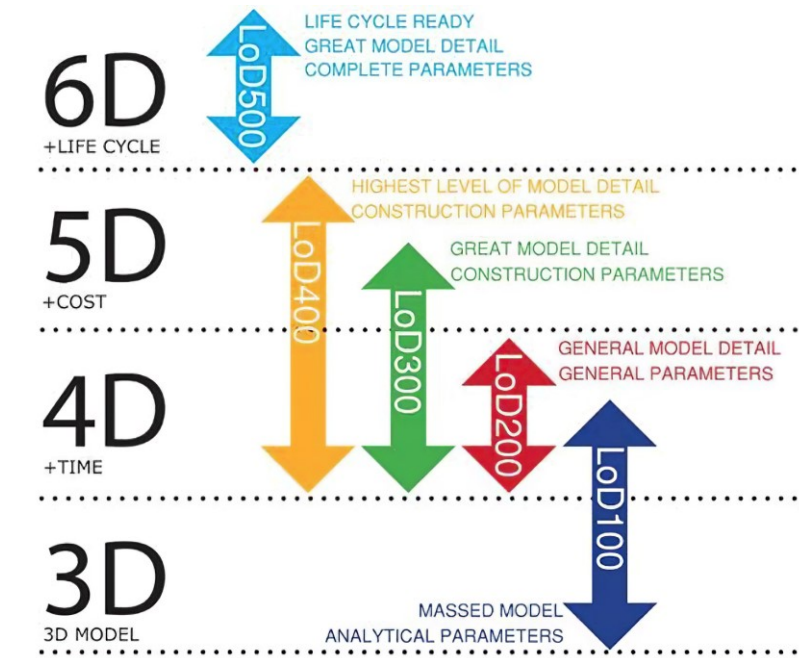


Figure 1-7: LOD for early phases and early BIM uses, expressed with additional dimensional aspect. (Source: www.cadeosys.com/services/model-with-different-ld/)

Figures 1.9 - 1.12 provide an example of how LOD can also be applied to a typical roadway project.

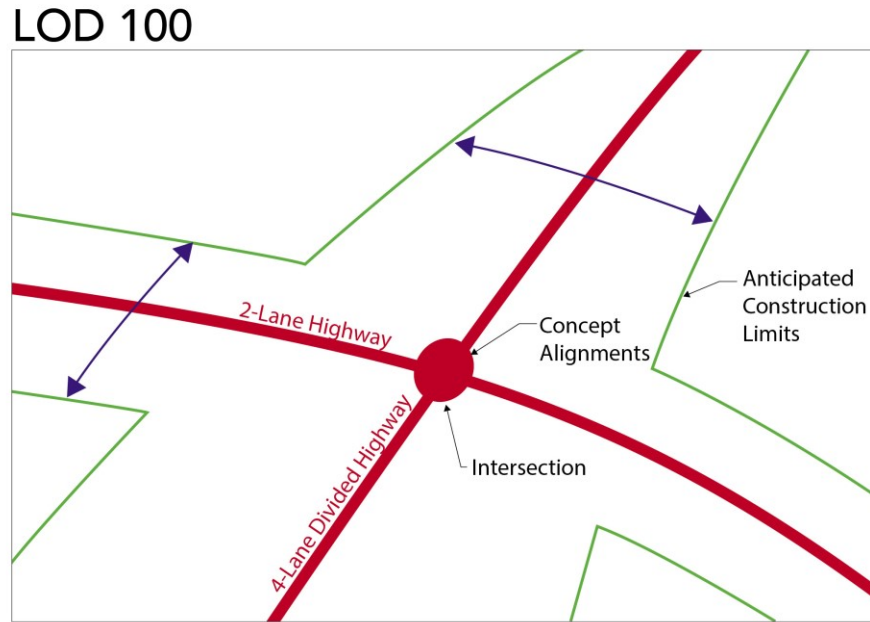


Figure 1-8: LOD 100 elements for a highway project.

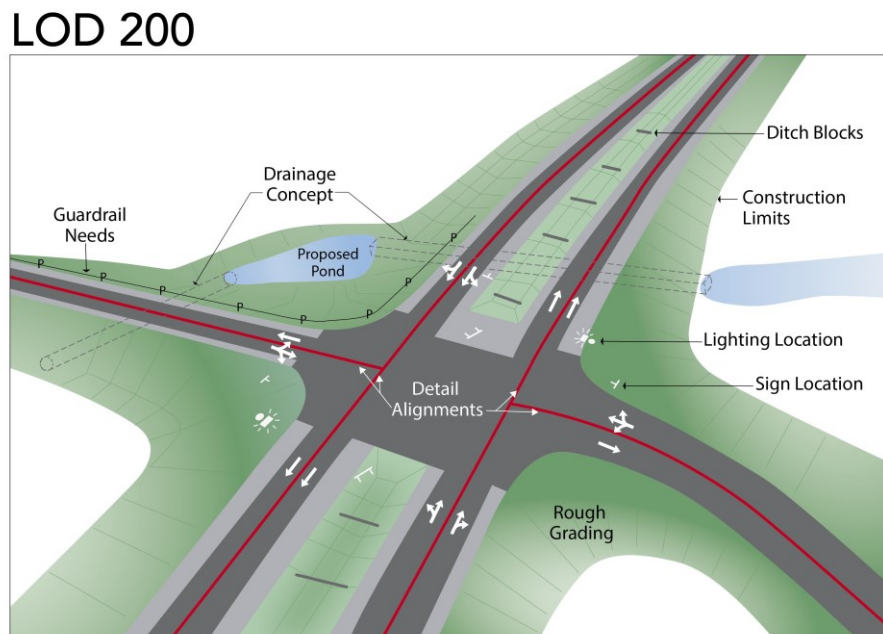


Figure 1-9: LOD 200 elements for a highway project.

LOD 300-400

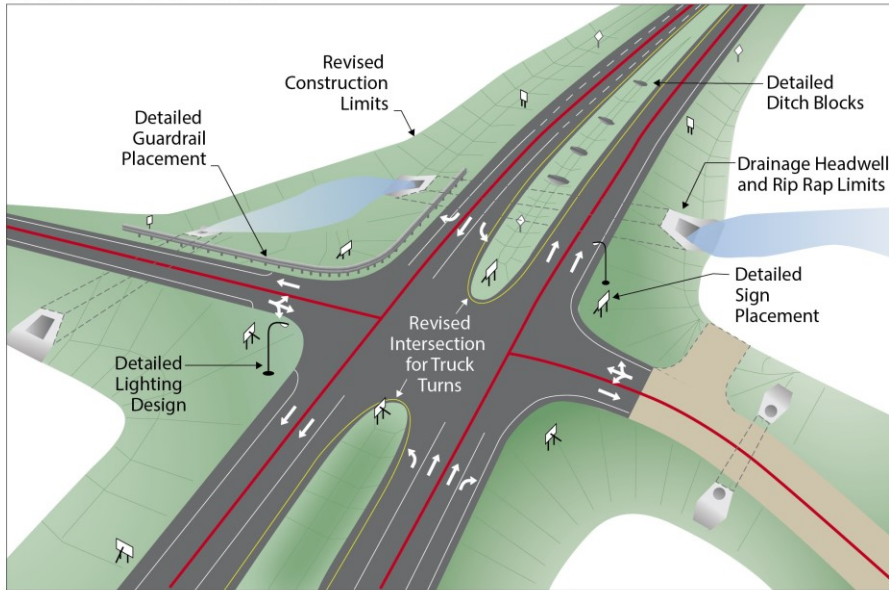


Figure 1-10: LOD 300-400 elements for a highway project.

LOD 500



Figure 1-11: LOD 500 elements for a highway project. (Image Source: SRF Consulting Group)

1.13 SUPPORTING INFRASTRUCTURE

1.13.1 Hardware Level Specifications

1. BIM Designer PC specifications
2. BIM Manager facilitation PC (portable) specifications
3. BIM Viewer PC specifications

1.13.2 Model Storage Protocol

1. Project team will use XXX cloud common data environment (CDE)
2. Project team will use local drive XXX
3. Design file versioning will be enforced via XXX

1.13.3 Data Backup and Archive Protocol

1. Project back-up will be performed nightly
2. Archive will take place at key project milestones

1.14 BENEFITS/SHORTCOMINGS

1.14.1 Benefits

- The BIMxp fosters understanding and purpose early in the project life cycle.
- The BIMxp provides a mechanism to obtain benefits.
- The BIMxp creates a framework for success and to manage (reduce) risk.
- Project Controls scheduling process compliments the BIMxp, providing a mechanism that facilitates BIM milestones and coordination of disciplinary processes.

1.14.2 Shortcomings

- Every project is unique underlying need for flexibility in BIMxp's and scheduling process.
- Change is happening fast in the industry; referencing past research can provide outdated information or promote disinformation.
- Entrenched workforce culture and siloes present challenges; the inability or unwillingness to change introduces significant risk for BIM for Infrastructure projects.
- The civil transportation design industry must re-write the book and modify existing BIM standards and documents.

1.15 NEXT STEPS

Potential next steps include:

- Organize local user groups.
- Develop educational campaign and materials to engage counties and cities in Minnesota.
- Develop standards and processes that can work for a wide variety of agencies.
- Tie these preliminary design study findings to final design and construction process research studies to map out a complete transportation project life cycle.
- Generate additional pilot projects with cities and counties with different sizes and types of projects and leverage lessons learned from this initial pilot project.
- Develop Decision Support System matrix that helps owners determine projects that are “best fit” for BIM technology adoption.
- Learn from successes and errors by reaching out to early adopters of BIM for infrastructure in other states.
- Develop solid Key Performance Indicators (KPIs) and quantitative measures to track value.
- Gather and study transportation BIMxp’s made available by states, counties, and cities that adopt BIM for Infrastructure.
- Conduct additional research on work break-down structure differences between traditional projects versus BIM projects.
- Research and document ramifications of contract mechanisms on BIM roles and responsibilities.
- Identify Best Practices to move the civil engineering design community forward; identify weak areas in BIM for Infrastructure execution plan templates.
- Work with vendors.

CHAPTER 2: EMERGING 3D SURVEY (REALITY CAPTURE) TECHNIQUES

2.1 SUMMARY

This study has shown that data collected from both traditional and UAV methods result in data that is flexible for use in many forms providing a cost-effective means to collect survey data while obtaining additional formats for different use-case's and consumption in various software packages.

The necessary steps used to collect UAV data does not eliminate the need for traditional survey methods and techniques. In fact, using traditional survey ground control as well as traditional knowledge and standards to complete survey collection is a necessary skillset to augment potential limitations in UAV and other reality capture method technologies. Conversely, new reality capture methods provide benefits not available with traditional survey techniques.

2.2 TASK PURPOSE

Examine impact to project costs, planning, and design processes utilizing new methods that augment traditional survey methods, collectively known in industries as "Reality Capture" technologies. Develop procedures for data collection and processing into a usable format for preliminary design demonstration.

2.3 INTRODUCTION

Modern technologies have offered ways to generally collect more information while improving efficiency and reducing costs. From the transits and theodolites to total station and robotic survey, from field books to electronic data collection, from word descriptions to point databases, and manual plotting to electronic data processing, the efficiency of collecting topographic survey has increased exponentially. With newer technologies now being incorporated (such as static and mobile LiDAR, UAV photogrammetry, and GIS data sources, it is even more important for agencies to review existing means and methods to see what further efficiencies can be realized to reduce costs and positively impact public funding allocated to these projects.

UAV photogrammetry has been used more recently during construction to monitor materials management, operations and maintenance of infrastructure elements (such as bridge and building structures), and visualization base mapping. This project details the findings of applying UAV technologies to an existing design project, where traditional mapping has already been obtained for the length of the project, thus offering a unique opportunity to making a direct comparison of UAV technology results against the tried-and-true methods of traditional topographic survey collection methods.

2.4 APPROACH

The Marsh Lake Road project is a typical small to mid-size roadway construction project (approximately 1.7 miles in length) encountered in Minnesota. The existing roadway is generally a two-lane aggregate roadway with a rolling profile located in City of Victoria, residing entirely in Carver County. The roadway is bounded by older rural residential/farm properties, with new residential development occurring at an increasing pace. Due to increases in additional traffic and potential operation issues at the intersections of CR 43 and 11 at the west and east intersections of Marsh Lake Road, the City is pursuing plans to upgrade the facility to a paved, multi-lane roadway. The City is taking a phased approach with the design work, proceeding with a contract to complete the conceptual and preliminary design of the preferred alternatives, then developing a second contract to develop the final design and construction documents for the preferred alternative.

The existing right-of-way for the roadway is generally 66' wide and is consistent in width through-out its length. Development platting continues to occur and typically the plats would account for any planned road improvements anticipated to occur, but if new plats are filed, the City or County would need to plan for potential right of way acquisitions if the eventual preferred designs impact those properties. Complicating this, the project is exploring multiple alternative concepts which may impact different properties at different levels.

With this context in mind, the field data collection needs to capture enough data to facilitate multiple alternative configurations and deliverables, but also prove to be a cost-effective data collection method given available funding. Depending on the size of the project, agencies have a few avenues to collect this data, which include basic GIS data or public domain (i.e. USGS or DNR) mapping data for lower level detail¹⁰, to aerial photogrammetry or traditional surveying methodologies potentially coupled with static LiDAR for project level data collection for high detail and final design requirements.

The original topographic survey was collected by Carver County's survey crews using traditional survey methods and provided all work necessary to create the completed topographic files, including existing site grading, roadway features, drainage, and signage available as of July 9, 2014.

¹⁰ Note even public domain data such as Minnesota State LIDAR (DNR) is not always low-level detail; DNR LIDAR is 1-meter resolution in some areas, a huge leap towards engineering grade vs traditional USGS terrain products.



Figure 2-1: Marsh Lake Road UAV Survey Extents.

For this research, Carver County acquired additional survey using an Unmanned Aerial System (UAS) supplied by Collins Engineering, Inc. Using the original survey work as a guide, flight missions were developed allowing UAV data collection along the original established project footprint (Figure 2-1).

Once the reality capture flights were complete, data was processed to provide raw and compressed aerial images, ortho-mosaics of the surveyed area in GeoTIFF format, the topographic data point cloud, a Digital Surface Model (DSM), a Digital Terrain Model (DTM) and compressed ECW image formats.

Using the results from both the traditional and UAV collected data, performance metrics will be created between both collections to identify impacts to costs and planning needs necessary to perform the collections in the future.

2.5 METHODOLOGY

The creation of modern topographic survey CAD files generally mirrors the original means and methods used to establish the final deliverable. The surveyor needs to locate the project within its jurisdictional area, then establish field setups within the area to collect the field information, identify information follow an established definition to describe features, return the information to the office to data reduction and processing, and QA/QC on the product prior to deliverable. Regardless of the means and methods of the staff, equipment, or technology implemented used to obtain the data, generally these steps are always necessary to complete the data.

The traditional survey collection and UAS “Reality Capture” collections both provide specific site information pertinent to the development of a design project. For this project our study is specifically focused on measuring ROI for implementing reality capture collection in lieu of (or to augment) traditional survey, and to identify benefits and shortcomings anticipated for this implementation. Therefore, this discussion will focus more on comparing the results between the two methods and less

on how both methods were carried out. The exception to this will be a discussing the efficiency of the actual UAV versus other types of UAV's.

Comparisons will be normalized to provide an “apples to apples” comparison between methodologies. The traditional survey was performed by a government agency in which the hours and duration billed to perform the work is known but associated costs that a consultant may incur may not be comparative (labor, overhead, and profit considerations). Therefore, we are using hours and duration as the benchmark in comparing the level of effort to compare efficiencies.

Traditional Survey Collection¹¹

For this project the data was initially collected by traditional survey only (no supplemental data) by Carver County survey staff to address required data to complete final design. At the time, it was understood that additional alternatives would need to be studied (though those concepts were not yet known), so additional data points were collected in attempt to capture a larger footprint. The roadway survey was collected by cross-sectioning of the existing roadway into approximately 100' intervals, with the section width ranging from 100' to 300'. Supplemental data relevant to drainage and utility infrastructure, traffic signs, etc., were also collected. The data collection, including processing of the survey was initiated on or about December 3, 2012 and completed July 9, 2014 (based on survey date stamp in the CAD file), and then provided to the preliminary design consultant for use. The county collected the survey information using a two-person survey crew for both the control survey and the topographic surveys. The control survey used to locate the project within the established Carver County Coordinate System, was established using survey monuments previously establish outside the project limits, and then further established within the project limits to facilitate instruments traversing through the corridor. The vertical elevations were established at the same control points using traditional leveling methods, completing a level loop for each control point.

The completed survey included a dwg CAD data file containing the xyz data of all the surveyed points. The file also included supplemental information using LiDAR data from the MnDNR as a base terrain, and design information for development anticipated along the north side of Marsh Lake Road. For the purposes of this study, the traditional work of the survey data collection with the inclusion of the LiDAR and development plan (as office time) is included in this analysis.

UAV Survey Collection¹²

Collins Engineering used the [senseFly albris¹³](https://www.sensefly.com/drone/albris/) drone as the UAS collection solution. The senseFly albris² is an intelligent rotary drone designed for close mapping and industrial inspection applications. It is equipped with an autopilot and GPS. It features a fully stabilized TripleView (HD video, 38 MP still, thermal) camera head, five navcam sensors and five ultrasonic proximity sensors. Due to situational

¹¹ Based on information provided by Scott Smith, Carver County on July 23, 2018.

¹² Based on conversations Barritt Lovelace, Collins Engineering on June 1, 2018.

¹³ Website: <https://www.sensefly.com/drone/albris/>

awareness provided by this array of sensors the albris can fly close to objects in order achieve sub-millimeter ground sample distances (GSDs).

At low altitudes, or when flying close to objects, the albris is best operated in its Interactive ScreenFly mode. This includes features such as Cruise Control, Distance Lock and the auto-triggering of images. For safety of operation the albris is lightweight, fully shrouded and features multiple safety functionalities.



Figure 2-2: UAS flight operator and control center.



Figure 2-3: senseFly albris in the field on landing pad.

The project location had 10 Ground Control Points (GCP) placed along the project corridor. Also 10 check points were provided which were portable Propeller Aeropoints which are used to establish accurate location data at the point location. The proximity of the check points in relation to the GCP was established to that collected data could be manually measured against as a check. Generally, the GCP and check points ranged in elevation from 1004.8' +/- and 976.0 +/- . The Collins Engineering ground control points (GCP's) is provided in a mission GCP report ([Appendix C Collins GCP Report](#)).

The flight plan was made up of 15 flight missions, at a height where the collected survey data in the field would result in a minimum accuracy of 1 cm/pixel. The number of missions and the accuracy of the ground sampling are related to both the type of UAV used as well as the height at which the data collection is performed. For this project, the use a rotary type UAV allows the collection of 1 cm/pixel data, but the resulting flight plan increase the time of collection. Also, for linear-type projects such as this, Collins Engineering identified that fixed-wing UAV tend to be more appropriate as they can collect the data more efficiently over longer distances, but may suffer a reduction in the accuracy, approaching > 3 cm/pixel.



Figure 2-4: UAV collection points with GCP and Check Points. (Source: Pix4Dmapper)

The UAV flight data collection was initiated and completed on May 10, 2018. Weather conditions were generally favorable for the flight, but did have some instances of heavy wind, with sunny and overcast conditions. Generally, overcasts days with consistent cloud cover are considered ideal.

The UAV survey mission was planned and processed by Collins Engineering using the softwares eMotion 3 and Pix4D. eMotion 3 is a propriety software provided by senseFly (the UAV vendor) to plan the flight missions, automate the flight along the predefined flight path, and export the telemetry. eMotion's built-in tool set handles the georeferencing and preparation of images used for Pix4Dmapper, a tool with the Pix4D software.

Pix4Dmapper is a suite tool that uses the georeferenced telemetry data in conjunction with the photo imagery collected along multiple flight paths. This data then becomes point clouds of data points which are used to develop the terrain model in multiple formats. The process in which the terrain is developed uses methods nearly identical to traditional photogrammetry but different in that the software has a significant increase in data points that need to be processed. The software automates processing and data selection by implementing both Machine Learning and AI in its base products to facilitate correct selection and processing of known data points. Those automated processes are primarily triangulation

and classification of data points. Classification is performed based on the current [LAS Specification 1.4](#).¹⁴ For the Marsh Lake Road mission, data processing took place both locally on the consultant laptop and on Pix4D's cloud services. Based on the project size and the amount of data procured, the Pix4D cloud services provides improved processing speeds, thus reducing the amount of time necessary to reduce data derivatives for the required product deliverables.



Figure 2-5: Comparison of Propeller Aeropoint (left) and Carver County-provided Aerial Control Point.



Figure 2-6: General Locations of GCP and Check Points.

Processing time is generally dependent upon the size of the data set, and it was noted by the product vendor that for this level of data (collected at the < 1cm/pixel) that the Pix4D software was reaching the

¹⁴ Website: https://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf

maximum data amount for its existing cloud services to process effectively. However, the processing was completed in 80 hours.

Once Collins Engineering completed the processing final deliverables were delivered to Carver County and the LRRB project investigators on June 4, 2018. From start to finish, the total time from the initial UAS survey to delivery was 17 working days.

Propeller Aeropoints – Check Points

The propeller Aeropoints used on the project, while not officially proposed as a study on the project, were also used by Collins Engineering as a part of the study as well to test the accuracy of these devices when used as survey control in place of traditionally placed survey control.

The device is approximately 2' x 2' intended to act as a rapid deployment GCP for UAS data collection operations. The device uses built-in GPS which continually records its position within the Propeller Correction Network, a proprietary network developed nationally with permanent base stations to triangulate the devices location. Per product technical specifications¹⁵ a minimum of 10 AeroPoints are normally placed around the survey area and activated to begin procuring the positional data. The devices need to be active a minimum of 45 minutes to the GPS to accurately determine location. The devices are battery powered but are supplemented with solar panels as well. Fully charged with no solar recharging, the devices can run up to 45 hours. Stated accuracies for the devices are < 10 mm for both horizontal and vertical measurements.

Collins used the 10 Aeropoint devices as part of the check points for the UAS flight and referenced the Carver County-provided GCPs to compare accuracy. Results showed that 9 of 10 devices had less than 8 mm difference in the X and Y directions, and 5 of 10 devices had less than 10.0 mm in the Z direction, which is within the state tolerance.

Results

The results from both survey collection methods were compiled and summarized in Table 4 (next page). During the compilation of the results it was identified that the traditional survey had additional information collected in which the UAS would not be able to collect alone, which included drainage infrastructure and utilities. To account for this missing data, it was assumed that supplemental survey would be required, and that survey would follow traditional survey methods and data processing methods conducive to that data.

¹⁵ Website: <https://www.propelleraero.com/aeropoints/>

Table 4: Comparison of Effort Required to Perform Survey Data Collection for Marsh Lake Road

Data Collection Type	Staff (FTE)	Total Staff (hrs)	Process Time (hrs)	Costs (\$)	Notes
Traditional Survey¹					
Project Control / Topographic	0.45	931.75		\$51,100	(4)
Data Reduction / Processing / (QA/QC) ³	0.28				(5)
		931.75		\$51,100	
UAV Reality Capture Survey²					
Project Control	0.28	575.75		\$18,990	(6)
UAV Topographical Survey	0.45	16		\$8,770	(7)
Data Reduction / Processing / (QA/QC)		24	80		(8)
Supplemental Survey	0.28	287.87		\$9,495	(9)
Data Reduction / Processing / (QA/QC) ³	0.28	16			(10)
		919.62	80	\$37,255	

Notes:

1. Hours based on conversation with Scott Smith (Carver County) on staff hours utilized to perform the work.
2. Hours presented based on conversation with Barritt Lovelace (Collins Engineering) describing actual staff and process time to reduce and deliver the data.
3. Process Time for traditional and supplemental survey is assumed concurrent with staff time.
4. Two-Person survey crew with equivalent FTE for office staff in terms of cost.
5. Processing includes downloading data from collection, reducing data geo-coordination data, spot and break lines were exported to CAD.
6. If Aeropoints used as only control, costs would be reduced further (Aeropoints were used as check point for GCPs).
7. One (1) additional member for training purposes.
8. Manual Time for Emotion 3 and Pix4D (4 and 20 hours) respectively.
9. Supplemental survey necessary to pick up underground and drainage features the UAV would not be able to collect.
10. Processing Time was necessary to reduce supplemental survey.

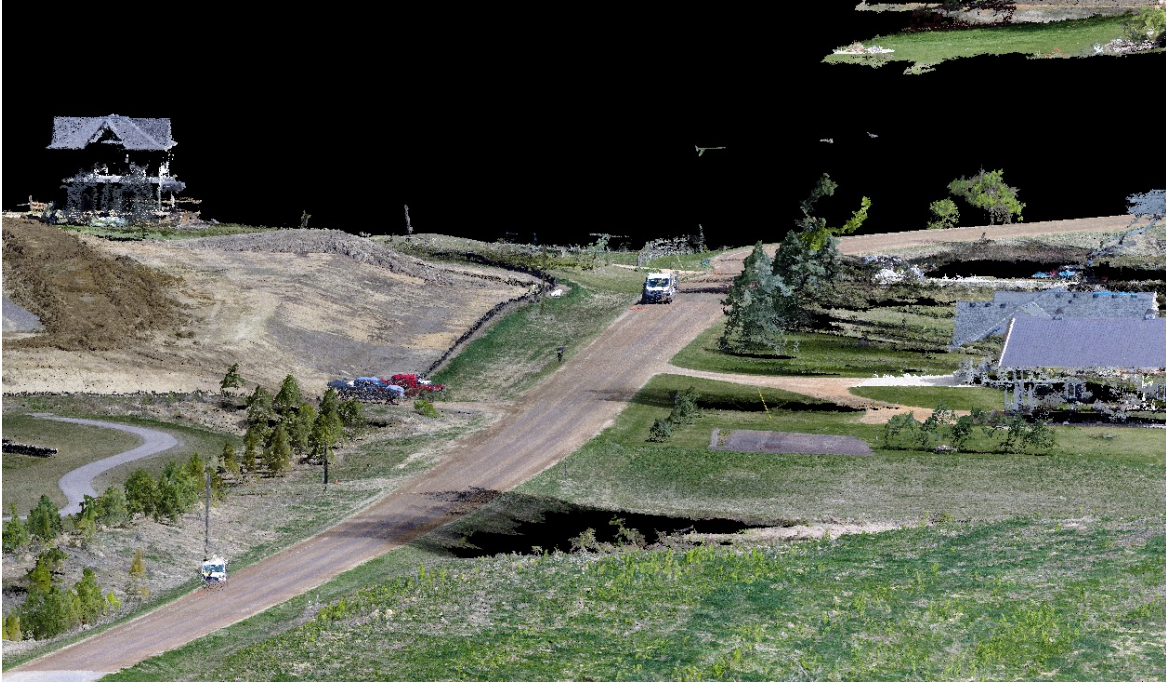


Figure 2-7: RGB visualization of point cloud – Marsh Lake Road.

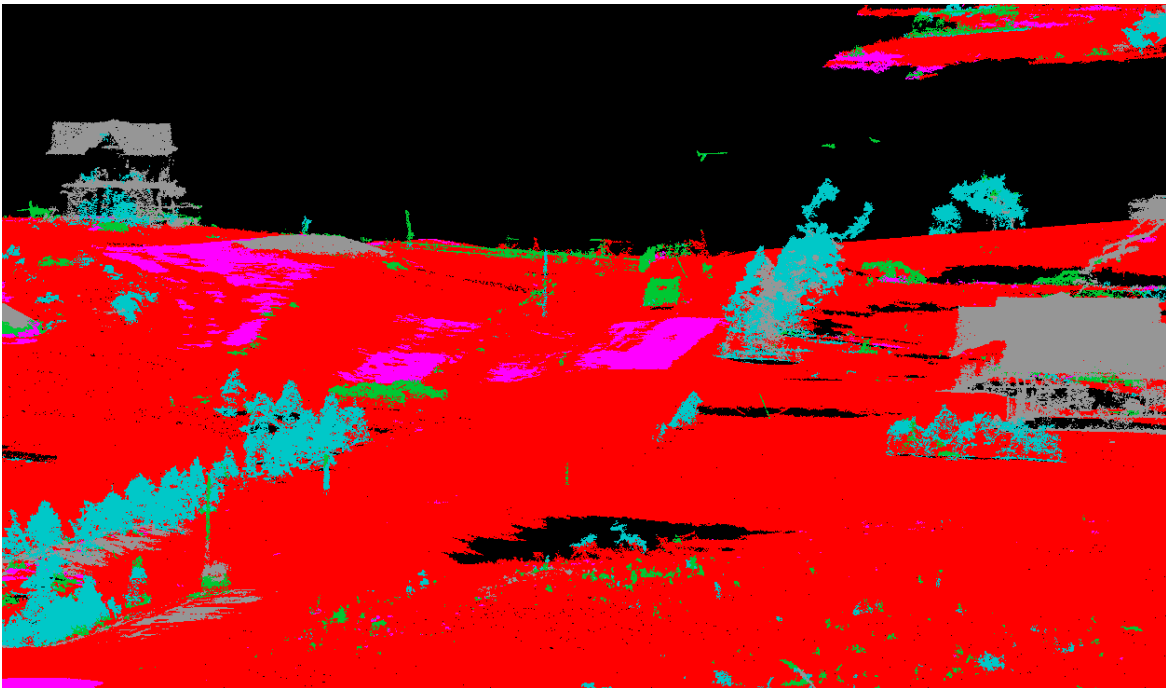


Figure 2-8: Classified point cloud visualization – Marsh Lake Road.

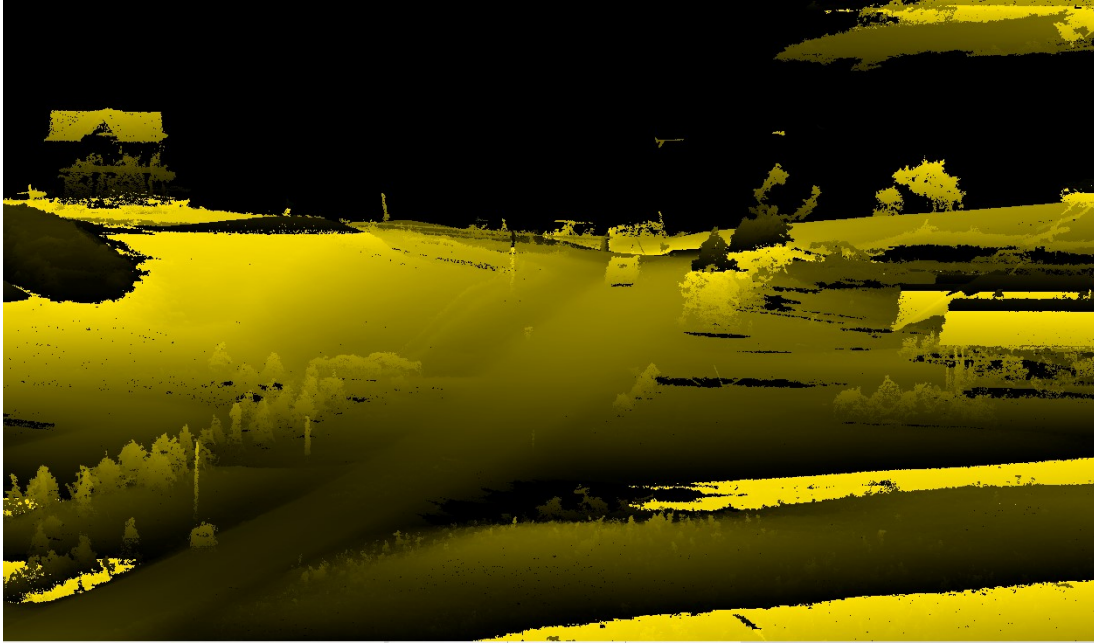


Figure 2-9: Monochromatic point cloud elevation surface – Marsh Lake Road.

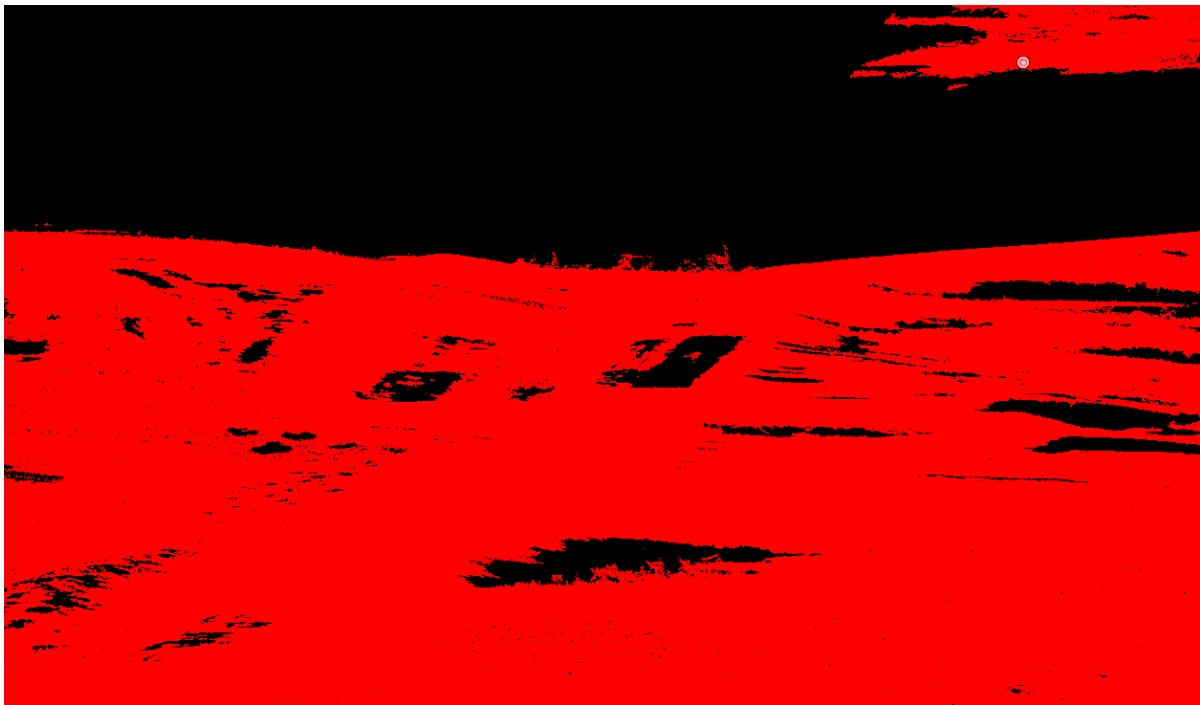


Figure 2-10: Classified bare earth (ground) point cloud– Marsh Lake Road.

2.6 BENEFITS/SHORTCOMINGS

Benefits:

- For similar overall level of effort, a significant increase in data is collected.
- Reduced staff time required for collection of data, thus reducing associated costs to taxpayers.
- Multiple file formats available once data is processed, allowing flexible use of data for alternative needs.
- Overall accuracy levels of UAS terrain data is comparable to traditional survey methods.
- Up-to-date aerial imagery part of the deliverable byproduct.

Shortcomings:

- Supplemental Survey means and methods are still required for underground infrastructure needs and verification for QA/QC purposes.
- Data processing requirements for large data sets may still require reprocessing to make design files manageable.
- For UAS in general, requirements for certification, operation, and maintenance may require outsourcing of work until agency staff elect to acquire skill sets to do this work themselves.
- Design software in general cannot use the data directly so processing to conform to software standards may be necessary depending on software package.
- Correct classification of the project data is necessary in order to extract appropriate information, for instance to have bare earth extracted for terrain modelling the ground points need to be classified as such.
- Agencies who choose to acquire the necessary equipment and training to operate UAS will incur additional costs in addition to costs to maintain regular survey equipment.

2.7 NEXT STEPS

Potential next steps include:

- Introduce software and documented methodology to local user groups.
- Research metrics further for other means of survey collection (for instance, static and mobile LiDAR) to develop toolkit to best select options for particular case studies.

CHAPTER 3: INTEGRATION OF GIS OVERLAYS INTO 3D

3.1 SUMMARY

Autodesk Infracore is not a GIS but a hybrid that integrates GIS data into a BIM database environment in a thoughtful and user-friendly manner. Infracore provides GIS data aggregation to enrich the planning and conceptual design process, making GIS data accessible for GIS professionals and non-GIS professionals alike. Users with CAD-only backgrounds reap ease-of-use benefits in a conceptual design environment that serves to break down traditional stereotypes between GIS and CAD. This is a significant human-use value factor representative of a larger industry-wide trend of continued convergence between traditionally disparate systems. Infracore's ability to ingest both vector and raster GIS data is unprecedented, representing an evolutionary step for interoperability in the civil engineering industry between GIS to CAD/BIM platforms. While always room for improvement, the current state of Infracore's GIS import and display functionality are so feature rich export limitations are forgiven (lack of round-trip data interoperability is examined further in Chapter 6). The benefits of its import feature set, generous file-type support, scalability, and data management functionality provide robust value.

Clearly the trend will be that GIS information will become embedded in BIM design software databases; similarly, BIM information (geometry and metadata) will be used in GIS-only systems¹⁶. As this continues the lines between the delivery mechanism (tools) themselves will continue to be blurred. This movement towards applications conducive to a single source of truth model (agnostic to platform) fosters transparency, collaboration, and consensus that breaks down historical data and workflow siloes. This ultimately benefits users, project owners, and taxpayers in the State of Minnesota.

3.2 TASK PURPOSE

Demonstrate interoperability, re-purposing of data, and enhanced communication; load feature-rich raster, vector, and geodatabase GIS data (such as wetlands or other data) into the 3D planning and alternatives design tool.

3.3 INTRODUCTION

Historically, GIS and CAD have been like oil and water to users of their respective craft. GIS has always been an information system strong in raster and vector spatial analysis, while CAD has been relegated to an arguably less intelligent but more precise drafting role. In recent years, major CAD vendors Autodesk and Bentley developed map suites and raster management tools, that in some areas directly try to compete with ESRI's GIS offerings.

¹⁶ See Chapter 7: Interoperability on ESRI-Autodesk and ESRI-Bentley collaborations.

Traditional processes to integrate GIS in CAD or BIM typically involved conversion to DWG or DGN, often with loss of attributes or other critical metadata. Conversely, CAD conversion processing to the GIS .shp or feature class format often resulted in poor geometry translation, predominantly due to differences in how the two types of programs work, compounded by their disciplinary nuances.

Today, emerging preliminary design and planning BIM software from both Bentley (OpenRoads Concept Station) and Autodesk (Infraworks) demonstrate unprecedented improvements showing a strong convergence of GIS data and light spatial analysis into 3D transportation BIM. Vendors are now also beginning to work together for more common interoperability including the exploration of common open-source file standards.

3.4 APPROACH

Infraworks is the primary tool selected for the pilot demonstration. Understanding how it works behind the scenes is critical in planning for GIS data integration. Infraworks utilizes [MySQL](https://en.wikipedia.org/wiki/MySQL)¹⁷ database technology to generate user pre-determined tile caches for memory management purposes (Figure 4.1). Infraworks (and its Bentley cousin Concept Station) are easily overwhelmed if poorly prepared and unwieldy data are used; the tile-caching routines illustrate how vendors are optimizing large-area spatial data management in new software releases.

3D design, display, and manipulation of geospatial data takes significant computing power, and the overall user experience can be enhanced through organized data management and efficient pre-planning. In addition to good data management practices, robust video display cards and 32-64gb of system ram (memory) are recommended. Laptop specifications used in this pilot were 4.2ghz CPU, 64gb system ram, and NVIDIA 1080ti (desktop) gaming video card with 8gb of video ram. All GIS data processing and Infraworks testing was performed on this workstation grade laptop specification.

Five factors drive planning for optimum GIS data management and compatibility in Infraworks:

1. Basic knowledge of geographic coordinate systems; ability to read metadata.
2. Pre-knowledge of the GIS attributes of data to be imported.
3. Pre-clipping (sub-setting) the extent of all imported data down to immediate project area.
4. Preparing pre-tiled raster data to be efficiently loaded and cached, optimizing data read-write operations.
5. Understanding how Infraworks layer management works, including ability to turn on/off layers in the Surface Layers and Model Explorer sub-modules.

Items 1-3 are standard GIS data management best practices. When combined with items 4-5, they provide the fundamentals for consuming vector and raster data in preliminary design BIM software.

¹⁷ <https://en.wikipedia.org/wiki/MySQL>

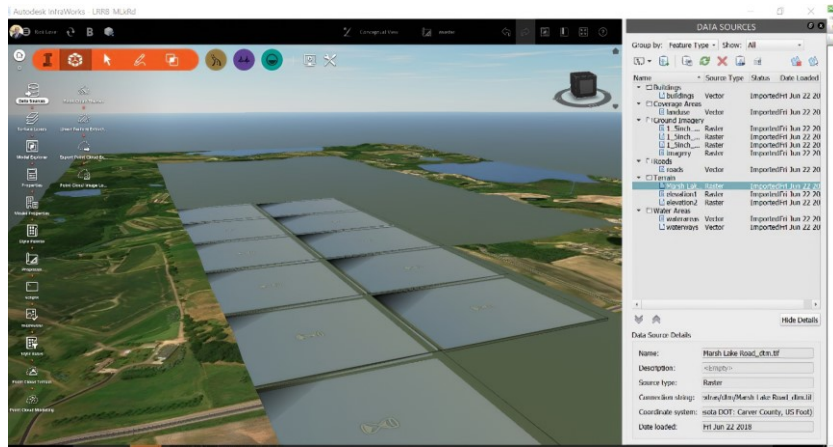


Figure 3-1: Database tile caching in Infraworks.

3.5 METHODOLOGY

GIS data used in the pilot project demonstration was sourced from the following:

- UAS Reality Capture data from Collins Engineering, processed as raster¹⁸⁾
- [Carver County Open Data Portal](https://data-carver.opendata.arcgis.com/)¹⁹ vector (points, lines, polygons)
- [Minnesota GeoSpatial Commons](https://gisdata.mn.gov/)²⁰ (vector)
- SRF Consulting L2 Wetlands Delineation (vector)
- MnGEO (Statewide raster LIDAR) (raster)

GIS data was prepared in Global Mapper due to ease of use and robust 64-bit processing capability; similar preparation could have been conducted with ArcGIS Toolbox, QGIS (open source), Manifold Systems, IDRISI, AutoCAD Map3D, Bentley Map, or other GIS-enabled packages.

All UAS source data was captured at 1cm resolution (proof of concept) by Collins Engineering. This level of resolution was so fine it resulted in unwieldy file sizes with larger spatial areas. To obtain both high quality and manageable file sizes, the aerial imagery and topography was resampled. Iterative testing identified sweet spots for both the imagery and topography to establish balance of quality and file size. Imagery was reduced from a 14gb file to three 150mb tiles using Enhanced compression wavelet (ECW) format @1.5" resolution using a 2:1 compression ratio. ECW was chosen as the ideal format not just because it is supported by Infraworks, but predominantly because it contains a sharpening compression algorithm that keeps pixels crisp. In contrast, the popular Mr. SID compression format is a smoothing

¹⁸ UAS topography capture is cell (pixel) based, resulting in raster derivatives but also processed into point clouds (vector).

¹⁹ <https://data-carver.opendata.arcgis.com/>

²⁰ <https://gisdata.mn.gov/>

algorithm that tends to blur or make pixels muddy. Topography was resampled to 6” pixels to balance file size and quality.

Chapter 6 of this project report addresses interoperability in more detail for GIS, CAD, BIM, and other 3D-modeling software. Due to the relevance of interoperability to this task (Infraworks GIS workflow demonstration) some is included here and defined as:

- A. GIS import compatibility
- B. GIS export compatibility (see Chapter 6)

GIS import compatibility

Multiple options exist to import GIS information into Infraworks. User decisions on which format(s) used and import method is contingent upon desired outcome as well as the user’s level of expertise and understanding of GIS.

1. First-time Infraworks users are introduced to the Model Builder tool, which allows spatial search for open-source GIS data. This is a convenient mechanism to obtain public-domain GIS data, including both USGS topography and Open Street Map (OSM) vector data. The intent of this tool is to provide generic basemap information upon which to build. The tool is presumably for non-GIS professionals who may not possess the background to search, download, and prepare custom GIS data or do not understand nuances of metadata and spatial coordinate systems. Topography from the model builder service is USGS 30m and 10m [NED \(National Elevation Dataset\)](https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned),²¹ dependent upon area chosen. BING Maps is the default aerial with varying resolution dependent upon location. Typical workflow using this data is initially for high-level conceptual exercises, with gradual replacement in the project area with data that has more fidelity, such as engineering-grade contours or higher-resolution imagery. This basemap data then provides context and sense-of-place filler information both inside the project area as well as on the immediate periphery.

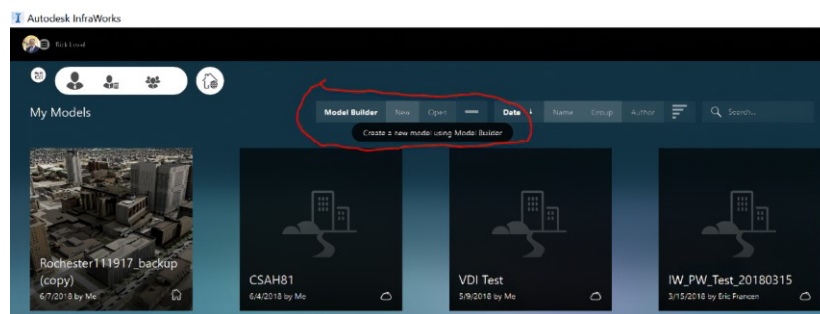


Figure 3-2: Screenshot of Model Builder in Infraworks.

²¹ <https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned> <<https://catalog.data.gov/dataset/usgs-national-elevation-dataset-ned>

2. ESRI Geodatabase (and other database files) are accessible via the Database Import option. This functionality was put in place soon after Autodesk Infrastructure Modeler (AIM) was re-branded to Infracore.

Raster Import

Infracore presents multiple raster imagery import options, including geo-referenced lossless PNG, geo-JPG, JPG2k, Mr.SID, ECW, and GeoTiff. (Autodesk Knowledge Network references supported image formats [here](#).²²) ESRI Grid and ESRI ASCII raster grid formats and multiple database types are supported and once loaded, become documented in the same location (Figure 3.3).

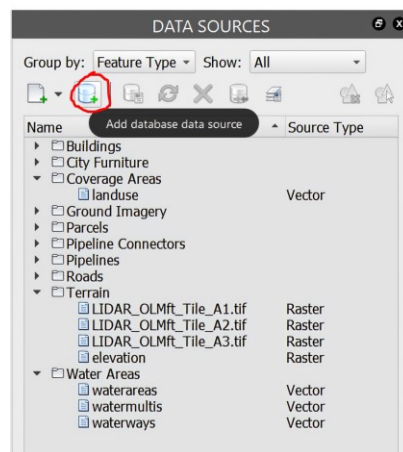


Figure 3-3: Infracore data sources tab.

In addition to raster imagery support, Infracore supports raster terrain import in the common USGS digital elevation model (DEM) and LandXML formats.

GeoTiff [heightmaps](#)²³ are also supported where white represents higher elevations and black the lower elevations, with gradients in between. Heightmap terrain files are more efficient in Infracore than DEM based file formats, both in terms of input file size and in the import/data-caching process.

Use of heightmap (raster greyscale images) for terrain is a [common practice in the video game industry](#)²⁴ due to processing efficiencies; the method and format is also supported in ESRI City Engine planning software, Autodesk Infracore, Autocad Map, and Bentley Descartes.

²² <https://knowledge.autodesk.com/support/infracore/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-UserHelp/files/GUID-D6DD9F27-E0A9-424C-B6D2-EAAC4B5EF7D2-htm.html>

²³ <https://en.wikipedia.org/wiki/Heightmap>

²⁴ <https://arxiv.org/pdf/1803.04612.pdf>

Figure 3.4 illustrates a heightmap displayed in Global Mapper while Figure 3.5 illustrates 32bit floating-point elevation sampling and export settings for data optimization.

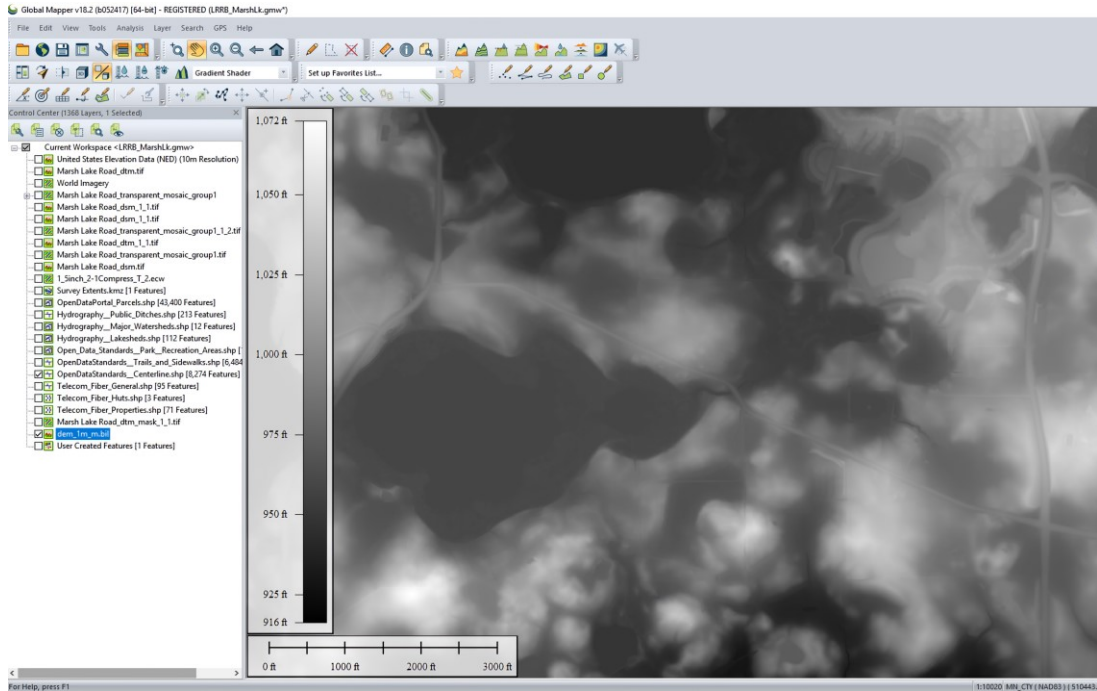


Figure 3-4: Greyscale terrain heightmap in Global Mapper.

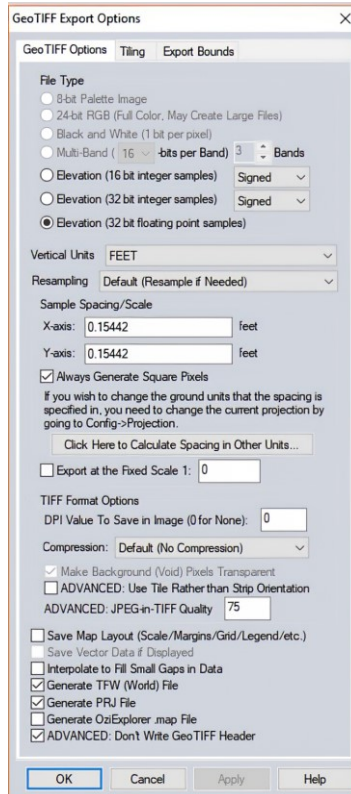


Figure 3-5: GeoTIFF export settings.

Figure 3.6 shows three tiles of terrain height maps loaded as GeoTIFF and the export process (circled in red). At this point, three optimizations have already occurred to help Infracore load files into the software's database memory caching process and facilitate with real-time display and performance:

1. Terrain clipped to project extents.
2. Terrain exported as height maps.
3. Tiling of heightmaps allowing user to turn on/off tiles to increase performance for macro area work.

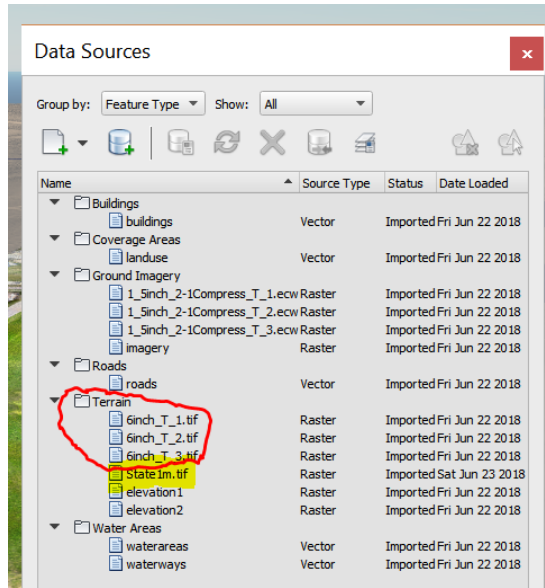


Figure 3-6: Heightmap tiles in Infraworks Data Manager.

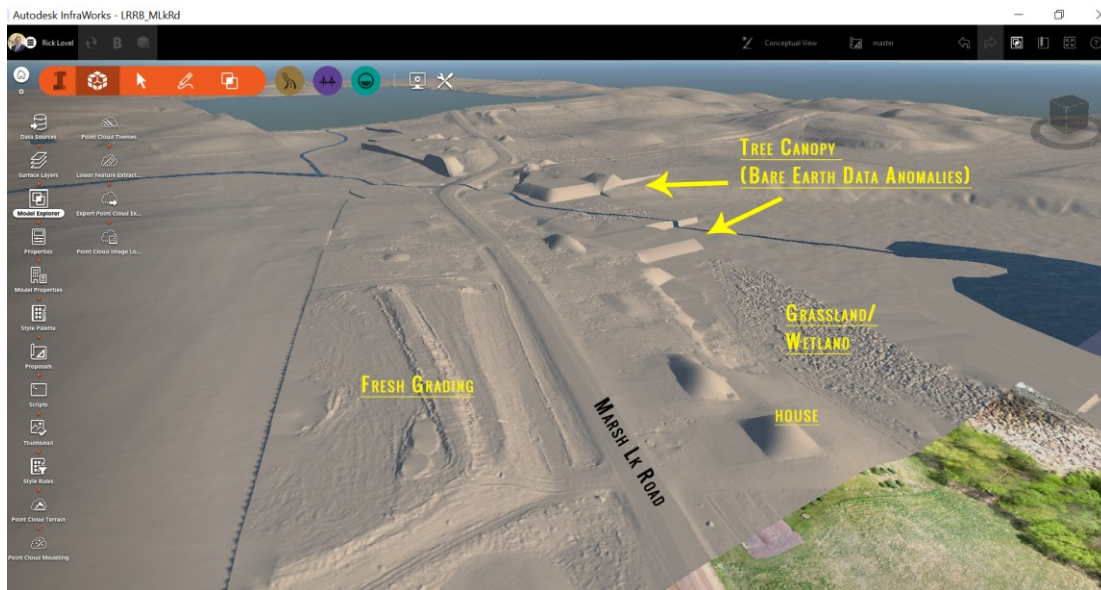


Figure 3-7: Visual inspection in Infraworks of resampled heightmap identifies tree canopy and structure data anomalies.

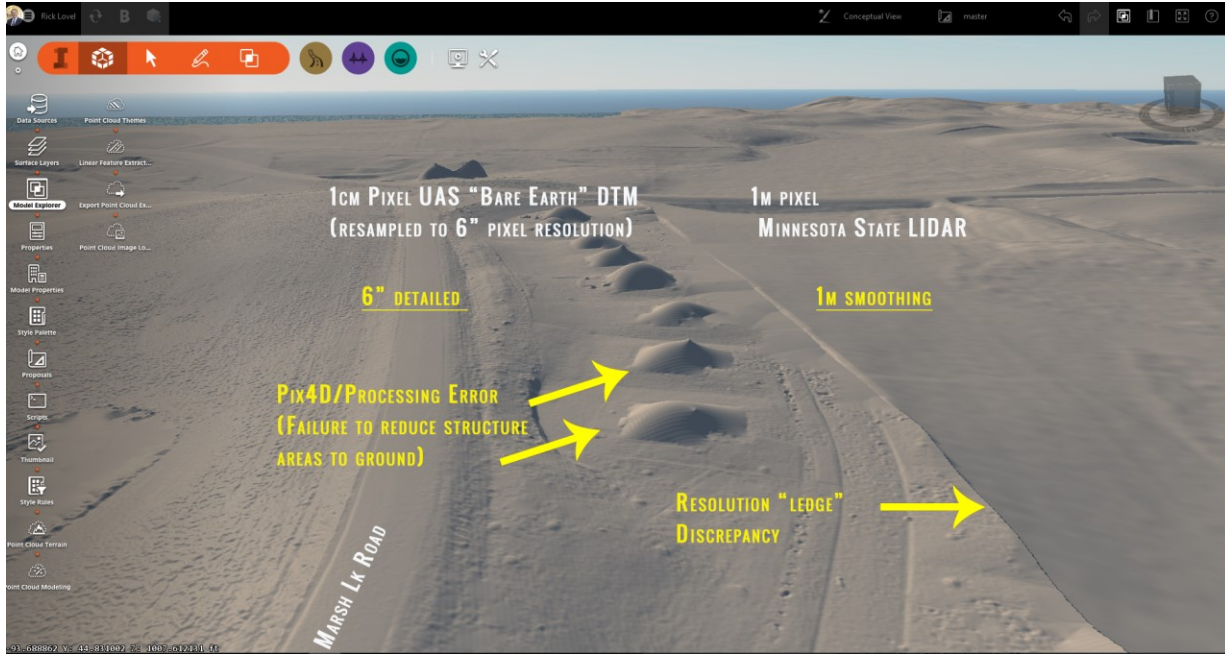


Figure 3-8: Comparison of 6-inch resolution (resampled) heightmap to Minnesota State 1-meter LIDAR (DNR) in Infracworks.

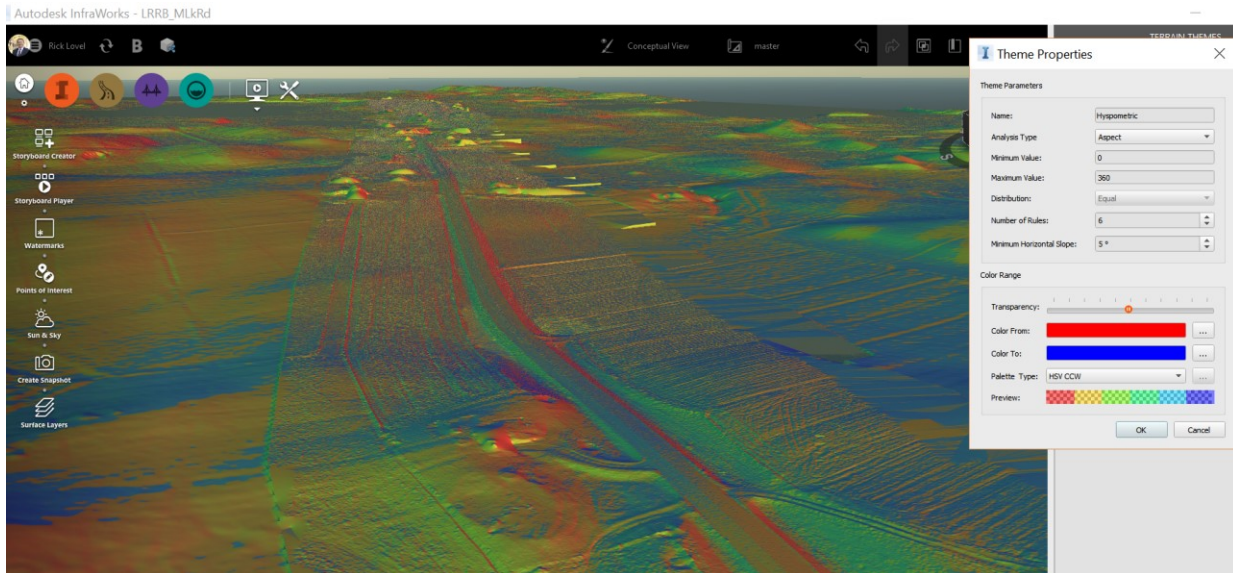


Figure 3-9: Infracworks terrain slope aspect analysis with thematic display functionality.

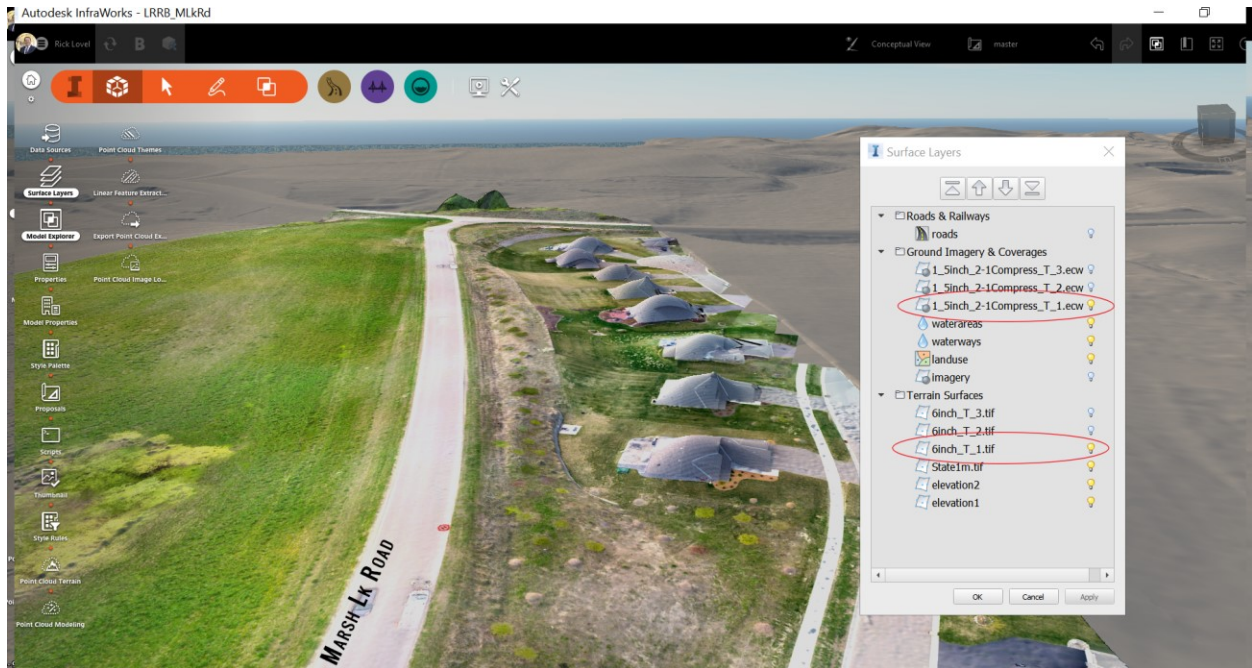


Figure 3-10: Re-sampled 1.5-inch resolution ECW format imagery and 6-inch terrain heightmap as GeoTIFFs, in Infracworks.

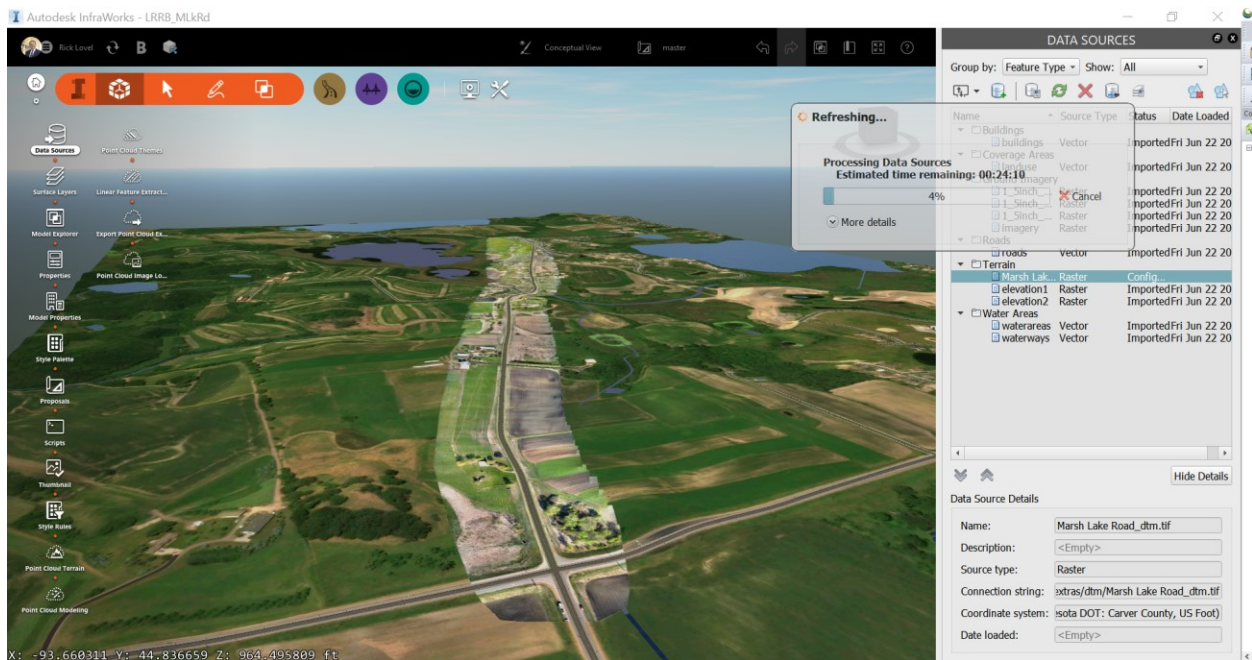


Figure 3-11: Entire Marsh Lake Road corridor, with Infracworks shown processing high-resolution data into cache.

Vector Import

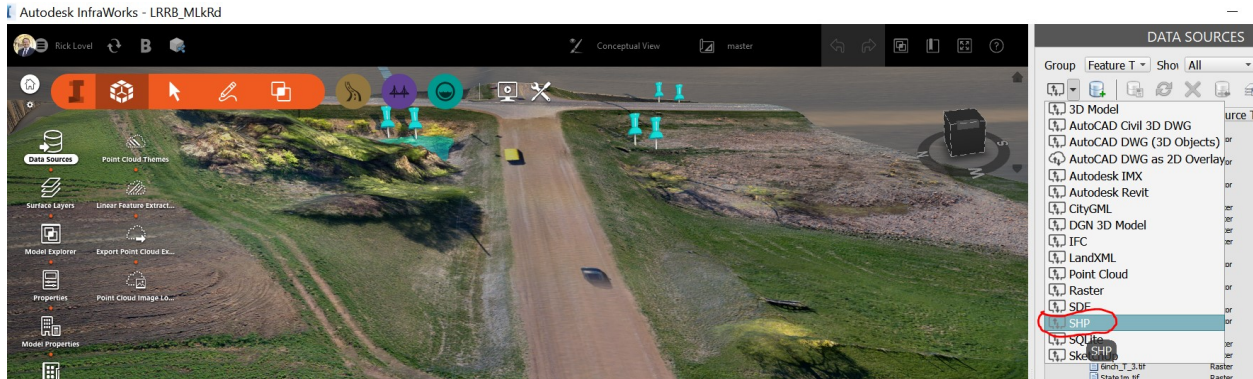


Figure 3-12: Infraworks screenshot illustrates support for the common ESRI shapefile format (in red above) as a direct data import option.

Using the Data Source tab in Infraworks, vector shapefiles for the pilot project are directly imported and then assigned projection and feature type, in this case: Parcels (see Figure 3.13).

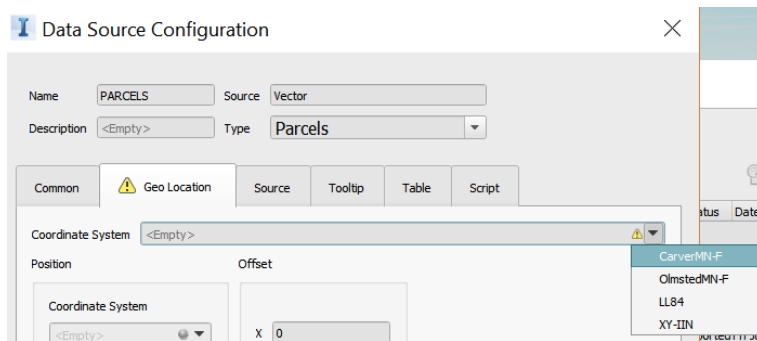


Figure 3-13: Screenshot of projection and feature type, after vector shapefile import.

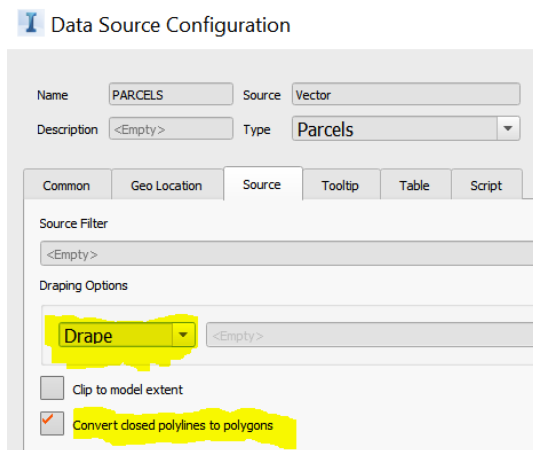


Figure 3-14: Options for vector line work.

Figure 3.14 illustrates the Infracworks options available to:

- a. Drape vectors on terrain and assign fixed elevation.
- b. Assign elevation from GIS attribute.
- c. Not to drape, in which case Infracworks assumes vector geometry is inherently 3D PolylineZ).
- d. Option to convert closed polylines to polygon geometry.

A variety of options also exist to apply display styles to the vector line-work. Figure 3.15 illustrates imported lines draped (conforming to terrain) with the default display style for parcels automatically assigned. When parcel geometry includes closed polygons, attributes for each parcel (such as ID, zoning, or ECT) can be accessed on the fly.

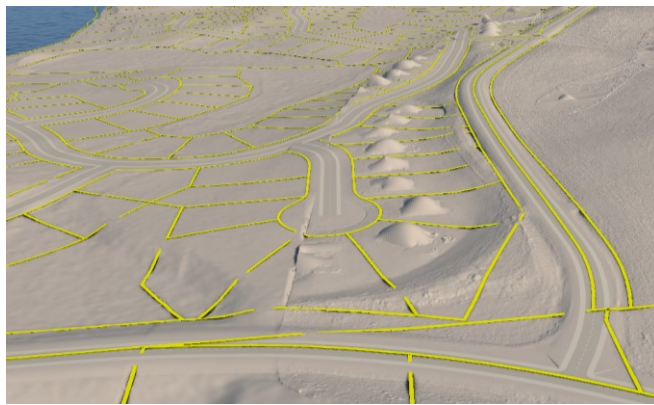


Figure 3-15: Imported vector lines (parcels) draped on terrain.

Level 2 Wetlands delineation data was imported as both vector point files (sampling points) and as polygons (wetlands). Once the GIS attribute table (Figure 3.16) is understood, critical attribute information can then be displayed by the user in Infracworks BIM environment.

Feat_Name	Datatile	Unflit_Pos	Flit_Pos	Data_Dicti	GPS_Week	GPS_Second	Vert_Prec	Horz_Prec	Point_ID	FIELD_ID	REPORT_ID
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	306101	0.3	0.3	1	SP-01	SP-1
Point_ge	NZRZ_9233_160824.cor	34	34	Generic	1911	307888	0.3	0.3	3	SP-02	SP-2
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	308880	0.4	0.3	5	SP-03	SP-3
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	310065	0.3	0.3	6	SP-04	SP-4
Point_ge	NZRZ_9233_160824.cor	31	31	Generic	1911	312500	0.3	0.3	21	SP-05	SP-5
Point_ge	NZRZ_9233_160824.cor	31	31	Generic	1911	313620	0.3	0.3	22	SP-06	SP-6
Point_ge	NZRZ_9233_160824.cor	103	103	Generic	1911	317236	0.3	0.3	50	SP-07	SP-7
Point_ge	NZRZ_9233_160824.cor	44	44	Generic	1911	318961	0.3	0.3	52	SP-08	SP-8
Point_ge	NZRZ_9233_160824.cor	41	41	Generic	1911	321007	0.3	0.3	66	SP-10	SP-10
Point_ge	NZRZ_9233_160824.cor	40	40	Generic	1911	323969	0.3	0.3	84	SP-12	SP-12
Point_ge	NZRZ_9233_160824.cor	46	46	Generic	1911	324054	0.3	0.3	85	SP-11	SP-11
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	325896	0.8	0.8	98	SP-13	SP-13
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	325975	3.2	3.9	99	SP-14	SP-14
Point_ge	NZRZ_9233_160824.cor	36	36	Generic	1911	337895	4	2.4	173	SP-18	SP-18
Point_ge	NZRZ_9233_160824.cor	31	31	Generic	1911	337939	3.2	3.3	174	SP-17	SP-17
Point_ge	NZRZ_9233_160824.cor	30	30	Generic	1911	338194	2.6	2.9	175	SP-19	SP-19
Point_ge	NZRZ_9233_160824.cor	34	34	Generic	1911	340877	1.4	1.2	190	SP-20	SP-20
Point_ge	NZRZ_9233_160824.cor	32	32	Generic	1911	340925	4	2.9	191	SP-21	SP-21
Point_ge	NZRZ_9233_160824.cor	37	37	Generic	1911	343589	0.8	0.5	195	SP-22	SP-22
Point_ge	NZRZ_9233_160824.cor	34	34	Generic	1911	345612	3.2	3.1	216	SP-23	SP-23
Point_ge	NZRZ_9233_160824.cor	32	32	Generic	1911	345659	3	1.5	217	SP-24	SP-24
Point_ge	NZ_9233_160902.cor	42	42	Generic	1912	483088	0.3	0.3	1	SP-25	SP-25
Point_ge	NZ_9233_160902.cor	35	35	Generic	1912	483922	0.3	0.3	2	SP-26	SP-26
Point_ge	NZ_9233_160902.cor	31	31	Generic	1912	488040	0.3	0.3	23	SP-27	SP-27
Point_ge	NZ_9233_160902.cor	31	31	Generic	1912	489164	0.4	0.3	24	SP-28	SP-28
Point_ge	NZ_9233_160902.cor	42	42	Generic	1912	494228	2.6	3.3	66	SP-29	SP-29
		0	0		0	0	0	0	0	SP-15	SP-15
		0	0		0	0	0	0	0	SP-16	SP-16
		0	0		0	0	0	0	0	SP-09	SP-9
Point_ge	9233_NZ_TEP.cor	30	30	Generic	1925	411919	0.3	0.3	1	SP-A	SP-30
Point_ge	9233_NZ_TEP.cor	31	31	Generic	1925	413080	0.3	0.3	3	SP-B	SP-31

Figure 3-16: Portion of GIS attribute table information from wetlands field work (ESRI ArcCatalog).

Figure 3.17 illustrates imported sampling points being classified as Points of Interest (Infraworks theme) with the sample point ID correlating into the wetlands report. More information can be exposed by utilizing pre-made queries, hyperlinks to photos, or other documentation such as the actual corresponding wetlands report.

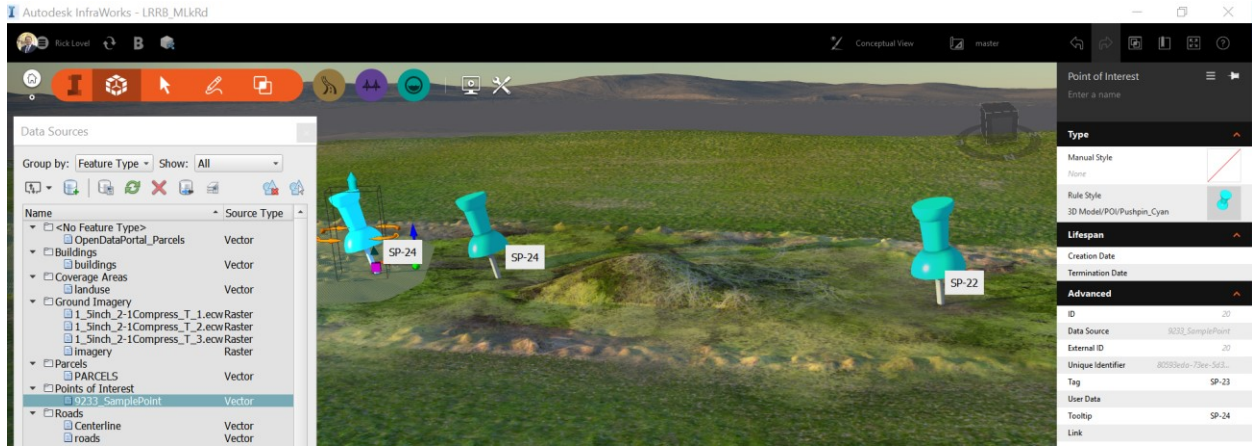


Figure 3-17: Infraworks' Points of Interest functionality.



Figure 3-18: Screenshot illustrating all wetlands sampling point location symbols, artificially exaggerated to better view all locations along corridor simultaneously.



Figure 3-19: Screenshot illustrating stylized GIS wetland delineation polygons combined with other GIS data.

3.6 BENEFITS/SHORTCOMINGS

Benefits:

- Model Builder tool provides quick and easy access to free, open-source GIS data for rapid base map creation.
- User-friendly import and data configuration process for manual data imports.
- Full coordinate system-aware database
- Model Explorer tool provides GIS-like ability to create overlay hierarchies and change visibility.
- Bookmarks tool saves common views for re-use, just like GIS software bookmarks.
- Proximity-based hover Tooltips info available from GIS attributes for vector point files (designated as Infracore Points of Interest).
- Imports point cloud data (if first processed by Autodesk RECAP).
- Multiple options for feature stylization and display once data is imported.
- First BIM software able to process large-extent, high-resolution GIS terrain and imagery.
- Database-caching technology behind the scenes facilitates consumption of large-area spatial datasets (in high resolution) that traditional CAD or GIS software is currently unable to process and display interactively in 3D.
- Provides 3D GIS context with sense of place to planning and design for civil works.
- Hypsometric shading for terrain elevation datasets.
- Infracore Sandbox (beta) included an upgrade to FDO-based connection to access ArcGIS online layers. (Released in full Infracore version 19.1.)

- Import support for many common GIS formats (including Oracle, SQL, and ESRI geodatabase formats). Loads GIS layers directly from geodatabase files via database manager.
- Some light spatial analysis available for terrain data
- Watershed analysis functionality ties to engineering drainage network functions of Infracore.
- Unwieldy GIS to CAD/BIM processes eliminated, making GIS more accessible.
- Infracore proposals provide Optioneering and ability to create non-destructive scenarios.
- BIM 360 facilitates sharing of GIS data embedded in Infracore.
- Ease-of-use breaks down data and workflow siloes found in traditional infrastructure project processes, providing a single source of truth (model) improving project communication, data interpretation, accelerating schedules, and reducing potential for human-caused error.

Shortcomings:

- No GIS-like legend present (persistence) for current scene layers.
- No robust (limited) spatial analysis capability.
- No export options for modified raster and vector data back to GIS-friendly formats.
- Only imports LIDAR or other point cloud data in rcv (Autodesk RECAP²⁵) format, thereby tying user back into Autodesk ecosystem. No direct LAZ or LAS support.
- Negative impacts to file layering and layer manipulation when exporting to 3D formats.
- IMX-export format ignores GIS overlays (except for topography) and does not export Infracore features that may have been created from GIS vector-data imports.

3.7 NEXT STEPS

Potential next steps include:

- Introduce software and documented methodology to local user groups.
- Research using advanced data queries and scripting tools to expose context of key attribute information.
- Research comparison of watershed calculation tool benefits/limitations vs traditional GIS-centric watershed analysis tools.
- Research, develop, and document best practices for efficient GIS-to-BIM workflows.
- Engage with Infracore Sandbox (beta) testing program and provide feedback to Autodesk.

²⁵ Autodesk Reality Capture (RECAP).

CHAPTER 4: 3D DECISION SUPPORT (CORRIDOR OPTIMIZATION)

4.1 SUMMARY

Suitability analysis has been in use in pure GIS applications in various forms for decades. The suitability “model” utilized by Infracore is not entirely unique. What is unique, is the integration of suitability (spatial analysis) with a transportation design process that semi-automatically converts results into generative output of corridors with profiles, structure locations and basic cost/volumes. In this respect the tool (and the software itself) represent somewhat of a landmark in GIS-BIM convergence. Geospatial processing models once built and executed by GIS professionals are now embedded in the design process. Knowledge based computational systems for transportation design facilitated by cloud computing have arrived.

The implications of this software (and other KBS tools) is that it replicates (and semi-automates) the regular design process that any roadway engineer needs to consider when developing initial concepts. The module mirrors the thought process of an engineer and assists in helping the engineer become rapidly productive. The speed, functionality, and reporting accentuate the designer’s ability to consider, vet, refine and select a preferred alternative in a cost-effective and efficient manner. This creates productivity gains that contribute to BIM use value and acceleration of the overall project life cycle as previously mentioned in the approach section of this chapter and reiterated in Figure 5 Impacts of life-cycle decisions on cost.

In addition to GIS suitability analysis/BIM convergence this represents a distinct paradigm shift for transportation engineering design in that more processes are becoming automated leveraging the power of the cloud and to an extent, artificial intelligence (AI) or machine learning algorithms. While still in its incubation period of implementation and adoption this points to what is on the near horizon for designers. The authors also do not have full understanding of how the tool algorithms works behind the scenes, as [Appendix D Autodesk Corridor Optimization Documentation](#) is the most current documentation available in any one place (other than Autodesk basic training videos).

Further research is warranted to better understand how to leverage the toolset, validation methods for best-fit level of accuracy results and how to best modify to allow a variety of agency standards in a variety of road/highway corridor scenarios. As previously noted in project limitations this demonstration project is likely not the appropriate context of use for this tool with the authors suggesting that larger scale corridor studies may be more of a “best-fit” scenario of use. What is clear is that subject matter experts (users) will be off-loading significant pieces of what is currently a step by step manual user workflow, by migrating to a semi-automated (presumably optimized) process. This is another significant future BIM use that brings value to the BIM for Infrastructure process.

4.2 TASK PURPOSE

Demonstrate functionality and current state of emerging generative design tools that function as [knowledge-based systems \(KBS\)](#)²⁶ (type of [decision support systems](#)²⁷) and that are delivered in part as cloud, [software-as-a-service \(SaaS\)](#)²⁸ processing business model. Understand potential work-flow best practices with future design processes.

4.3 INTRODUCTION

In the Architectural, Engineering and Construction (AEC) industry generative design delivered as a vendor cloud-based service is not new. As of the time of this paper for example, the Autodesk platform has steadily increased cloud-based processing tools that offer the convenience of unlimited power that facilitates off-loading of computationally heavy processes while also providing enhanced collaboration environments²⁹.

Architectural BIM simulation, processing, and collaboration services in the cloud have been prevalent for some time. Research published in 2004 (Journal of Information Technology in Construction)³⁰ noted: “In the architecture, engineering and construction sector, cloud-BIM integration is considered to be the second generation of building information management (BIM) development and is expected to produce another wave of change across the construction industry.”

²⁶ https://en.wikipedia.org/wiki/Knowledge-based_systems

²⁷ https://en.wikipedia.org/wiki/Decision_support_system

²⁸ https://en.wikipedia.org/wiki/Software_as_a_service

²⁹ <https://bim360.autodesk.com/>

³⁰ A REVIEW OF CLOUD-BASED BIM TECHNOLOGY IN THE CONSTRUCTION SECTOR SUBMITTED: August 2014
PUBLISHED: September 2014 at <http://www.itcon.org/2014/16> GUEST EDITORS: Wang X., Li H., Wong J. and Li H.



Figure 4-1: Autodesk KBS and SaaS tools. (Source: Cadac Group)

Manufacturing design and Architecture have led the adoption of [KBS](#)³¹ tools for simulation and energy analysis by leveraging infinite scalability to quickly augment or validate designs. In architecture BIM application REVIT for example, energy and structural analysis along with other computational heavy uses such as rendering for visualizations provide unprecedented accessibility and convenience. In the current Autodesk business model for example, anyone with an Autodesk account, software, and “cloud credits³²” can access processing power from anywhere with an internet connection on practically any device including mobile.

Along with this evolution in access to computational power comes workflow process-changes; the decision-making process typically performed by an Architect or Engineer is increasingly augmented by machine learning algorithms. The subject matter expert then, still manages the variable inputs and validate the results. But the actual process is facilitated semi-automatically by a KBS decision support type of process that is no longer confined to the desktop. Autodesk actually refers to the module studied in this chapter as “[a Magic Button of Optimized Roadway Design](#).”³³

Narahara et al. (2006) noted that amongst the emerging design automation systems, generative systems have been assisting designers to rapidly explore design solutions and can enhance the design process by saving time and effort or allowing an increased number of alternatives to be examined for the same cost and within the design requirements.

³¹ https://en.wikipedia.org/wiki/Knowledge-based_systems

³² Cloud credits is a pay as you go service business model for added simulation and other features utilizing cloud (Amazon) instances.

³³ <https://knowledge.autodesk.com/search-result/caas/auonline/content/au/global/en/au-online/classes-on-demand/class-catalog/classes/year-2014/infraworks/cv5385-p/jcr-content.html>

For transportation, generative design KBS tools (at this time) appear to be neither mature nor prevalent, but change is constant. Three interesting KBS examples have daylighted in Autodesk preliminary design software Infracore that hint of significant things to come, specifically for transportation design engineering. Figure 4-2 illustrates these three services (modules) found under the Roadway>Analysis tab of Infracore (v.19.1.37.0).

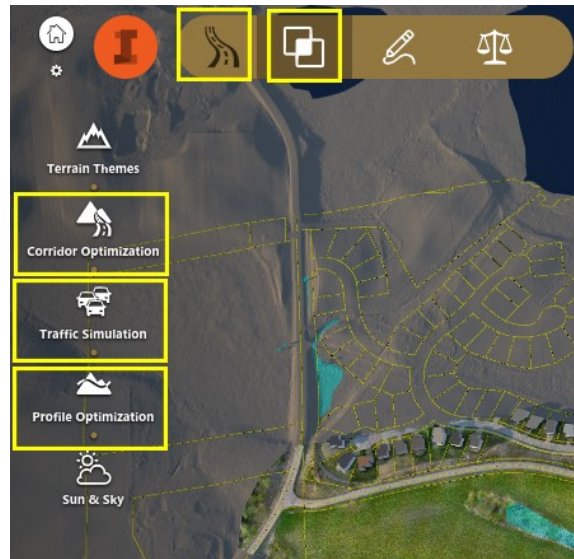


Figure 4-2: Example of Autodesk KBS Cloud Services in Infracore. (Source: SRF Consulting Group)

4.4 APPROACH

This project studies emerging conceptual-design BIM for infrastructure tools and processes, with the intent to determine value during the early project life-cycle phases, up to handoff at the end of 30% design. Chapter 4 will discuss optimization prioritizing horizontal alignments, and Chapter 5 will focus on vertical alignments. This task specifically focuses upon the GIS/BIM hybrid, Software as a Service (SaaS) delivered, Corridor Optimization tool found in Autodesk Infracore (Figure 4-2). This tool was first daylighted to users of the Infracore Sandbox (beta program) then appeared in a Infracore full version with a caveat as shown in (Figure 4-3) denoting its preview status. Finally, in more recent releases the corridor optimization module is offered as a fully embedded feature module (Figure 4-4).

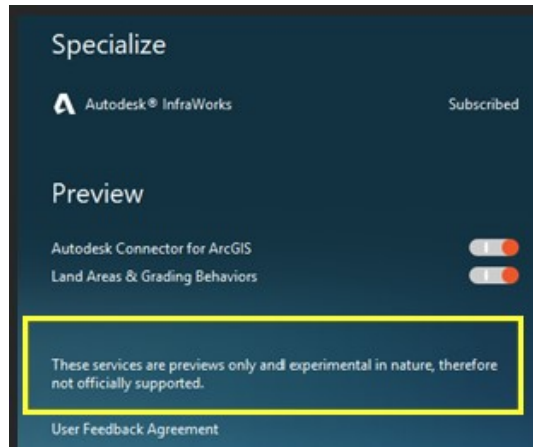


Figure 4-3: Infraworks evolution disclaimer. (Source: SRF Consulting Group)

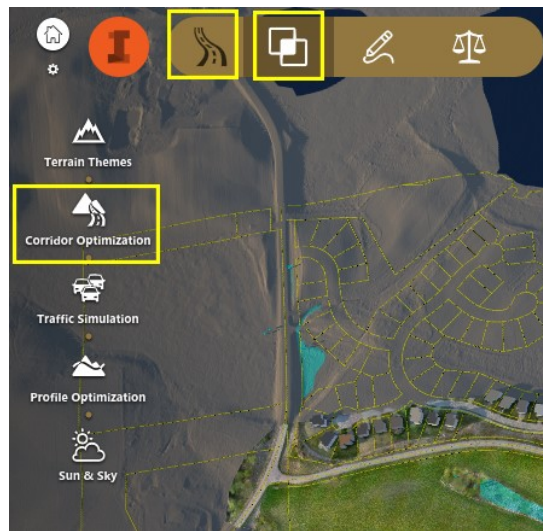


Figure 4-4: Fully embedded module. (Source: SRF Consulting Group)

For some projects, use of this tool may significantly affect the underlying concept provided by the popular value/return graphic (Figure 4-5) illustrating the larger impact of early design decisions vs. later decisions; (this is the central value thesis for this project to study conceptual design areas that have the most potential to bring value to a project).

The visual and rapid 3D design environment found in Infraworks (and counterpart Bentley Concept Station) promotes collaboration and by nature promotes rapid consensus building; in turn, accelerating project decision-making. KBS tools included with the software have the potential to further expedite the design process adding cumulative value to the early portions of project life cycles relationship curve shown in Figure 4-5. Additional benefits to the project life cycle using these tools and new processes are that the value in time gained and (presumably accuracy) effectively reduces the total cost of ownership (TCO) of investment in BIM tools and training.

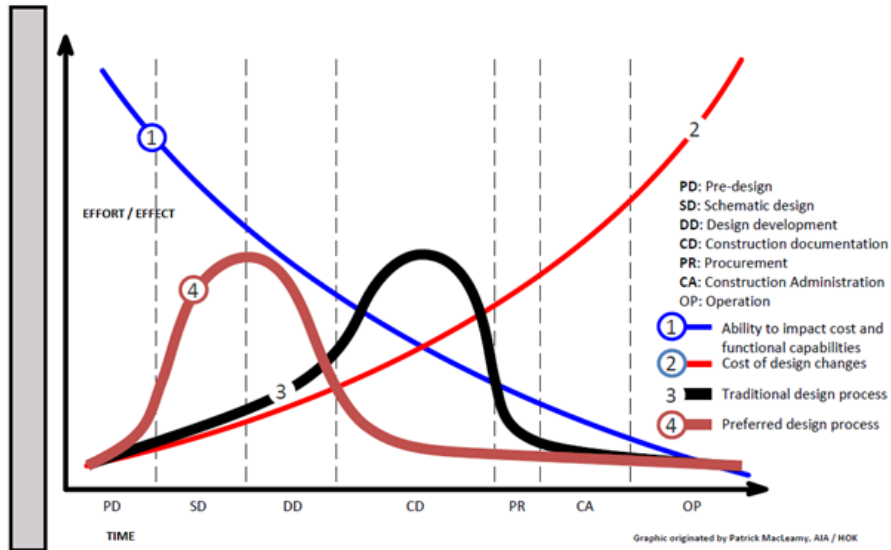


Figure 4-5: Impact of design changes on cost.

Chapter 1 noted that from an overall architecture/engineering/construction (AEC) perspective in the U.S., architecture and manufacturing has led the way, followed by the construction industry, and finally by transportation engineering. The inference is that this same pattern will emerge in transportation design with adoption of cloud-based simulation and generative design since the Architecture industry has been using similar methods for years.

4.5 CORRIDOR OPTIMIZATION METHODOLOGY

Autodesk 2017 ([Appendix D Autodesk Corridor Optimization Documentation](#)) provides generalized instructions for the Optimization tool along with some insight on how the tool operates behind the scenes.

Figure 4-4 identifies the Corridor Optimization tool found under the interface tabs Roads>Analysis>Corridor Optimization. Autodesk (reference) describes this tool as “automated method for infrastructure planners that want to find an optimal alignment for any cleared transportation path capable of allowing a vehicle to pass. The input to the method may include, but is not limited to, terrain data, starting and end point for the path or a starting alignment for the path, design constraints, geographical information data such as roads, railways, buildings, user preferences and ranking (weights). The method also requires cost input that may include earthwork costs, construction costs, land costs, environmental costs, etc. The method then searches for an alignment that tries to minimize the costs, or any combination of costs, while respecting the given constraints.

Table 5 (next page) illustrates sequential steps for input and execution of the Corridor Optimization module.

Table 5: Corridor Optimization Workflow Steps

Step	Process
1	Load Terrain and layers to be utilized as suitability model inputs
2	Define Suitability Model, Weightings, and Avoidance Zones (where applicable)
4	Sketch potential route path
5	Define final (advanced) design parameters (required speed, curve alignment restraints, slopes, grade, and construction unit costs (optional))
6	Execute model optimization in cloud service
7	Download Report, profile, create new Infracore Proposal to display optimized solution
8	Review/Validate results, export preferred alternative from Infracore to Civil 3D

4.5.1 Tool Pre-Requisites

The following pre-existing inputs are required prior to utilizing the tool itself.

1. Terrain data – Infracore processes all terrain inputs as cell-based grids for caching in memory. All the spatial analysis taking place within this tool utilizes the grid cell values for computation of weightings and costs (where applicable).
2. Constraint data- (Suitability Map or Manual avoidance zones). Design constraint examples include:
 - a. Existing roads, railways, buildings, wetlands
 - b. Suitability maps allow user assigned weightings for these variables (Figure 4-9).
 - c. Avoidance zones can be imported as ESRI shp files or can be drawn using the editing tool found in the optimization interface.
3. Alignment start/end points –
4. Cost data- (hard and soft costs) * optional, and can include:
 - a. Earthwork costs
 - b. Construction costs
 - c. Land costs
 - d. Environmental costs

Additional use assumptions:

- Costs were left at default settings as the baseline with implication that multiple corridor optimization pass results are measured against themselves.
- Both a suitability map and manual avoidance zones were used due to pre-existing potential route constraints of the demo project being a re-construction (widening) of an existing alignment. (It is not clear now if implementation of this tool on this type of project is a best-use scenario; this approach may be causing algorithm errors).
- Avoidance zones were manually digitized using tools shown in Figures 4-6 and 4-7. This was intended to help enforce this example projects' pre-existing corridor restraints
- Suitability map included Buildings, Level 2 Wetland Delineation, and existing hydrological features.
- Terrain used in the immediate vicinity of the existing corridor right of way (ROW) is 6" resolution cell-based grid derived from the UAS survey (Chapter 2, Emerging 3D Survey – Reality Capture). This fine resolution (computationally heavy) dataset may not be conducive to the original intent of the tool (conceptual/preliminary design). User testing of Corridor Optimization experienced slow progress at times due to many memory cache refresh processes using the base terrain grid.
- Authors make no claim as to expertise with the corridor optimization module nor accuracy of the results (further research warranted).
- Tool utilizes AASHTO standards as assumptions in algorithm and this appears locked down by vendor. Future research (or iterative updates by the vendor) will determine level of customization for setting variables that comply with each jurisdictional standard.

4.5.2 Avoidance Zones

Avoidance zones are zones that the method will try to avoid at any cost. In some rare cases, an avoidance zone cannot be avoided. In that case, the method tries to find an alignment that violates the avoidance zone over the smallest distance possible.

Avoidance zones can be imported as SHP files and marked as such, or they can be drawn directly from the optimization tool as seen in Figure 4-6 and shown weighted in Figure 4-7.

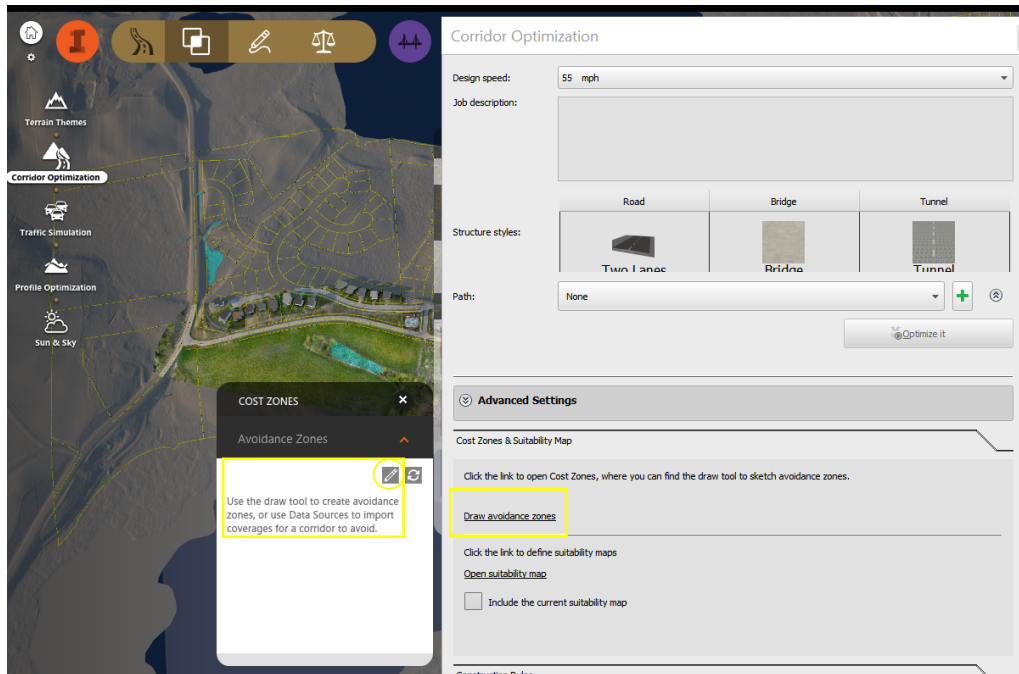


Figure 4-6: Avoidance Zone Digitizing. (Source: SRF Consulting Group)

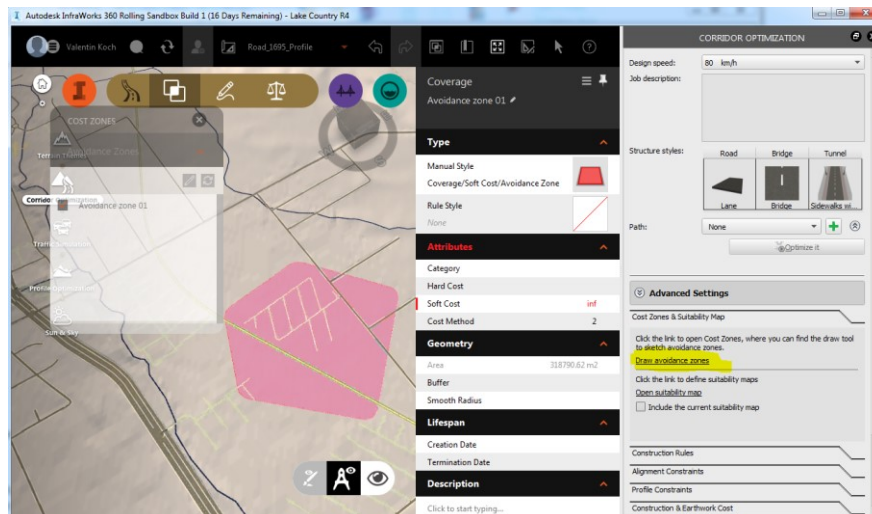


Figure 4-7: Avoidance Zone Settings. (Source: SRF Consulting Group)

4.5.3 Suitability Maps

Autodesk documentation points out “suitability maps can be created using simple functions that model costs such as environmental sensitive areas (for example noise pollution via inverse square law). Suitability maps can also be created from existing GIS (Geographic Information Systems) data. The suitability map is stored in memory as an h×w matrix with the same orientation as the terrain and is used to compute the soft costs.” (Figure 4-8).

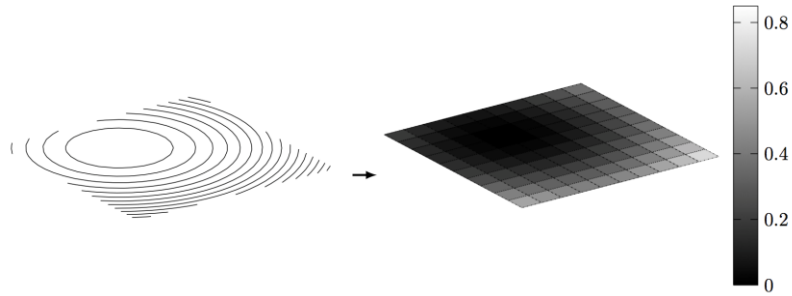


Figure 4-8: Basis of Suitability Computations. (Source: Autodesk, Inc.)

Suitability maps use grid buffering and display using hypsometric color gradient styles based upon user determined cost weightings. Weightings are easily adjusted on-the-fly with slider bars. Since each project is unique, future Best Practice’s would include documentation of metadata to define assumptions used when determining the weight variables. In the Marsh Lake Road pilot example, layers and weightings shown in Figure 4-9 were utilized as a first-cut baseline of inputs. Multiple suitability maps can be created as the tool allows user to choose different map options.

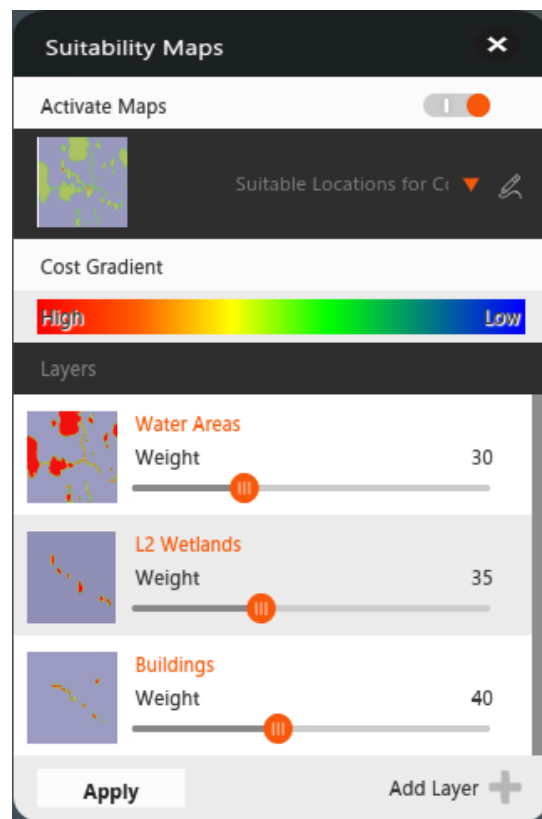


Figure 4-9: Suitability Map Layer Weighting. (Source: SRF Consulting Group)

Users must understand how individual weightings affect the optimization process results and that cumulative layer weightings logically have even more significant impact. If existing conditions include buildings within near proximity to wetlands layers (for example) then cumulative weighting for potential

route areas may be intensified, thereby impacting the final optimization solution. An example of this cumulative weighting costs of two layers (wetland + buildings) shown in Figure 4-10 in red gradient areas.

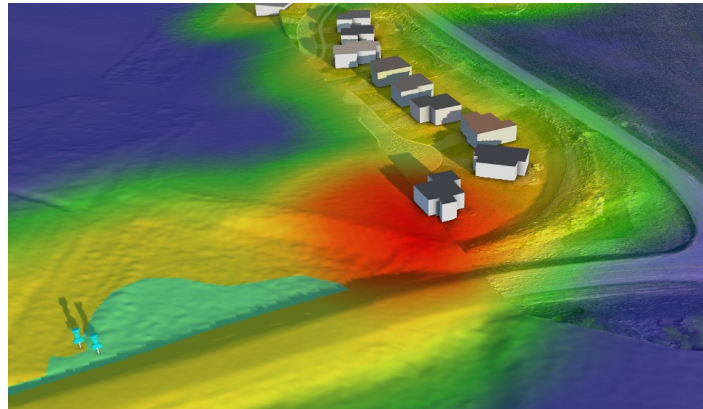


Figure 4-10: Impact of Cumulative Weighting. (Source: SRF Consulting Group)

4.5.4 Corridor Path Set-Up

The corridor optimization module provides users with a sketch tool to indicate potential route options. The sketch tool is dependent upon drawing within corner extent widgets as well as staying upon the terrain surface itself. Deviation from this will generate error alert as shown in Figure 4-11.

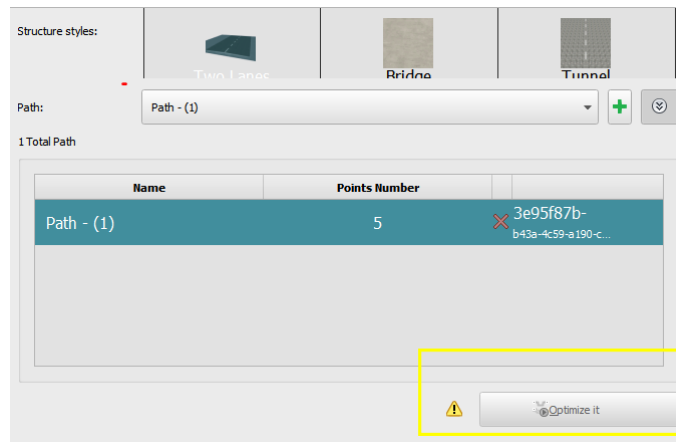


Figure 4-11: Optimization Error Alert. (Source: SRF Consulting Group)

The sketch tool places points of intersection (PIs) along that route intersecting with the terrain. Autodesk documentation ([Appendix D Autodesk Corridor Optimization](#)) illustrates in more depth how the route interacts with the terrain grid-cells to generate a best-fit calculation. The optimization module also uses AASHTO design assumptions therefore it is not immediately clear how to overcome error-generation when implementing other standards such as the standards used in subject research project (Minnesota State Aid 8820.9936) (known to differ from AASHTO). Design constraints such as design

speed and minimum curve radius impact the ability to add PIs; example of this error is shown in Figure 4-12. These are baseline inputs required for the solution to process.



Figure 4-12: Example of PI Error. (Source: SRF Consulting Group)

Figure 4-11 demonstrates how the “Optimize it” button (allowing user to send the job to the cloud for processing) generates an exclamation point and remains greyed out until all conditions are met.

4.5.5 Advanced Design Constraints

Once a path is built Infracore allows the user to select additional design constraints beginning with a desired design speed and typical section. Structure styles are used if there is expected bridge or tunnel structure.

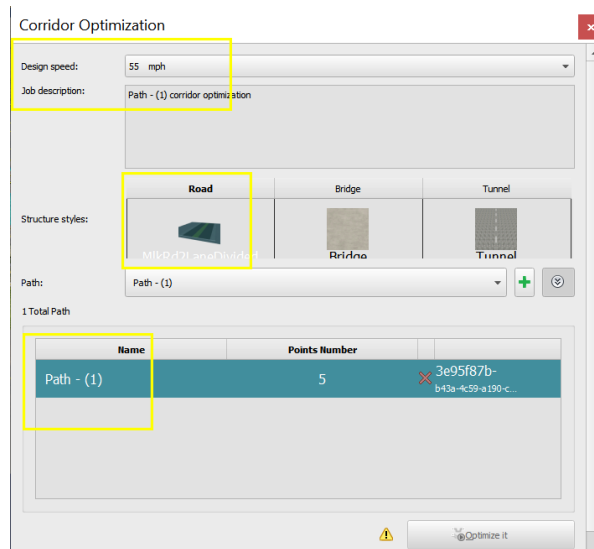


Figure 4-13: Primary Design Variable Selection. (Source: SRF Consulting Group)

In this demonstration, these are left unchecked (Figure 4-15). It is important to note that the algorithm is smart enough to realize that when crossing a water feature a structure is required, and it will implement a pre-defined structure style if the user so desires. These setting are then combined with selection of the previously sketched path.

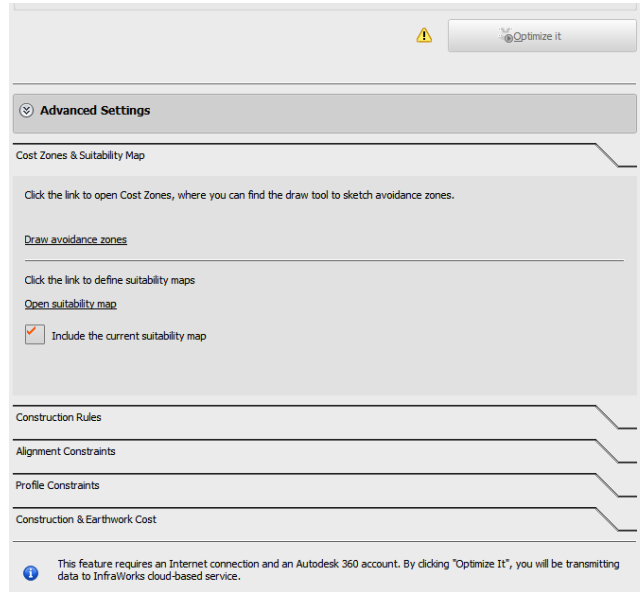


Figure 4-14: Advanced Variables – Constraint Maps. (Source: SRF Consulting Group)

After Constraint Maps or Avoidance Zones are selected (Figure 4-14), construction rules such as roadside grading limits, and cut/fill slopes are entered. Figure 4.15 illustrates these settings for the demonstration project.

Next, maximum grade input is added (Figure 4-16) followed by curve alignment restraint (Figure 4-17).

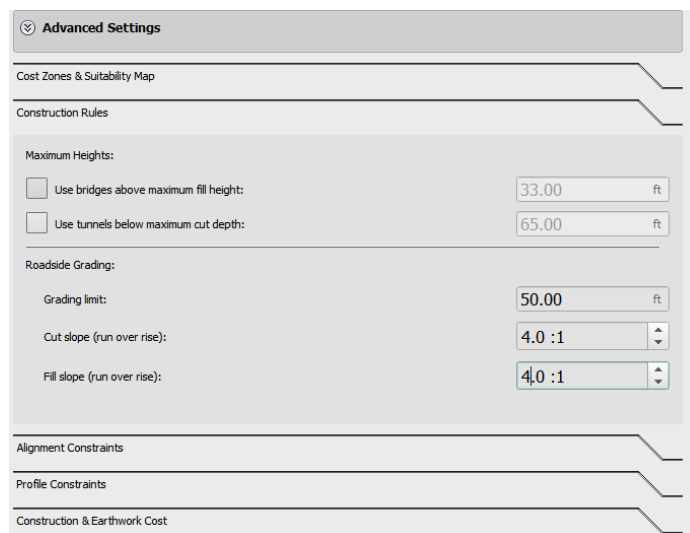


Figure 4-15: Grading and Slope Variables. (Source: SRF Consulting Group)

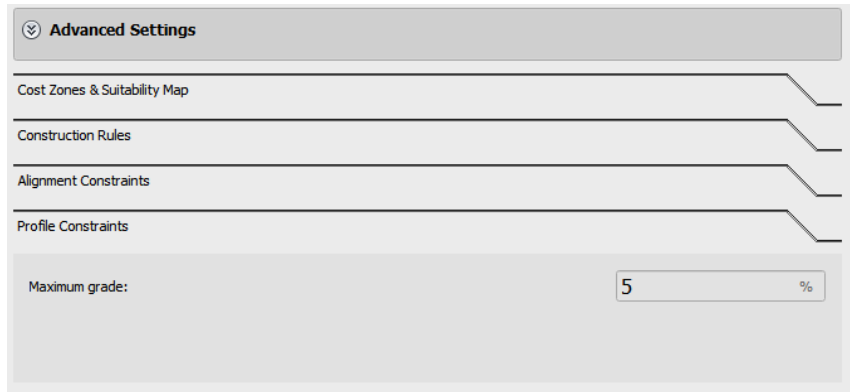


Figure 4-16: Maximum Grade Input. (Source: SRF Consulting Group)

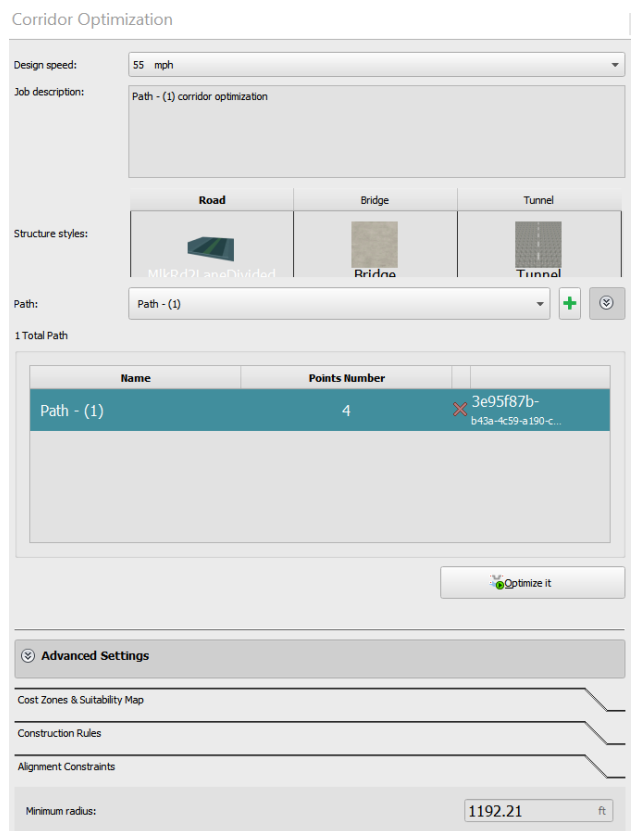


Figure 4-17: Minimum Radius. (Source: SRF Consulting Group)

After maximum grade, and curve constraints the final step before submittal to the processing engine is to input actual unit costs for construction and earthworks (Figure 4-18). As noted previously for demonstration purposes only, baseline default costs were accepted with the intent to quantitatively compare multiple model optimization runs amongst themselves using the same defaults.

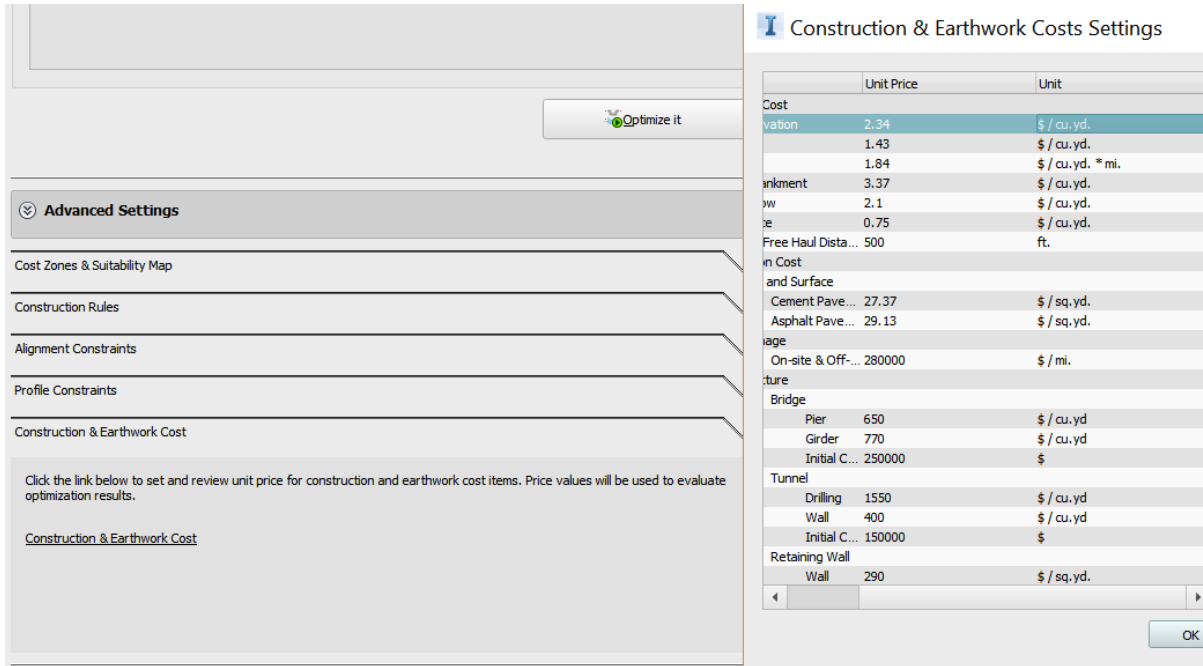


Figure 4-18: Construction and Earthwork Input. (Source: SRF Consulting Group)



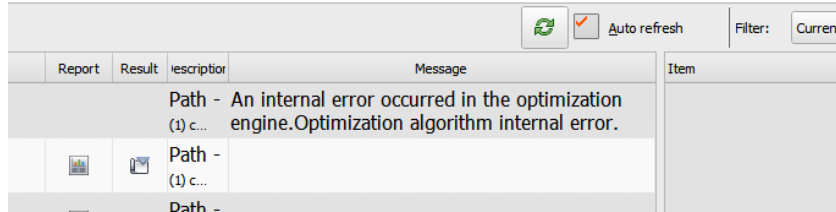
Figure 4-19: Submission and Autodesk Notice. (Graphic: SRF Consulting Group)

The final step is for the user to submit the optimization “job” to the Autodesk 360 service running on an Amazon cloud instance. The notice at bottom of Figure 4-19 notifies user their job inputs are being communicated via Autodesk Cloud services.

4.5.6 Module Execution Results

Limited time exposure by investigators within the optimization module along with the potential functional limitations due to its relatively early nature may have contributed to several false-starts at optimization. Several optimization “runs” appeared to process in the Autodesk Cloud, but resulted in

error messages such as those show in Figures 4-20 and 4-21. These may result from user input error due to assumptions using a combination of avoidance zones combined with a suitability map³⁴. Both constraints are shown together in Figure 4-22.



The screenshot shows a software interface with a table of messages. At the top right, there is a refresh icon, a checked 'Auto refresh' checkbox, and a 'Filter: Current' dropdown. The table has columns for 'Report', 'Result', 'Description', 'Message', and 'Item'. The first row shows an error message: 'Path - An internal error occurred in the optimization engine. Optimization algorithm internal error.' Below this, there are more rows with 'Path -' and '(1) c...' in the 'Description' column.

Report	Result	Description	Message	Item
		Path -	An internal error occurred in the optimization engine. Optimization algorithm internal error.	
		(1) c...		
		Path -		
		(1) c...		
		Dath -		

Figure 4-20: Optimization algorithm internal (failure) error. (Source: SRF Consulting Group)

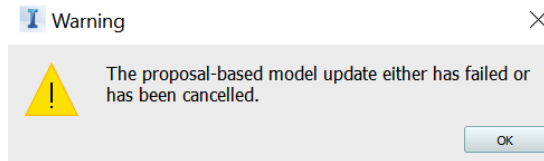


Figure 4-21: Unknown Error (2). (Source: SRF Consulting Group)

³⁴ As noted in previous assumptions this may also be result of other user input errors or other unknown conditional factors (including bugs) that pre-exist with the optimization algorithm.

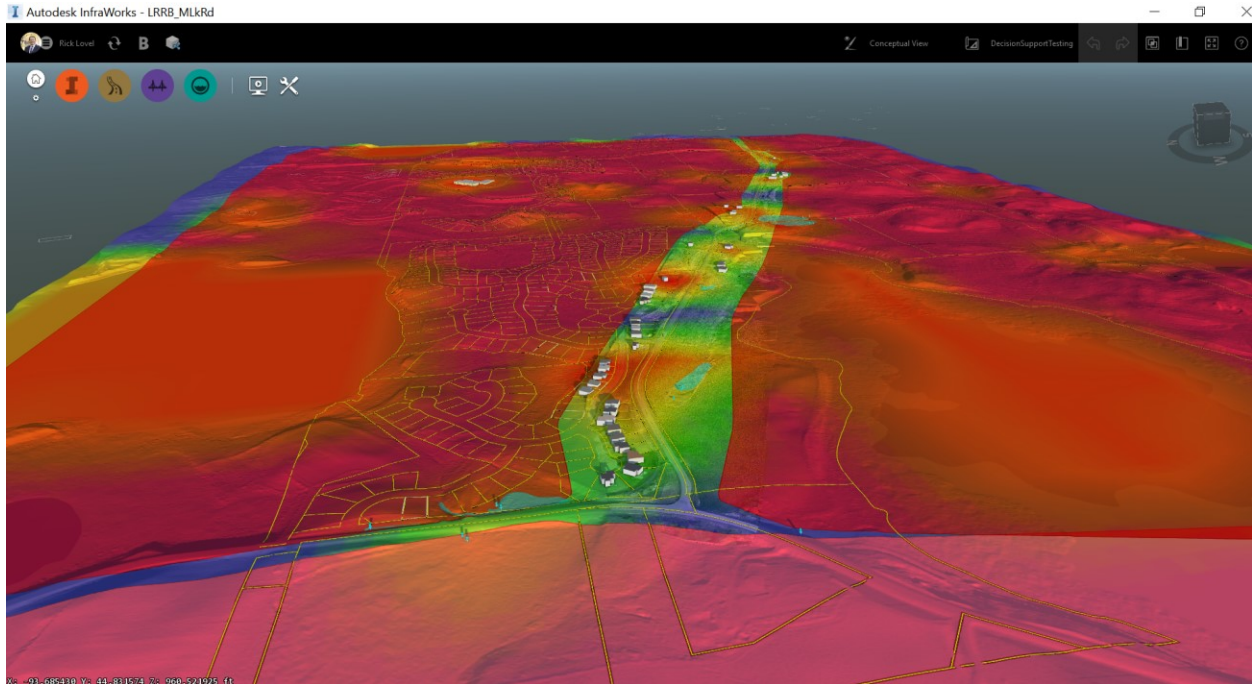


Figure 4-22: Avoidance Zones Used with Suitability Map. (Source: SRF Consulting Group)

The use case for this pilot project (forcing a solution into an existing roadway corridor) may have contributed to these errors in that investigators are applying brute-force constraints to the solution that may be conflicting with the module's underlying algorithm, negating positive results. These unknowns warrant further investigation as to how the module works behind the scenes as well as developing best practices that provide recommended types of best-fit projects.

In another trial and error example intended to develop understanding of how the tool operates, an optimization was sent for processing using a route with avoidance zones while not enabling use of a suitability map. In this case the algorithm appeared to deliver exactly what it was told to do, respecting all avoidance areas, yet generating a route right through areas of wetlands and even a home (Figure 4-23).

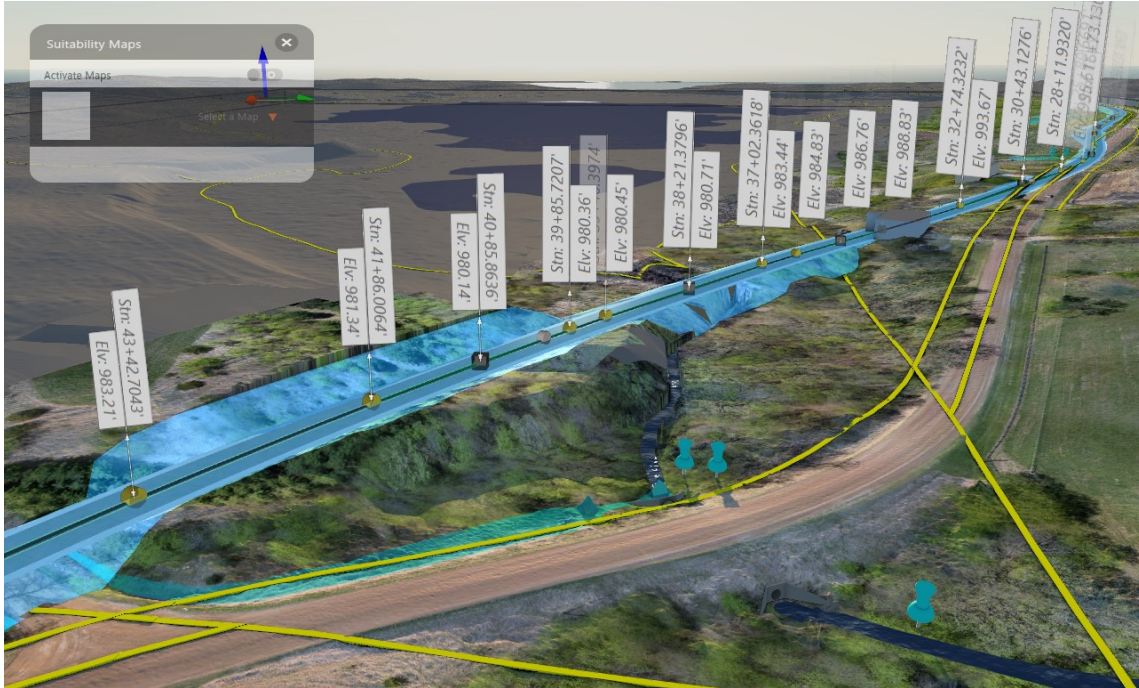


Figure 4-23: Optimized Solution using Avoidance Zones with No Suitability Map. (Source: SRF Consulting Group)

Upon a successful optimization submission run, job results are returned via report and an Infracore road route profile (utilizing user pre-determined cross-section). These are downloaded by user from Autodesk cloud service when prompted. When obtaining the profile information, Infracore conveniently prompts the user to create a new proposal utilizing the optimization job results as seen in Figure 4-24 and Figure 4-25.

Job Monitor

Track ID	Type	Status	Submit Time	End Time	Report	Result	Description	Message
V2019A06...	Corr...	✓	27 Jul 2018 15:28:38	27 Jul 2018 16:00:10			Path - (1) corridor optimization	
V2019A07...	Corr...	✗	27 Jul 2018 14:45:05	27 Jul 2018 14:52:37			Path - (1) corridor optimization	Create a proposal to view the result in the model optimization occurred in the op...
V2019A00...	Corr...	✓	26 Jul 2018 14:53:28	26 Jul 2018 15:24:31			Path - (1) corridor optimization	
V2019A01...	Corr...	✓	26 Jul 2018 09:15:44	26 Jul 2018 09:16:45			Path - (1) corridor optimization	
V2019A04...	Corr...	✓	25 Jul 2018 12:24:51	25 Jul 2018 12:56:20			Path - (1) corridor optimization	
V2019A06...	Corr...	✓	24 Jul 2018 21:28:36	24 Jul 2018 21:33:37			Path - (1) corridor optimization	

Item: General

- Styles
 - Component/Cust...
 - Road width 23.62 ft.
 - Datum width 40.03 ft.
 - Cut slope 25.00 %
 - Fill slope 25.00 %
 - Bridge/Bridge
 - Street/Tunnel
- Construction Rules
- Alignment Constraints
 - Minimum radius 1192.21 ft.
- Profile Constraints
 - Maximum grade 5.75%
- Earthwork Cost
 - Excavation 2.34 \$ / cu.yd.
 - Load 1.43 \$ / cu.yd.
 - Haul 1.84 \$ / cu.yd. *
 - Embankment 3.37 \$ / cu.yd.
 - Borrow 2.1 \$ / cu.yd.

Figure 4-24: New Proposal User Prompt (1). (Source: SRF Consulting Group)

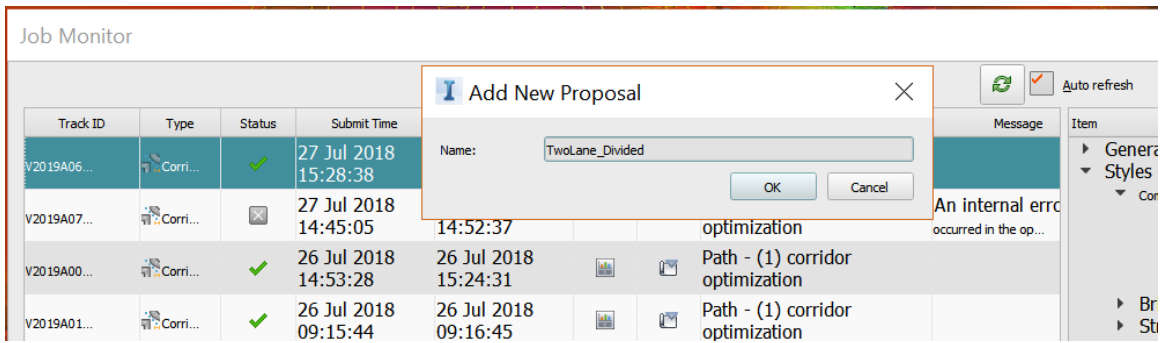


Figure 4-25: New Proposal User Prompt (2). (Source: SRF Consulting Group)

Figure 4-26 shows results of two optimization “runs” (using user pre-determined profile) and illustrates how adjusting design constraints may affect results. These Infracore component roads are then transferable back into Civil3D for more mature design.

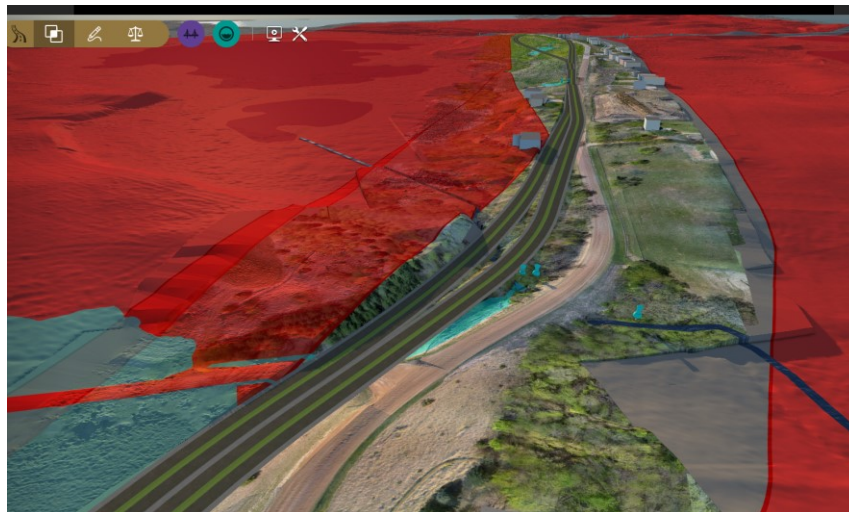


Figure 4-26: Ramifications of Design Constraints. (Source: SRF Consulting Group)

Figure 4-27 provides snapshot of results of a single cost-optimized route. Infracore provides a corresponding report for results ([Appendix E Corridor Optimization Report](#)).

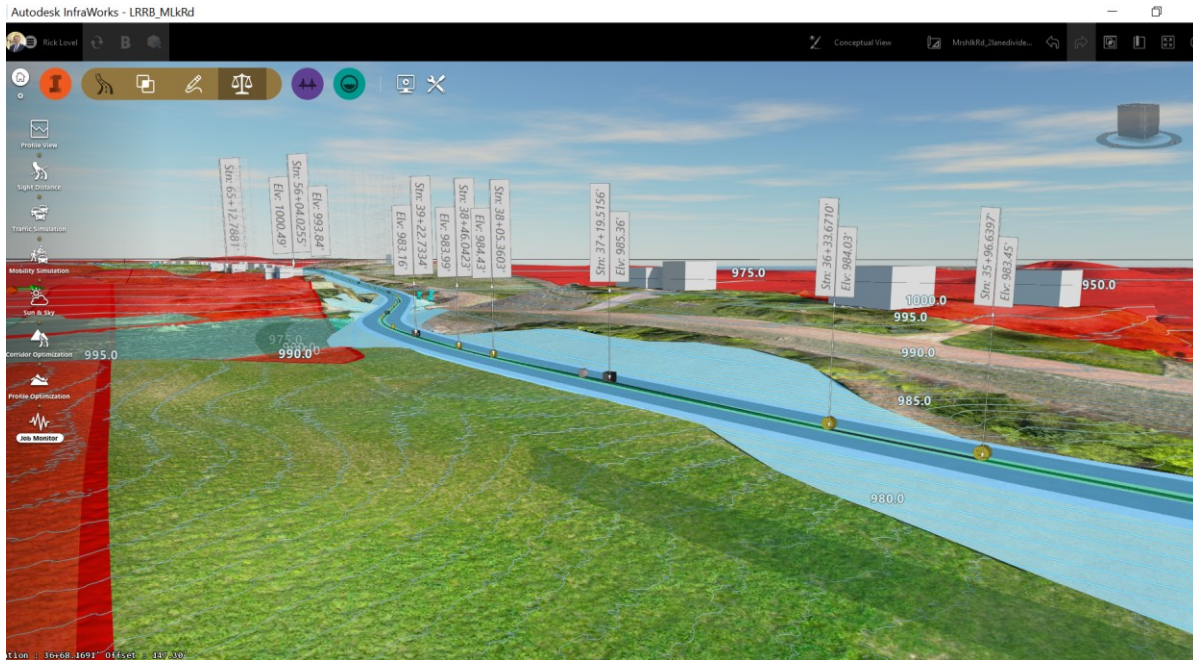


Figure 4-27: Optimized Route Example. (Source: SRF Consulting Group)

4.6 BENEFITS/SHORTCOMINGS

Benefits:

- Tedious design work-tasks are becoming more automated
- Easy to follow interface steps mimicking design thought process of an engineer
- Multiple route options can be quickly completed, allowing further comparison and contrast of alternatives in a short period, including quantitative cost and volume information.
- Automatic report generation is cost effective approach supporting informed decision-making and releasing engineers from repetitive material generation.
- Design engineers will be released from redundant and potentially error prone processes and empowered with different types of design roles.
- Suitability map weighting schemes provide flexibility for establishing priorities
- Potential Profile Optimization benefits to the BIM life cycle include the following:
 - a. Contribute to cumulative BIM Use's (increased BIM Use = increased return on investment) on a project.
 - b. Accelerated alternatives development (accelerated schedule = reduction of cost).
 - c. Early rapid visual (qualitative and quantitative) reporting on understanding of costs and ramifications of decisions made for route alternatives analysis.

Shortcomings:

- This demonstration project not most conducive to appropriate context of use for this tool with the authors suggesting that larger scale corridor studies may be more of a “best-fit” scenario of use.
- Limited documentation for Corridor Optimization module creates ambiguity.
- No apparent way to save advanced design inputs (user must re-input each time module is accessed).
- Model run errors provide vague descriptions (no de-bugging path for user to investigate).
- Lack of more in-depth research with the Corridor Optimization module to validate results.
- No clear path to override default AASHTO assumptions with other agency-specific design parameters.
- Vendor Cloud Credits business model could become cost prohibitive if charges increase³⁵.
- Somewhat of a black-box and solutions developed without proper engineering oversight could result in faulty decisions or ramifications to later project design phases.

4.7 NEXT STEPS

Potential next steps include:

- Develop standardized processes (inputs) to Corridor Optimization that can work for a wide variety of transportation projects and design standards for agencies.
- Develop BIMxp section outlines to set expectations and assumptions for KBS tools such as Corridor Optimization.
- This research scope of work does not account for deep dive into this tool. The lack of documentation or evidence of real-world practicality and accuracy contrasted by the inference of significant potential value to optimize the design alternatives process warrant future research projects specifically in this area.
- Tie these preliminary design study findings to final design and construction process research studies to map out a complete transportation project life cycle.
- Conduct additional pilot projects with cities and counties on projects of different sizes and types to contrast and compare Corridor Optimization results.
- Organize local user groups.
- Learn from successes and errors by reaching out to early adopters using this module on projects in other states or jurisdictions.
- Develop solid Key Performance Indicators (KPIs) and quantitative measures to track value of the Corridor Optimization module vs traditional methods.
- Identify Best Practices to move the civil engineering design community forward.
- Work with vendors on new iterations of the module.

³⁵ Currently, corridor optimization appears to be free of charge cloud service.

CHAPTER 5: ADVANCED 3D PRELIMINARY DESIGN FOR ACCELERATED ALTERNATIVES

5.1 SUMMARY

This chapter speaks to the fact that generative design has been in use for some time by other sectors and is only new to the transportation industry itself. When originally released in Infracore the profile optimization tool (featured in this chapter) was provided by Autodesk with a standard Autodesk caveat “for review purposes only” which is a standard part of Autodesk’s release roadmap modus operandi while bugs get worked out. It is significant for the industry that at the time of this writing, this type of module has graduated from beta mode and is now available for full production. While still in its infancy this graduation to a mainstream feature implies that Autodesk has A: fine-tuned and is comfortable with the algorithm, B. has worked out any significant bugs, and C. is adding this tool to a growing list of offerings that monetize services in the cloud.

This is an exciting stepping-stone for the transportation design industry. Artificial intelligence and machine learning will continue to bring optimizations into the transportation design process, and as the 2004 Journal of Information Technology in Construction predicted, we are entering the second generation of BIM development where knowledge-based systems will augment the civil engineer’s tools and capabilities.

5.2 TASK PURPOSE

Explore the ability to rapidly develop alternatives using parametric design principles. Demonstrate route profile optimization, semi-automatic preliminary quantities evaluation, and re-purposing data for public outreach.

5.3 INTRODUCTION

Chapter 4 (Task 4: 3D Corridor Decision Support [Optimization]) noted cloud-based generative design services provided by vendors are not new. Autodesk and Bentley have both increased availability of cloud processing tools that offer the convenience of unlimited power and off-loading of computational-heavy processes while also providing enhanced collaboration environments.³⁶

³⁶ <https://bim360.autodesk.com/>

Research published in 2004 (Journal of Information Technology in Construction)³⁷ provided: “In the architecture, engineering and construction sector, cloud-BIM integration is considered to be the second generation of building information management (BIM) development, expected to produce another wave of change across the construction industry.” Both the profile optimization module studied in this chapter as well as the corridor optimization module (Chapter 4) leverage these intelligent cloud services.



Figure 5-1: Categories of Autodesk KBS and SaaS Cloud Services. (Source: Cadac Group)

In addition to access to unprecedented computational power comes workflow process-changes; the subject matter expert (typically an engineer or CADD technician) is effectively released from many of the mundane, repetitive, and time-consuming tasks. Succar (2011) identified this redundant effort throughout the design process. These repetitive tasks are now increasingly augmented by machine-learning algorithms and massive compute power. In this instance, road profile optimization is being semi-automated. The engineer controls the inputs and variables and analyzes the outputs for potential changes but off-loads the rest of the tedious process. Engineers are subsequently being rewarded with more available time by off-loading these repetitive CADD drafting-intensive elements. This additional time can be used to evaluate more profile and quantities configurations, re-allocated to other project tasks, or just absorbed as acceleration of schedule. As mentioned in Chapter 4, Autodesk a refers to the roadway profile optimization tool as “[a Magic Button of Optimized Roadway Design](#).”³⁸ This workflow is facilitated semi-automatically by [generative design](#)³⁹ processes no longer confined solely to the desktop.

³⁷ A Review of Cloud-based BIM Technology in the Construction Sector. Submitted: August 2014. Published: September 2014 at <http://www.itcon.org/2014/16> GUEST EDITORS: Wang X., Li H., Wong J. and Li H.

³⁸ <https://knowledge.autodesk.com/search-result/caas/auonline/content/au/global/en/au-online/classes-on-demand/class-catalog/classes/year-2014/infraworks/cv5385-p/jcr-content.html>

³⁹ <https://www.newequipment.com/research-and-development/what-generative-design-and-why-its-future-manufacturing>

5.4 APPROACH

While Chapter 4 explored the cloud-based Corridor Optimization module, Chapter 5 focuses upon vertical roadway profile alignment optimization. Figure 5.2 illustrates the location of the cloud-based Profile Optimization module featured in this chapter, that can be found under the Roadway>Analysis tab of Infracore (v.19.1.37.0).

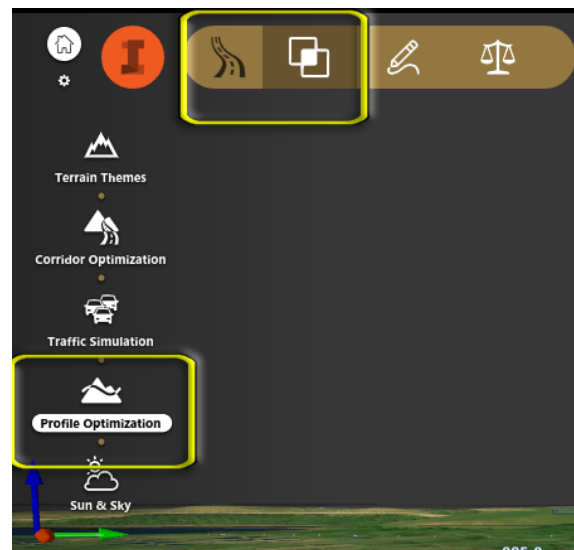


Figure 5-2: Infracore Profile Optimization module. (Source: SRF Consulting Group)

One primary goal for this pilot project is testing of new tools and processes that reduce the amount of time spent getting to a preferred alternative and optimized design profile. The current transportation industry method develops multiple alternatives in Civil 3D (or Bentley equivalent) and generates reams of paper plans for evaluation. Typically, with the traditional method, the design consultant and client also go back and forth in a time-consuming process that is inefficient and costly to the project budget (ultimately for taxpayers) and inherently error prone. The reader should note that Corridor Optimization shown in Chapter 4 and this chapter's Profile Optimization build upon each other's results in a rapid, visual, and fluid manner—all while never once opening final design software (in this case Civil 3D). The process also does not generate paper plan sets that ultimately get thrown away. Multiple-route alternatives are identified (scenarios), then refined into a preferred alternative (including iterative preliminary quantity analysis) followed by optimization of preferred alternative profile. This is no different than the traditional process with two major exceptions: 1. the process used to get to the same solution is inherently more efficient, and 2. it is only after this new process takes place that the file is then exported to Civil3D for final design. Many users continue to try to force Infracore (or Bentley Concept Station) into their traditional workflows, when they should be using these emerging tools first and then migrate the design into more mature design software. Tools are being adopted without full understanding of their intended use-case implication and impacts to accompanying processes. The export format used to eventually move information into final design is the Civil3D-friendly *.imx (Autodesk Infracore exchange) format.

These new methods result in savings by significantly reducing time and cost by reducing design hours (staff) and review hours (designer/consultant) compared to outdated traditional process(es). Specifically, the project benefits and savings include:

- Accelerated project timeline to construction
- Dollar savings (allowing more options to be studied)
- Ability to release project funds to other tasks such as public engagement
- Visual design process (increasing intra-disciplinary collaboration and understanding with major stakeholders during preliminary stages)
- Increased accuracy and reduction of RFIs (ability for clash detection and improved project communications)
- 50% lower advanced visualization costs (base 3D models can be repurposed into higher-end visualizations suitable for public consumption)

The window of opportunity to provide significant value and positively impact project costs is captured during the Schematic and Pre-design phases. This high-value sweet-spot is shown highlighted in yellow in the MacLeamy project life-cycle curve (Figure 5-3).

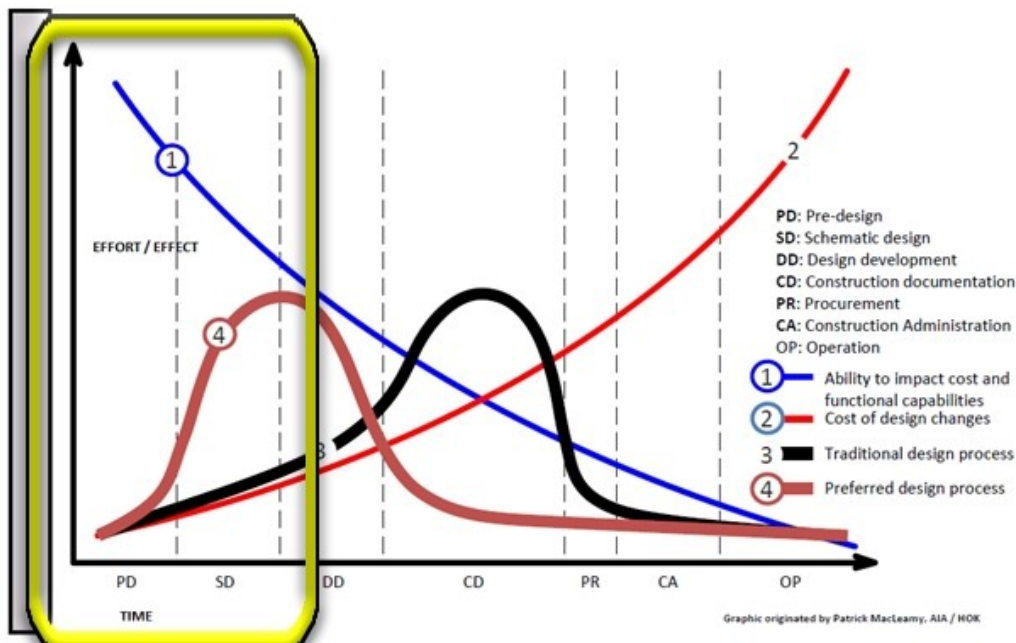


Figure 5-3: High-value opportunity area of MacLeamy Curve. (Original Source Graphic Modified by SRF Consulting Group)

Chapter 4 illustrated workflow where multiple options for routes were developed in Infracore in first-cut scenarios, an evaluation process resulting in an optimized corridor solution. This solution is then fed to the Profile Optimization module which is also semi-automated and further reducing staff design time.

5.5 PROFILE OPTIMIZATION METHODOLOGY

In order to understand the cloud tools prior to beginning the route profile optimization process, a search of Autodesk help documents offer a [high-level explanation](#)⁴⁰ of what transpires once a route is submitted: Autodesk: “Optimization jobs are processed in the cloud and return existing ground profiles along the centerline of the road. The process detects when the profile crosses other roads and designs intersections. An algorithm detects water crossings and computes the cost of placing bridges. Earthwork costs are calculated based on the width of the road and the width of the transition zone defined in the road style; the wider the transition zone width, the more accurate the earthwork volume estimates.”

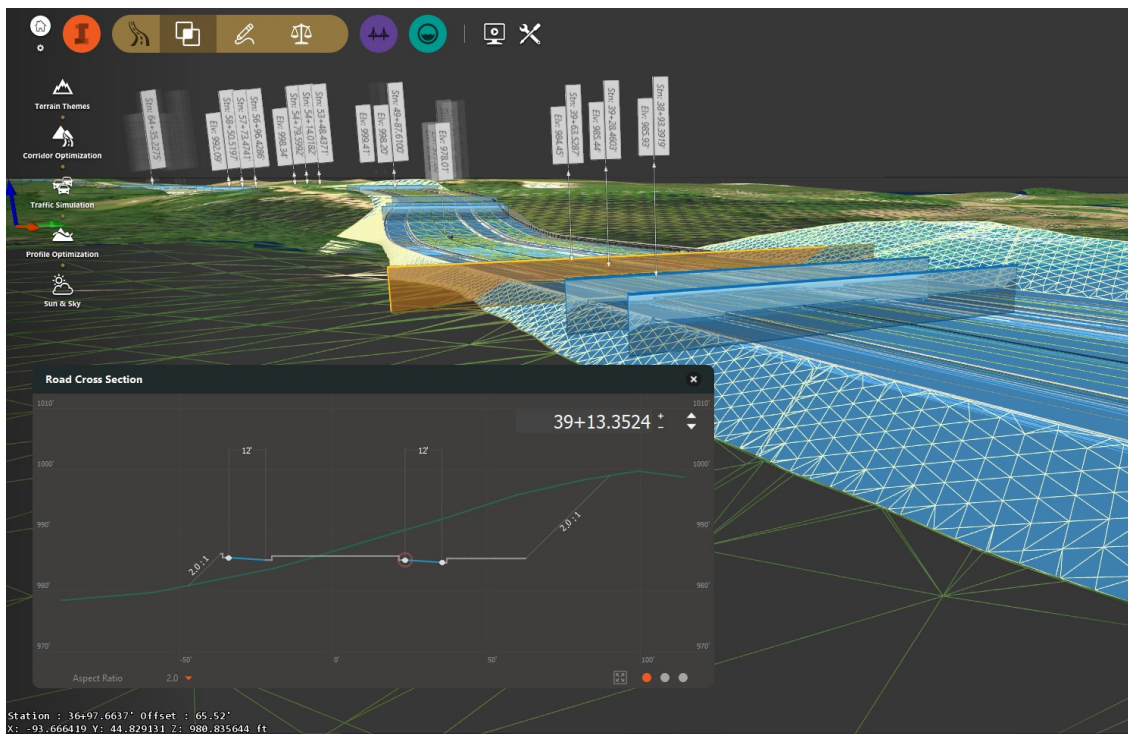


Figure 5-4: 3D alternative with cross-section and super elevation. (Source: SRF Consulting Group)

Once a preferred alternative alignment has been developed it can be utilized as input to the Profile Optimization module (Figure 5-6). Prior to launching the profile optimization process, the preferred route alternative can be examined in greater detail using interactive cross-section display tools that include stationing and super elevation (Figure 5-4). In addition, the road profiles interface (Figure 5-5) can be utilized prior to running the optimization module to manually add, subtract, or edit PVI, curves, and other elements. Drainage (parametric preliminary culvert for Six-mile Creek shown in Figure 5-5) can also be manually modified.

⁴⁰ <http://help.autodesk.com/view/INFMDR/2016/ENU/?guid=GUID-4CDA03BB-E75F-463D-B925-0B35554B4C83>

Infraworks Profile Optimization Module Pre-requisites

Use of this module is dependent upon several pre-requisite steps:

1. Preferred alternative identified and available as Infraworks [Component Road](#)⁴¹
2. Grading inputs: Cut/Fill Slopes and Maximum Grading Distance
3. Design variables entered must meet range of default AASHTO settings
4. Feeding parameters into the Advanced Settings tabs
5. Autodesk BIM 360 account (required from Infraworks, v19 on)
6. Personal or cloud credits totaling minimum 100 credits (required per profile optimization)

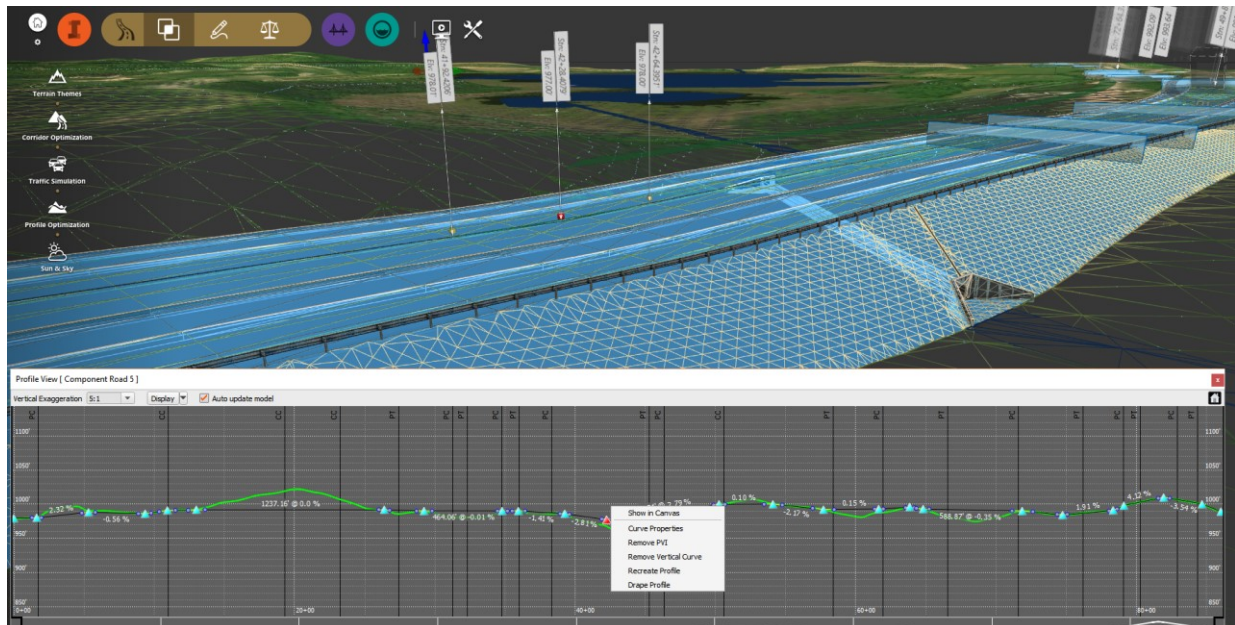


Figure 5-5: Parametric profile editing. (Source: SRF Consulting Group)

Figure 5-6 shows the user interface for profile optimization. The “Optimize it” button must display an associated green light, otherwise the optimization job will not be uploaded to the cloud for processing. The fundamental pre-requisites listed previously must be met to obtain the green signal and avoid the optimization warnings shown in Figure 5-7. Failure to meet these requirements will result in errors displayed as yellow exclamation marks along with two separate prompts (dependent upon error type) such as the two shown in Figure 5-7.

⁴¹ <https://knowledge.autodesk.com/support/infraworks/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-RoadsandHighways/files/GUID-75F9DBE1-08B7-4644-9A90-3B212727C13B-htm.html>

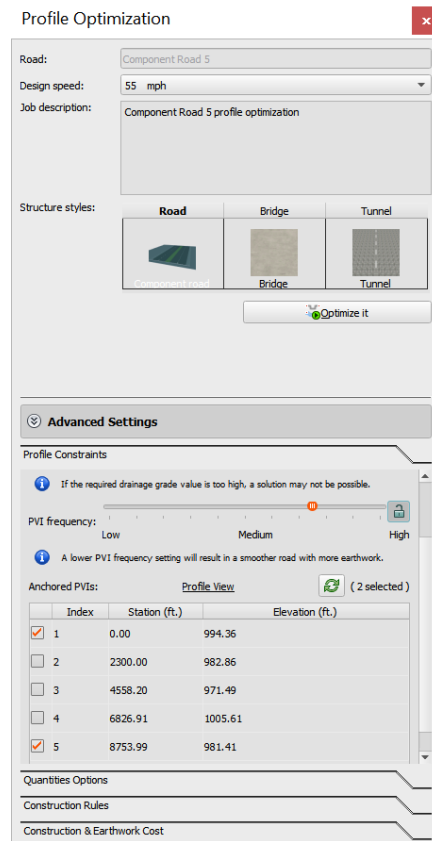


Figure 5-6: Profile Optimization interface. (Graphic: SRF Consulting Group)

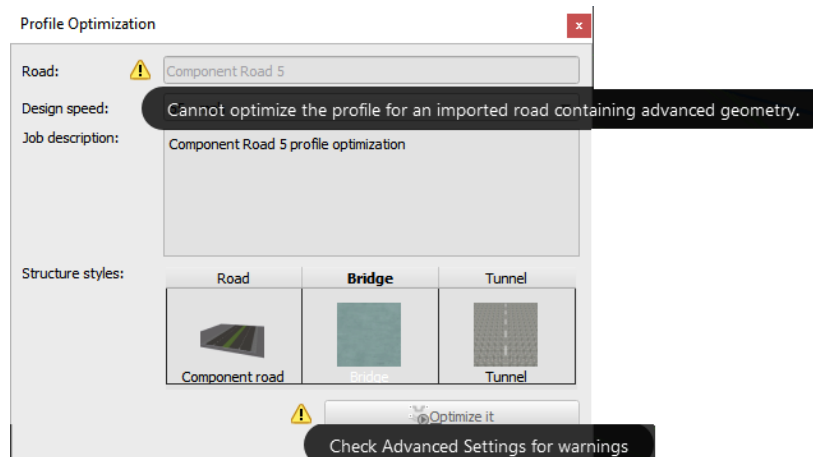


Figure 5-7: Optimization warnings. (Source: SRF Consulting)

Prior to moving into the advanced settings (bottom of Figure 5-6) the user selects the grading method, limit, and cut/fill slopes for the component road that has been applied (Figure 5-8). Other options include visual display settings to depict cut fill slope materials.


Grading	
Material	
Material/Land Cover/Brown Pea Gravel	
Grading Method	Fixed Slope ▼
Grading Limit	<u>50.00'</u>
Cut Slope	<u>3.00 : 1</u>
Fill Slope	<u>3.00 : 1</u>

Figure 5-8: Grading Options. (Graphic: SRF Consulting Group)

Profile Optimization Advanced Settings

Figure 5-9 introduces the four advanced settings tabs provided for the user to further refine design parameters. The first sub-module (Profile Constraints, Figure 5-10) allows the user to set maximum profile grade, minimum point of vertical intersection (PVI) spacing, and required drainage grade.

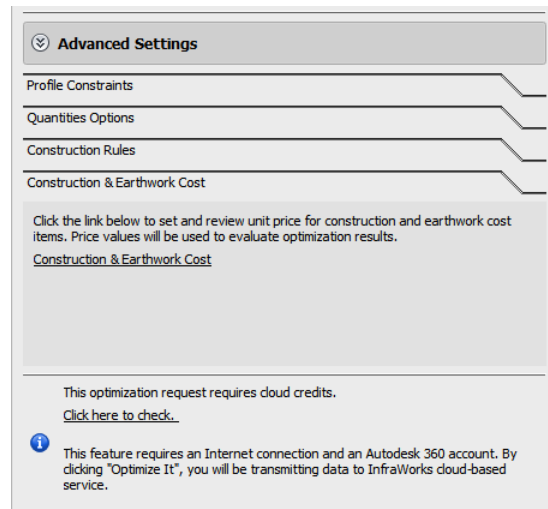


Figure 5-9: Profile Optimization Advanced Settings. (Source: SRF Consulting Group)

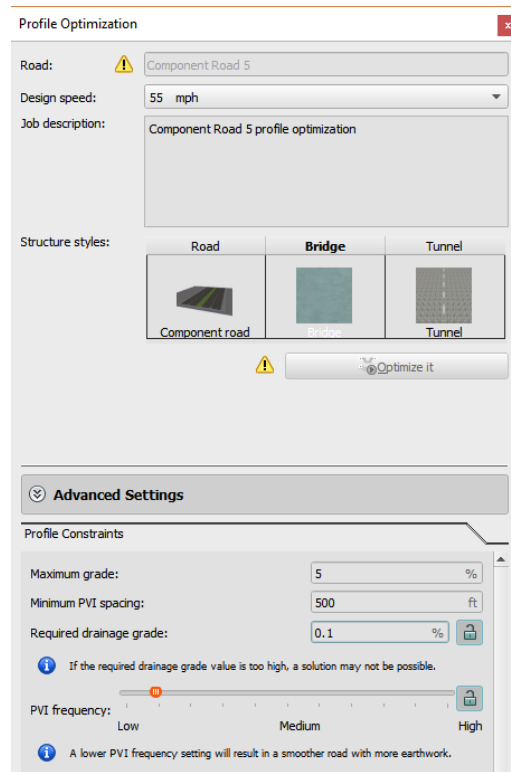


Figure 5-10: Profile Constraints. (Source: SRF Consulting Group)

In terms of actual Minnesota design standards, the maximum grade of the profile and the required drainage grade are normal standard values to be considered. MnDOT’s Road Design Manual (RDM) provides maximum grade values based on the roadway function class, roadway setting, terrain, and design speed. State Aid rules currently do not specify maximum rates. However, the RDM does provide a reasonable grade to consider for this project. Recall that the context for Marsh Lake Road is a rural, arterial roadway in rolling terrain. Based on those criteria, 5% is a reasonable maximum grade to consider for the project.

MnDOT also prescribes a minimum drainage grade of 0.5% in the prevention of surface ponding of water and to facilitate surface drainage. The intent of this minimum grade is to address long tangents of pavement in urban settings, as curb and gutters collect the water, then convey the water to drainage inlet structures. In practice, it is impossible to meet this grade when low points are developed on profiles; however, in terms of drainage design, these locations are treated differently. Again, State Aid does not prescribe a minimum drainage grade, but given the planned urban-drainage context with curb and gutter placement, 0.5% is a reasonable minimum grade to consider.

The minimum PVI spacing value is more esoteric since it appears to capture the design intent on several factors not initially apparent to the user. Considering the design process, the PVI is defined as the point of vertical intersection utilizing station and elevation values where tangent grades change instantaneously. Between PVI locations, the vertical alignment contains portions of vertical curves near the PVI locations, and tangent lengths of grades between the beginning and end of vertical curves.

Depending on project context there is in some cases a minimum length of grade necessary to address certain considerations. For high-speed roadways, MnDOT suggests a minimum of 500 feet between vertical curves, but keep in mind that the length may need to be increased (i.e., for truck climbing). Also, since the profile needs to address one-half of any vertical curve, which is dependent on design speed, profile grades on the approach of curves, as well as algebraic difference in grades, its apparent that the minimum PVI spacing can be subjective depending on those stated factors. One approach to address what the minimum value could be would be to evaluate the conceptual vertical alignment from the Corridor Optimization Task to establish a first guess for the value. If upon running the optimization it appears the minimum PVI spacing is not desirable, modifying the value and re-running the optimization may improve the profile. Keep in mind, however, that rerunning the optimization will incur additional cloud credit consumption.

In conjunction with the minimum PVI spacing, the PVI frequency slider selection also drives how often the PVIs are placed. Generally, the lower frequency will result in longer, smoother profiles, while a higher frequency results in more PVI, shorter vertical curve lengths, and a more rolling profile.

Finally, the Anchored PVI setting box allows the user to select the critical control points and approach grades along the proposed vertical alignment, which minimally should include the profile ties as well as any internal vertical control points needed to be met. The user does need to keep in mind that setting control points within the minimum PVI spacing will not allow the optimized profile to initiate processing. For Marsh Lake Road we are only concerned with meeting the elevation and approach grades at the project termini.

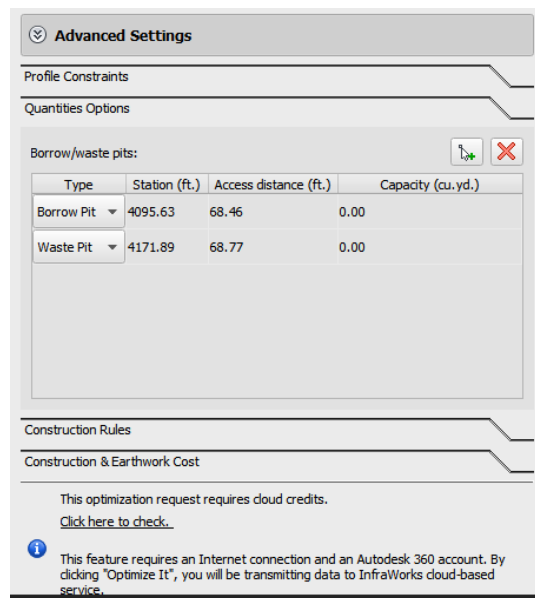


Figure 5-11: Quantities Options. (Source: SRF Consulting Group)

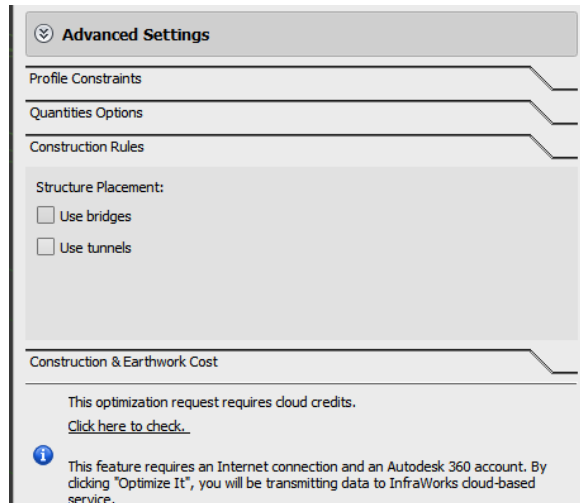


Figure 5-12: Construction Rules. (Source: SRF Consulting Group)

Beyond profile constraints (Figure 5-10), Infracore provides options to interactively designate locations (add or delete) for quantity borrow and waste pits (Figure 5-11). This is followed by setting basic construction rules to include bridges or tunnels (Figure 5-12). The final advanced settings parameter available to the user is providing construction and earthwork unit costs. For demonstration purposes, unit costs were left at default values as shown in Figure 5-13. Note the option to set a Free Haul Distance.

Cost Item	Unit Price	Unit
Earthwork Cost		
Excavation	2.34	\$ / cu.yd.
Load	1.43	\$ / cu.yd.
Haul	1.84	\$ / cu.yd. * mi.
Embankment	3.37	\$ / cu.yd.
Borrow	2.1	\$ / cu.yd.
Waste	0.75	\$ / cu.yd.
<input checked="" type="checkbox"/> Free Haul Distance	500	ft.
Construction Cost		
Base and Surface		
Cement Pavement	27.37	\$ / sq.yd.
Asphalt Pavement	29.13	\$ / sq.yd.
Drainage		
On-site & Off-site	280000	\$ / mi.
Structure		
Bridge		
Tunnel		
Retaining Wall		
Wall	290	\$ / sq.yd.
Initial Cost	1000	\$
Traffic Engineering		
Signing	2400	\$ / mi.
Lighting	24000	\$ / mi.
Signal	8000	\$ / mi.
Incidentals		
Utilities	170000	\$ / mi.
Walls	0	\$ / sq.ft.
Miscellaneous	175	\$ / l.sum

Figure 5-13: Construction and Earthwork Costs. (Source: SRF Consulting Group)

At this point, if all pre-conditions and variables for the Profile Optimization module have been met, the user is rewarded with a green light next to the Optimize it button as shown in Figure 5-14. If the user does not have enough cloud credits to run the job (Infraworks prompts for 100), an error (Figure 5-15) will result.

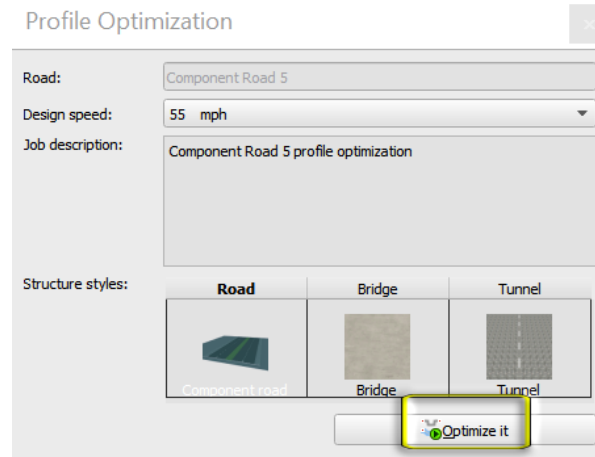


Figure 5-14: Job Submission. (Source: SRF Consulting Group)

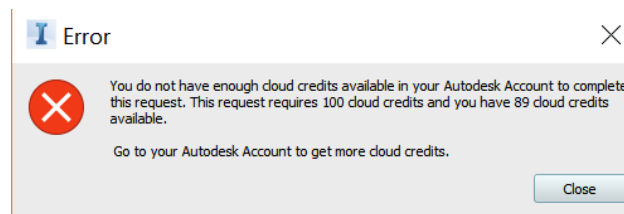


Figure 5-15: Available cloud credits error. (Source: SRF Consulting Group)

Notably, cloud credits must be purchased from the Autodesk store at a cost of \$1 per credit. This monetization of cloud processing time pays for Autodesk leasing CPU instances on Amazon Web Services (or other cloud processing provider such as Microsoft Azure) and presumably returns a profit back to Autodesk for providing the service. Help documentation on Autodesk’s own website provides cost information directly, contrary to the Infraworks’ prompt that states each optimization run costs 100 credits; the Autodesk help entry seen [here](http://help.autodesk.com/view/INFMDR/2016/ENU/?guid=GUID-4CDA03BB-E75F-463D-B925-0B35554B4C83)⁴² suggests “The cost of a profile optimization job is determined by the length of the road being optimized.” The authors of this study were charged 100 credits to run the first optimization job and 100 credits for each additional optimization test (four total),⁴³ even though the project route is less than two miles in total length. It should be noted that while significant time was spent by the authors determining nuances of the module (including potential impacts to optimization submittals from geometry and variable changes), the optimization submittal and processing time itself was only one hour. Autodesk is presumably implying that the \$100 service

⁴² <http://help.autodesk.com/view/INFMDR/2016/ENU/?guid=GUID-4CDA03BB-E75F-463D-B925-0B35554B4C83>

⁴³ One of the four optimization runs for which Autodesk charged the authors \$100 returned faulty results.

charge is significant savings in both cost and time vs. what might take a seasoned engineer an entire day to develop by traditional methods.

Aside from the inferred time-value debate, there further understanding of the nuances of the service(s) are needed including digging deeper into the background algorithm constraints of what is currently a “black box” service.

Profile Optimization Submittal

Upon successful job submittal to the Autodesk cloud processing service, the user is rewarded with a progress bar (Figure 5-16) and able to further track the submittal in the Infracore Job Monitor interface (Figure 5-17).

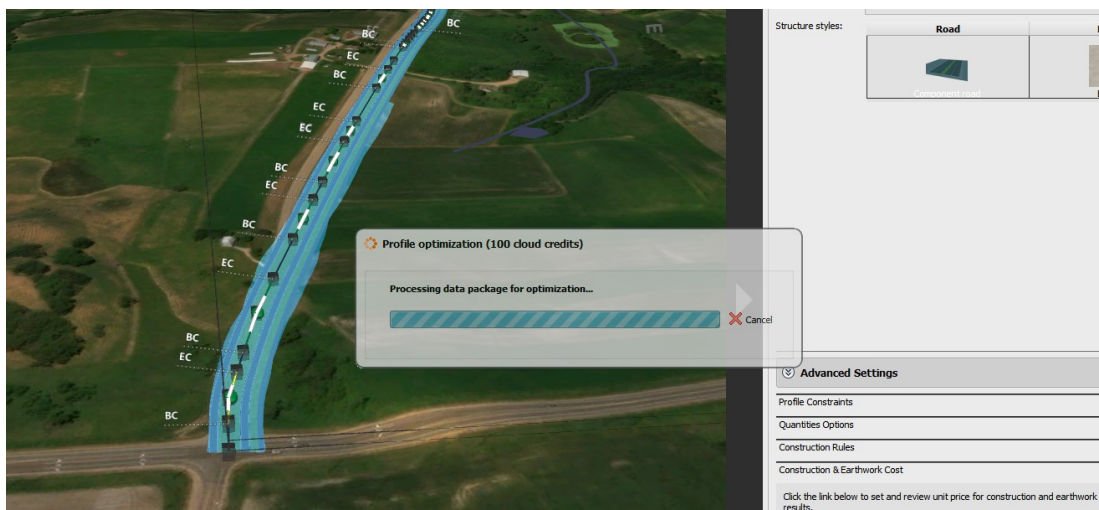


Figure 5-16: Profile optimization processing message prompt. (Source: SRF Consulting Group)

Infracore Job Monitor

Infracore provides a job monitoring interface for the user to track progress and history. Figure 5-17 on the following page illustrates the authors’ previous cloud submissions when using the corridor optimization tools in addition to the current profile optimization job.

Track ID	Type	Status	Submit Time	End Time	Report	Result	Description	Message
V20 19A05040237	Corridor	✓	31 Jul 2018 11:20:31	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A02385634	Corridor	✓	31 Jul 2018 00:55:17	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A05435779	Corridor	✓	30 Jul 2018 23:06:15	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A04651502	Corridor	✓	30 Jul 2018 20:33:33	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A06521555	Corridor	✓	27 Jul 2018 15:28:38	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A07054323	Corridor	✗	27 Jul 2018 14:45:05	16 Sep 2018 13:43:00			Path - (1) corridor optimization	An internal error occurred in the optimization engine. Optimization algorithm internal error.
V20 19A00290394	Corridor	✓	26 Jul 2018 14:53:28	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A01029738	Corridor	✓	26 Jul 2018 09:15:44	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A04570616	Corridor	✓	25 Jul 2018 12:24:51	16 Sep 2018 13:43:00			Path - (1) corridor optimization	
V20 19A06365726	Corridor	✓	24 Jul 2018 21:28:36	16 Sep 2018 13:43:00			Path - (1) corridor optimization	

Figure 5-17: Infracore Job Monitor. (Source: SRF Consulting Group)

Upon submission of the job, in addition to the progress bar shown previously (Figure 5-16) the user may leverage Job Monitor filtering capabilities (Figure 5-18) to track individual and historical job status.

Track ID	Type	Status	Submit Time	End Time	Report	Result	Description
V20 19A04357066	Profile	In progress	17 Sep 2018 16:10:32				Component Road 5 profile optimization

Figure 5-18: Filtered job tracking. (Source: SRF Consulting Group)

Profile Optimization Results

After submitting the job to the Autodesk cloud service, the user is notified by email (Figure 5-19) that multiple files are ready to download. The IMX file provided for download is the actual new profile geometry. Other email attachments include cost estimation and earth volumes report also found in [Appendix F Vertical Profile Optimization Report](#). Note that no intersection geometry for each end-of-the-road segment (nor any local resident access road) was submitted in the model runs at this juncture, resulting in these impacts to volumes and costs not being included.



Figure 5-19: Cloud email notification. (Source: SRF Consulting Group.)

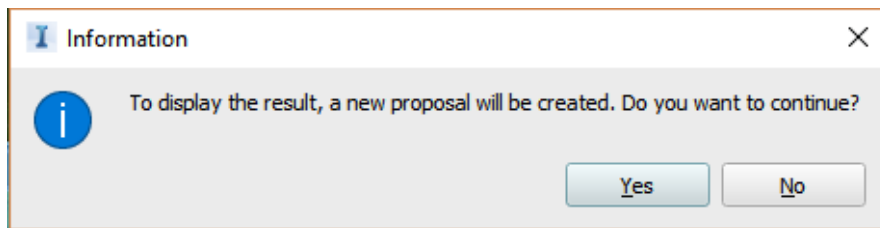


Figure 5-20: New proposal (scenario) prompt. (Source: SRF Consulting Group)

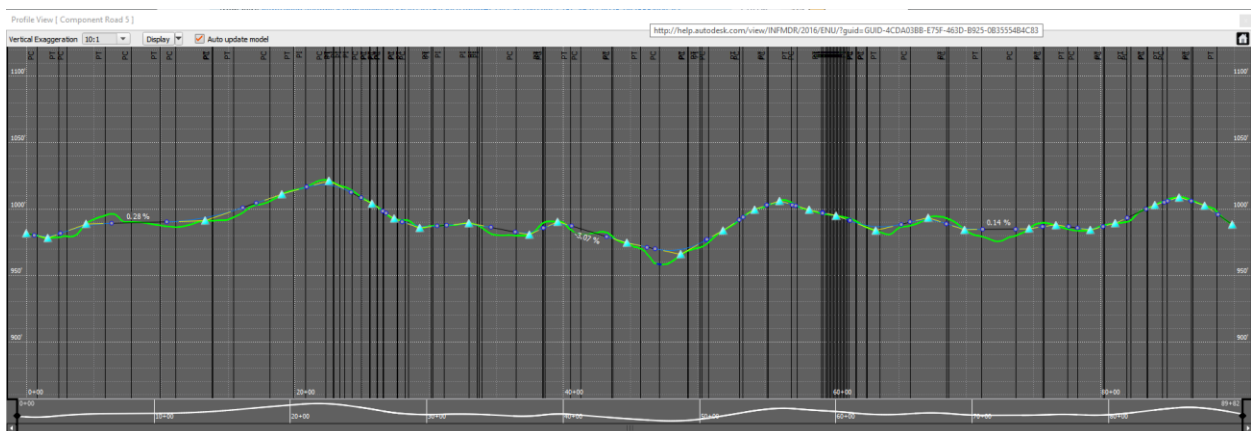


Figure 5-21: Initial (input) road profile submitted to cloud for optimization. (Source: SRF Consulting Group)

When downloading, and installing the Autodesk geometry imx file, Infracworks conveniently assumes the user does not want to not overwrite the original profile and asks for permission to put it in a new

proposal (scenario) as seen in Figure 5-20. This maintains the functionality that allows the user to switch between profiles to contrast and compare. Figure 5-21 illustrates road profile comparisons of the before optimization (submission) followed by Figure 5-22 showing the after-optimization results.

5.6 DESIGN-TIME VISUALIZATION FUNCTIONALITY

One significant process change with the new BIM approach is that the 3D design software provides a multitude of visualization opportunities at design-time (for internal review) with owners and major stakeholders, and finally as an output to be refined further in higher end, dedicated visualization software for the public outreach process. The new process not only embraces and enables visualization during design-time activities to speed decision making but provides 3D model outputs to more advanced visualization software (for public outreach). Previously rapid prototyping of 3D models from 2D plans consisted of 50% of visualization costs. One benefit of the BIM process then, is that this cost is now eliminated because the engineers are already designing in 3D. Visualization is therefore no longer stereotyped as a luxury, but as AASHTO puts it, visualization is “now an expected and critical part of every civil project throughout its life cycle.”

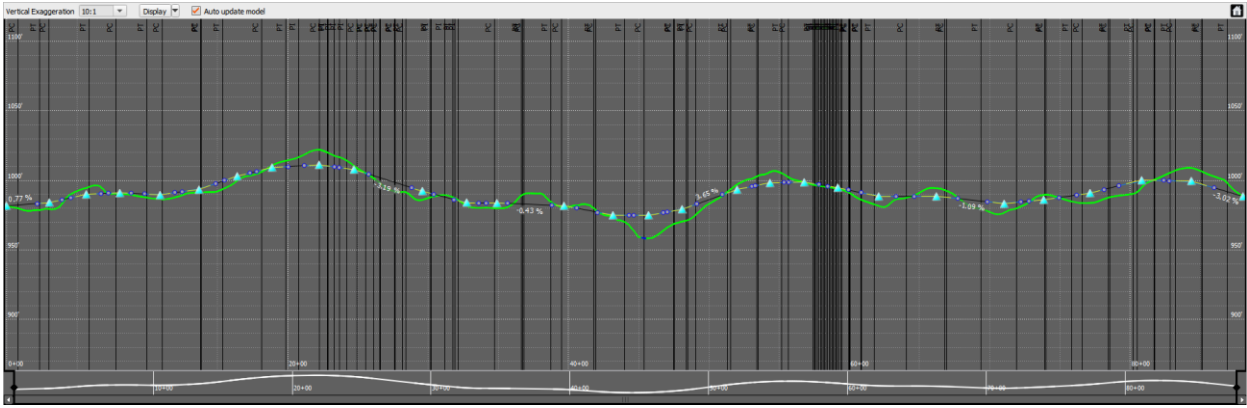


Figure 5-22: Optimized road profile. (Source: SRF Consulting Group)

Infraworks facilitates visualization throughout its workflows, and as shown in Figure 5-23, will conveniently create an animation directly from a pre-existing component road’s route. For this study, a composite video illustrating design-time visualization capabilities is provided as an unlisted YouTube link: <https://www.youtube.com/watch?v=RJZHGspGnM&feature=youtu.be>.

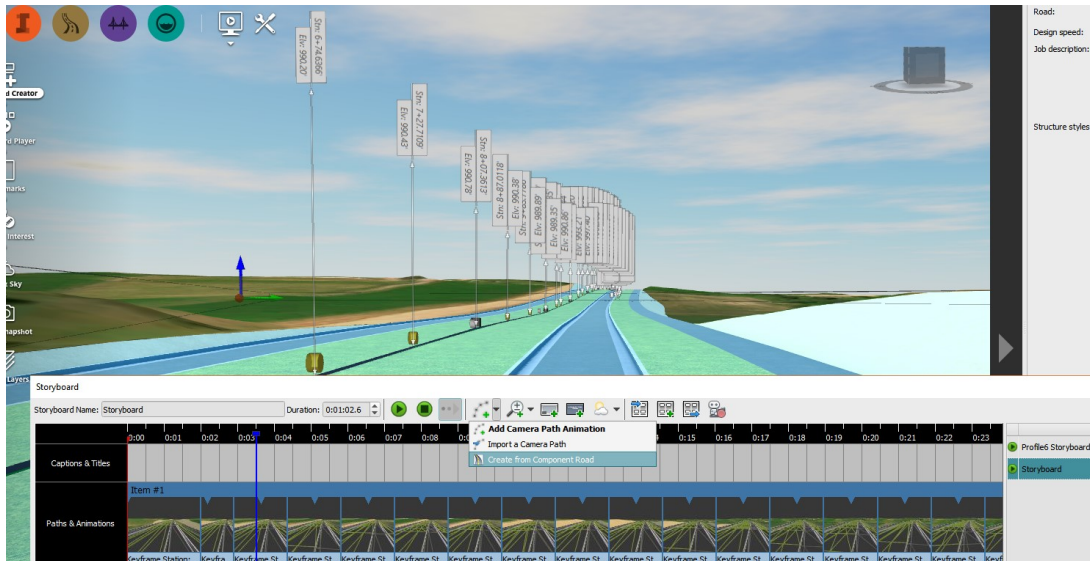


Figure 5-23: Build animation from component road. (Source: SRF Consulting Group)

Note that Infracore is not a high-end render engine and does not export high-end, rendered public outreach content. It does however include the functionality to export the optimized route models and terrain in common 3D formats such as FBX or OBJ that can then be read and upgraded by other software such as 3DS Max, Maya, Lumion, or other. In the design-review example provided, one video was created using Infracore video export, and then overlaid with an engineering view was to provide contrast and comparison.

Note that while this demonstration utilizes Autodesk software, the Bentley preliminary design equivalent (Concept Station) provides similar functionality.

5.7 BENEFITS/SHORTCOMINGS

Potential Benefits:

- Required time to optimize road profiles appears to be reduced by factor of ~8 hours over traditional method.
- Preliminary costs and quantities are semi-automatically generated along with profile optimizations, allowing rapid quantitative comparison of alternatives.
- Semi-automation releases engineering staff from repetitive work tasks.
- Semi-automation allows analysis of increased number of road profile alternatives that would normally not be afforded within project budget (using traditional methods).
- Off-loading of computationally heavy tasks to the cloud could ease IT budgets and provide design engineering opportunities using more ubiquitous hardware
- Available 3D profile reduces visualization costs, facilitates discussion, decision-making and consensus

Potential Shortcomings:

- Black box (Aashto settings, but otherwise unknown parameters driving background algorithm).
- Current inability to override parameters for unique situations.
- Optimization appears very sensitive to changes to initial design constraints.
- Cloud credits business model for access to generative design (Software Service as a Service) could get expensive and may not appeal to all users.
- Cloud credit costs may be more difficult to pass through to clients.
- One out of four \$100 profile optimization submittals tested by the authors returned bad geometry upon downloading results. Neither re-downloading and re-loading of the imx file, nor Infracore view re-generation of scene solved this problem. It is not clear if this was a one-time anomaly or another cause. Figure 5-24 displays the issue.
- Job Monitor filter not working correctly (9/20/18) (inconsistent or non-existent result for some filter settings).

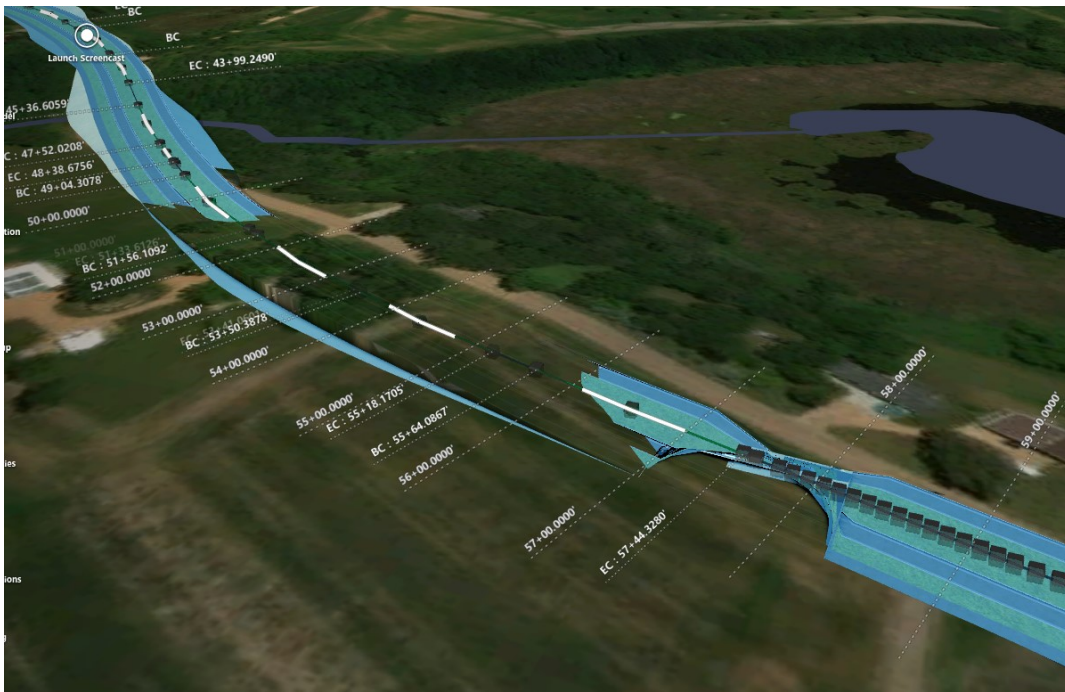


Figure 5-24: Faulty optimization results. (Source: SRF Consulting Group)

5.8 NEXT STEPS

Potential recommended next steps include:

- Continued testing in theoretical research mode to push the module limits and to gain better understand idiosyncrasies of the module.
- In-depth examination and use of the Profile Optimization module on actual pilot projects to contrast and compare with traditional methods.

- Initial tests utilized main road profile with no intersections; future tests should incrementally add more geometry such as main intersections or local resident access roads with corresponding turn-lanes.
- Work with Autodesk to better understand background algorithm constraints and identify future abilities to customize to meet unique client specifications.
- Develop standardized parameters and data entry for different types of road projects, and (for example) projects that include roundabouts.
- Interoperability of optimized profile geometry with other packages for QAQC and data re-purposing.
- Documentation of best practices for Cities and Counties wanting to adopt the technology and workflows.

CHAPTER 6: DATA INTEROPERABILITY

6.1 SUMMARY

Interoperability is ideally a two-way street of round-trip import and export compatibility with no metadata or geometry data loss. InfraWorks GIS import functionality is now unprecedented. Conversely, Infraworks data export has significant limitations. Vendors have little incentive to make investments in export capability that feed platforms beyond their own software ecosystem. Some practical work-flow arguments exist, but business economics likely weighs against this ever becoming a reality since both InfraWorks development and its Bentley cousin (Concept Station) compete directly for the same market-share. Likewise, neither Bentley nor Autodesk has much incentive to provide interoperability with middleware packages, as each wants to own this space as well. The movement towards IFC as a nationally accepted exchange format may impact this. The game-changing ESRI-Autodesk alliance also hints towards GIS integration roadmap clues and to the future (i.e., dead-end or enhanced) of Autodesk Map3D.

Autodesk InfraWorks⁴⁴ enriches the planning and design process by making GIS vector and raster accessible for GIS- and non-GIS professionals alike. Because of this, users with CADD-only backgrounds reap ease of data access and ease of use benefits that break down traditional stereotypes and siloes between GIS and CADD. This is a significant improvement in human use-factor value that is one benefit from the continued convergence of GIS and CADD systems. InfraWorks' ability to ingest vector, raster, and geodatabase GIS information as both a direct file import and via online service represents an evolutionary step for interoperability in the civil engineering industry that brings the natural and human environment (GIS) together with the built environment (CADD/BIM). While export capabilities are currently limited and true round-trip interoperability is still missing, the benefits of InfraWorks' import feature set, file support, scalability, and data management functionality provides value beyond that ever before seen in planning or preliminary design software packages.

Vendors are making more investments in interoperability than ever before. The Autodesk-ESRI⁴⁵ alliance has also announced compatibility of Autodesk REVIT (architectural/structural BIM) within ESRI software City Engine (and ArcGIS Pro). Meanwhile, Bentley Systems recently announced⁴⁶ the release of an open-source JavaScript library to “improve the accessibility, for both visualization and analytical visibility, of infrastructure digital twins.” Bentley is also aligned with the open-source geospatial foundation (OSGEO),⁴⁷ its open-source MapServer,⁴⁸ and is supporting the CESIUM open-source JavaScript library project for world-class 3D globes and map.

⁴⁴ and Bentley equivalent Concept Station

⁴⁵ Also, ESRI-Bentley

⁴⁶ <https://www.bentley.com/en/about-us/news/2018/october/17/open-source-library-imodeljs>

⁴⁷ <https://www.osgeo.org/>

⁴⁸ <https://www.osgeo.org/projects/mapserver/>

Our industry is experiencing a rapid paradigm shift where the lines will continue to blur (e.g., GIS information will become BIM or in other cases, BIM information [geometry and metadata] will be used in GIS-only systems. With transportation design now migrating to database platforms, it all becomes potentially shared common data environment (CDE) information that will someday be seamlessly accessed across platforms and disciplines. This shared information will soon embody a new meaning beyond design or design BIM-GIS. The model-centric CDE world will soon be embedded with design analytics, cloud-based performance analytics, and real-time systems that report into (or from) the built environment. Interoperability standards will be the mechanism makes this happen.

In its current state, InfraWorks only exports modified topography back to Civil3D in the proprietary InfraWorks imx exchange format with no backwards compatibility to GIS. InfraWorks does export entire models into 3D formats; unfortunately, these are somewhat eclectic formats predominantly unfamiliar to CADD or GIS users unless they have significant 3D modeling or visualization background. These 3D model formats are neither GIS- nor CADD-friendly for traditional users and are unwieldy for traditional design use. Conversely, visualization experts may appreciate and leverage these file export options. The vendor may be assuming the user is already on one platform and/or is pushing the user to stay within its Autodesk ecosystem (Civil3D, Navisworks, 3DS Max, or Maya).

6.2 TASK PURPOSE

Demonstrate interoperability, or the compatibility of InfraWorks BIM with GIS and engineering data.

6.3 INTRODUCTION

At its core, the value argument for BIM and 3D modeling centers upon BIM uses (model re-use) and data re-use. Without compatibility, there is no re-use. Life-cycle BIM processes rely on robust interoperability for data transfer, sharing, and work-discipline collaboration. Even with file (geometry) compatibility, metadata loss frequently occurs. This calls for more industry research and advancement to ensure that the translation of both geometry and metadata is carried forward through the project plan/design/construct/operate life cycle.

Today, emerging preliminary design and planning BIM software from major vendors Bentley (Concept Station) and Autodesk (InfraWorks) demonstrate interoperability improvements with not only GIS and survey information, but also with emerging Reality Capture⁴⁹ data products (such as Autodesk ReCAP and Bentley Context Capture), CADD systems, and BIM middleware (such as Bentley Navigator, Autodesk Navisworks, Tekla, and others). Vendors are now also beginning to work together for more common interoperability including exploring open source file standards. Because of open standards and collaborative improvements between vendors such as ESRI, Bentley, and Autodesk, a future trend may be that transportation agencies can be less single platform focused and adopt more of a use the best available tool at your disposal approach. While some DOTs (Florida or Wisconsin for example) already

⁴⁹ <https://en.wikipedia.org/wiki/RealityCapture>

support multiple design platforms, the majority remain locked into a single software ecosystem (Bentley or Autodesk).

6.4 APPROACH

This project examines emerging conceptual design BIM for infrastructure tools and processes with the intent to determine value during the early project life-cycle phases, up to handoff at the end of 30% design. It mirrors a traditionally delivered project with the intent to capture differences, lessons learned, pitfalls, as well as potential qualitative and quantitative return on investment value.

For the purposes of this discussion, we define the 30% design milestone at the point in time where the leading agency can begin the process to acquire right-of-way and/or easements for the proposed project. The acquisition limits need to entirely contain the construction limits, but also allow enough flexibility to allow for potential adjustments for later detail design items. By extension this means the typical section, the proposed horizontal and vertical alignment, super elevation determined for any curvature, the mass grading related to the design elements, would be defined meeting the minimum design requirements for the agency, but also include conservative adjustments to include anticipated items not normally addressed until later in the project life cycle, including but not limited to traffic barrier installation, minor drainage features, utility infrastructure, landscaping, and intersection detail design.

Autodesk InfraWorks was selected for the pilot demonstration to provide consistency with the CADD platform of the jurisdiction that the project resides within (Carver County, Minnesota). This task is not intended to be an exhaustive review of all InfraWorks compatibility with other systems, but to have a focus on integration with the typical sequential steps and data sources of a small BIM-for-Infrastructure project using current state of industry knowledge and software (up to 30% design handoff).

Understanding how this software works with information from different sources and platforms is critical when planning for data integration with GIS, other CADD systems, middleware (such as Navisworks for clash detection), or with a niche discipline system such as VISSIM traffic.

InfraWorks' native format uses the imx file extension built upon open source Feature Data Object (FDO) data access technology. FDO is defined by OSGEO⁵⁰ as an application programming interface (API⁵¹) for manipulating, defining, and analyzing geospatial information—regardless of where it is stored. FDO was originally developed by Autodesk to provide a technology that could access many different geospatial data sources through a common mechanism and first shipped with Autodesk Map 3D in the spring of 2004.⁵² In 2006, Autodesk released FDO as open source. Both 3D and 2.5D geometry and attribute data

⁵⁰ <http://fdo.osgeo.org/>

⁵¹ https://en.wikipedia.org/wiki/Application_programming_interface

⁵² <http://fdo.osgeo.org/history.html>

is stored internally to InfraWorks in an SQLite⁵³ database; FDO technology facilitates moving this data in and out of InfraWorks.

6.5 METHODOLOGY

For the purposes of this pilot project exercise, interoperability is examined as a process tied directly to conceptual design BIM software (Autodesk InfraWorks) in the context of multiple, multi-disciplinary activities of a project. Compatibility tables with database and single file formats are provided in Appendix F and sourced from the (Autodesk knowledge network).⁵⁴

While in-depth, exhaustive review is beyond the scope of this task, the following categories begin to define areas of need, interest, and further study:

- A. Database import/export compatibility
- B. CADD import/export compatibility
- C. CADD data integrity
- D. GIS import/export compatibility
- E. GIS attribute data integrity (after import and after export)
- F. GIS data geometry integrity (after import and after export)
- G. 3D Model import/export compatibility (from/to visualization only)
- H. 3D Model export compatibility (to 30% design software))
- I. 3D Model metadata integrity
- J. Middleware software package compatibility (potential)

6.5.1 GIS Import Compatibility

Many options exist to ingest GIS information into InfraWorks. User decisions regarding which formats are used as well as the import method are dependent upon desired outcome and level of expertise with and understanding of GIS. Chapter 3 (GIS) provided an in-depth workflow demonstration for implementation of both raster, vector, and geodatabase-sourced GIS data.

Autodesk has made significant advances that benefit GIS professionals and non-professionals alike. Chapter 3 also noted that first-time InfraWorks users are introduced to the “Model Builder” tool, which allows spatial search and download of open-source GIS data. This is a convenient mechanism to obtain public-domain GIS data (USGS topography, aerial imagery, and Open Street Map [OSM] vector data). The intent is to provide real-world context by providing easy access to base-map data into the cad-centric environment.

⁵³ <https://www.sqlite.org/about.html>

⁵⁴ Last Updated: August 11th, 2017. <https://knowledge.autodesk.com/support/InfraWorks/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-UserHelp/files/GUID-D6DD9F27-E0A9-424C-B6D2-EAAC4B5EF7D2-hm.html>

More recently, ESRI and Autodesk announced a strategic alliance⁵⁵ that brings the ESRI ArcGIS online world (The Science of Where) closer together with Autodesk's 'Make Anything' slogan and appears in InfraWorks as the [Autodesk Connector for ArcGIS](#).⁵⁶ This supplements the geospatial data access limitations imposed by the Model Builder module by providing easier access to vast amounts of GIS data from the ArcGIS online (AGOL) data ecosystem. Touted as building a bridge between GIS and BIM, Autodesk's stated goals include "providing industry and city planners the ability to design in the context of the real world. This will allow communities to build more connected, resilient cities and infrastructure with a focused eye towards sustainability." The civil engineering industry suffers from historical, institutional, and disciplinary silos that by nature create less than optimum workflows. Therefore, users who embrace the new concept of convergence and interoperability will be the immediate winners—the users and project teams who make faster and more informed decisions because they are no longer working within those traditional data siloes. Ultimately, taxpayers will benefit from this paradigm shift as the industry works smarter, not harder.

6.5.2 Export Compatibility

In its current version (v19.02), InfraWorks contains no direct GIS export, and full export capability only consists of three types of files:

1. Non-GIS compatible 3D modeling formats: Wavefront OBJ, FBX, and Collada (DAE).
2. Autodesk InfraWorks Exchange format (imx) (intended to go back and forth with Civil 3D)
3. JSON style library objects (for reading back into InfraWorks projects)

Clearly, Autodesk intends for users to feed InfraWorks models to Civil 3D as the predominant downstream destination for final design activities. InfraWorks' current data exchange with Civil 3D includes numerous caveats, some of which are documented by Autodesk here.⁵⁷ Notably, import to InfraWorks from Civil 3D is restricted by Autodesk: "Certain Autodesk Civil 3D alignment and profile entity types produce component roads that can be edited in Autodesk InfraWorks, while other types produce roads that may not be editable, and certain Autodesk Civil 3D profile entities cannot be brought into InfraWorks at all. If an Autodesk Civil 3D alignment contains any geometry unsupported in InfraWorks, the component road will be displayed but will not be editable. You can still perform other operations with these objects such as site analysis and storyboarding".

⁵⁵ <https://www.autodesk.com/solutions/bim/hub/autodesk-esri>

⁵⁶ <https://knowledge.autodesk.com/support/InfraWorks/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-UserHelp/files/GUID-AFF4B76A-F6C1-455C-805C-95DF98189806-htm.html>

⁵⁷ <https://knowledge.autodesk.com/support/InfraWorks/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-UserHelp/files/GUID-03CD8D13-2192-4561-B5C1-18D7069F3DBF-htm.html>

6.5.3 City GML Import

The open source City Geographic Markup Language ([CityGML](https://www.citygml.org/)⁵⁸, xml variant) is a standardized data model and exchange format for 3D city models and landscape and is part of the official international Open Geospatial Consortium (OGC⁵⁹) standard. Figure 6.1 illustrates InfraWorks' message to the user that CityGML is no longer directly supported, but that it can be converted using the free CityGML importer for InfraWorks or the industry standard FME⁶⁰ data translation application, which converts information into Autodesk imx format. Removal of direct CityGML support is an interesting reduction in interoperability by Autodesk given that A., the functionality already existed in the application, and B., open geospatial standards are continually becoming more mainstream.

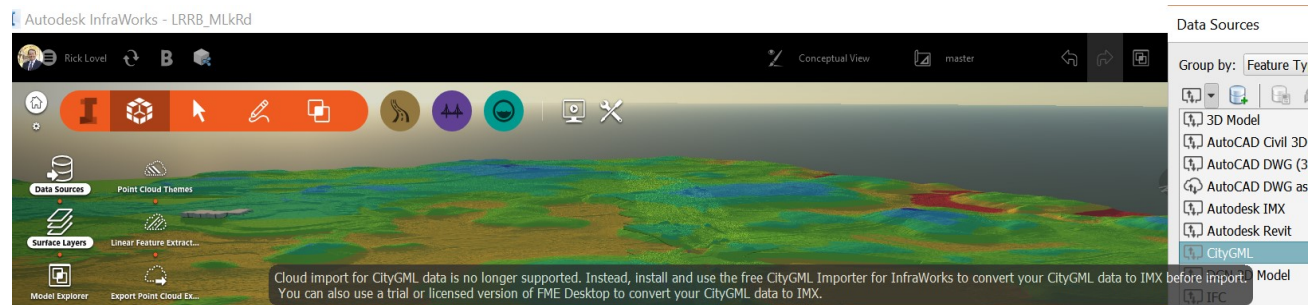


Figure 6-1: CityGML Import. (Source: SRF Consulting Group)

⁵⁸ <https://www.citygml.org/>

⁵⁹ <http://www.opengeospatial.org/>

⁶⁰ <https://www.safe.com/>

6.5.4 Emerging Standards

National standards for civil engineering BIM data-exchange formats have been slow to evolve within the U.S. transportation industry compared to architectural BIM standards adoption. Early transportation data-exchange roadmaps centered upon bridge structures favoring TransXML (or XML variants) and are now evolving to trend towards the Industry Foundation Classes (IFC) format. This evolution is partially represented in Table 6 below:

Table 6: High-level Timeline: Transportation BIM Data Exchange Studies

2004	NCHRP Project 20-64
2006	Chen et al ⁶¹ identified need for standardization of information exchange in 3D models
2007	Ziering, et al.,
2011	NCHRP 20-07 Task 295
2013	FHWA Cooperative Agreement DTFH61-11-H-0027 specifically called out the acronym for Bridge Information Modeling (BrIM) and the need for a BrIM task force to study data exchange.
2014	FHWA Cooperative Agreement DTFH61-11-H-0027 (2014) Bridge Data File Protocols for Interoperability and Life Cycle Management continued to examine xml, Industry Foundation Classes (IFC, ⁶²) and OpenBrIM. ⁶³
2016	FHWA published ⁶⁴ Bridge Information Modeling Standardization Report Volume I– Information Exchanges, further identifying processes and activities that feed data exchange.
2016	Bridge Information Modeling Standardization Report Volume 2 ⁶⁵ continued looking at IFC schemas, as well as revisiting Open BrIM and LandXML.
2016	Michigan Department of Transportation sponsored research ⁶⁶ (Development of 3D and 4D Bridge Models and Plans [published 2018]).
2017- Current	AASHTO BIM for Bridges and Structures, TPF-5(372) pooled fund to facilitate wide use of IFC as an exchange standard for bridges. (National Cooperative Highway Research Program, 2017.)

⁶¹ Chen, S. S., Li, J.-W. & Tangirala, V.-K., 2006. Accelerating the Design and Delivery of Bridges with 3D Bridge Information Modeling: Pilot Study of 3D-Centric Modeling Processes for Integrated Design and Construction of Highway Bridges, Washington, DC: Transportation Research Board.

⁶² <https://www.buildingsmart.org/about/what-is-openbim/ifc-introduction/>

⁶³ <https://collaboration.fhwa.dot.gov/dot/fhwa/ascbt/brim/default.aspx>

⁶⁴ FHWA-HIF-16-011

⁶⁵ <https://www.fhwa.dot.gov/bridge/pubs/hif16011/hif16011c.pdf>

⁶⁶ Contract 2016-0175 https://www.michigan.gov/documents/mdot/SPR-1647_-_Development_of_3D_and_4D_Bridge_Models_and_Plans_624125_7.pdf

At the time of this report, work on standardization of U.S. BrIM model data-exchange formats appear to be favoring IFC. Meanwhile, ISO 16739, IFC for data-sharing in the construction and facility management industries was adopted as a preferred industry BIM exchange format for buildings and is currently at IFC version 4 (IFC4).

The International BuildingSmart⁶⁷ IFC for Infrastructure extension project (IFC-Alignment)⁶⁸ indicates that it will also provide an (international) baseline for IFC-Bridge and IFC-Road.

The implication for the U.S. transportation industry may be that if IFC is fully adopted for civil structures, civil horizontal works could possibly follow. Since the IFC schema in part consists of semantic data relationships designed to carry information forward in the life cycle, ideally both import and export capability using this format should exist in preliminary design packages as well. IFC compatibility already exists in Autodesk REVIT, Civil 3D, Navisworks, InfraWorks, and MEP, while some packages (including InfraWorks) only reads (but not write) IFC format.

6.6 BENEFITS/SHORTCOMINGS

Potential Benefits:

- [Autodesk Connector for ArcGIS](#)⁶⁹ removes geospatial data-access limitations imposed by the Model Builder module. Provides easy access to vast amounts of GIS data into InfraWorks. This assumes user has a pre-existing ESRI ArcGIS online account. Generates an ESRI login prompt in InfraWorks (if not already logged in).
- Autodesk Connector for ArcGIS enriches the planning and design process and eliminates traditional disciplinary barriers.
- Provides import support for many common GIS formats (including Oracle, SQL, and ESRI geodatabase formats).
- User-friendly import and data configuration process.
- Imports point cloud data (if first processed by Autodesk RECAP).
- Loads GIS layers directly from geodatabase files via database manager.
- Provides multiple options for feature stylization and display once data is imported.
- Exports to 3D formats that can be consumed by Sketchup, 3DS Max, Maya, Rhino, or other 3D visualization modeling software.
- Imports LandXML formatted data.
- Imports IFC.
- Imports Autodesk Revit files.
- Good Microstation 2D/3D DGN support

⁶⁷ <http://www.buildingsmart-tech.org/>

⁶⁸ <http://www.buildingsmart-tech.org/infrastructure/projects/alignment>

⁶⁹ <https://knowledge.autodesk.com/support/InfraWorks/learn-explore/caas/CloudHelp/cloudhelp/ENU/InfraWorks-UserHelp/files/GUID-AFF4B76A-F6C1-455C-805C-95DF98189806-htm.html>

- Imports Sketchup.
- Database-caching technology “behind the scenes” facilitates consumption of large area spatial datasets (in high resolution) that would typically bring traditional CADD or GIS software and hardware to a standstill.
- Demonstrates the industry trend of continued convergence between GIS, CADD, and BIM.
- Eliminates some unwieldy GIS to CADD or CADD to GIS processes.
- Ease of use breaks down data and workflow siloes found in traditional infrastructure project processes, improving project communication, data interpretation, accelerating schedules, and reducing potential for human-caused error.

Potential Shortcomings:

- Restricted data translation compatibility within the Autodesk suite itself (Civil 3D); limited translation of surfaces; no direct pass-through of corridor model assemblies between Civil 3D and InfraWorks.
- DWG import restricts user to own/maintain other Autodesk software as pre-requisite to importing DWGs.
- No export options for data back into GIS-friendly formats.
- No IFC export format.
- No direct LAZ or LAS support. Imports LIDAR point cloud data in rcp (Autodesk RECAP⁷⁰) (only) format, thereby tying users back into Autodesk ecosystem.
- Potential for severe metadata loss when exporting to the few available formats.
- Negative impacts to file layering and ability to manipulate layers when exporting to available 3D formats.
- 3D file export formats are more common to architecture, visualization professionals, or game design industry, with low compatibility with most civil engineering software. There is also low civil CADD/BIM user knowledge of these formats.
- IMX export format ignores GIS overlays (except for topography); may not export InfraWorks’ features that may have been created from GIS vector data imports.
- C3D import to InfraWorks only translates some geometries.
- Autodesk recommends modeling of shared parametric parts catalogs in Autodesk Inventor, (a potential challenge for users without access to Inventor, or who are unfamiliar with the use of Inventor).

⁷⁰ Autodesk RealityCapture (RECAP)

6.7 NEXT STEPS

Potential next steps include:

- Thorough testing and review of the Autodesk ArcGIS Online Connector.
- Study of metadata flow through project life cycles, from preliminary design (preferred alternative), through construction, and into operations and maintenance.
- Study of interoperability requirements for middleware packages that facilitate valuable BIM uses (such as clash detection or 4D).
- Investigate contractor needs and examine interoperability from there backwards into life cycle to better understand end goals. Examples of this should include:
 - In-depth documentation on Trimble Business Center (TBC), and identification of valuable attribute information that should be carried through life cycle into TBC and beyond.
 - In-depth documentation of TOPCON (or other common construction software package) requirements
- Identify Best Practices that support moving the local roads civil engineering design community forward; identify workarounds to overcome current limitations.
- More work to understand, resolve or develop automated workarounds for Civil3D to InfraWorks assemblies' translation issues
- Work with Autodesk and other vendors advocating for true round-trip interoperability
- Further engagement in InfraWorks Sandbox (beta) testing program; provide vendor feedback.
- Create local user groups for advancing preliminary design BIM.
- Research task to examine AASHTOWare project data requirements and interoperability roadmap; interface with AASHTOWare working group.

CHAPTER 7: FINAL MEMORANDUM ON RESEARCH BENEFITS (IDENTIFY MEASURES OF QUANTITATIVE AND QUALITATIVE ROI)

7.1 SUMMARY

44% of all AEC BIM users do not formally measure their ROI; another 43% measure ROI on less than 50% of their projects. The remaining 13% is thought to represent the most advanced BIM adopters who never measure ROI because they already know the value and no longer feel the need to measure. These statistics largely represent BIM in architecture and BIM in engineering trades of MEP related to the building industry. There remains a noted lack of public domain information on civil transportation BIM implementations in general.

Documented transportation studies of BIM in the 0% to 30% design phase are (as of 12/05/18 non-existent). Other pitfalls include agencies rushing into 3D and BIM because they want AMG models, completely bypassing other potential available value. Therefore, the intent of this project was to step back to the beginning to examine emerging conceptual design BIM for infrastructure tools and processes and unearth potential clues towards qualitative and quantitative return on investment value (up to handoff at the end of 30% design). Appendix G Project Benefits provides initial findings. Limitations in this scope and lack of standardized methods to track value infer future work remains to better understand impacts of 0-30% BIM on the rest of the project life cycle. There is also need for longer-term project life-cycle observation to fully understand the value that BIM brings from survey through design and construction and into operations, maintenance, and management of capital assets throughout their useful lifespan.

Despite insights from findings of the Wisconsin Department of Transportation on the Mitchell Interchange, recommendations by FHWA, and a few other examples, there are still no standardized mechanisms to develop full ROI studies for transportation projects of all sizes, especially for more typical sized (non-mega) projects. Next steps (previous section) noted FHWA recommendations and proposes other potential avenues to generate more data for measurement and establishment of standardized techniques for measurement.

BIM has shown there is value of more accurate designs with reduced risks. However, the risk to owners and designers is that if new tools are forced into old siloes and inefficient processes, ROI could be negative. For consultants, contractors, and owners to be successful with BIM (positive ROI) there must be a paradigm shift from the traditional siloed disciplines to a more collaborative management practice; a practice that stipulates a process management, operations management, and lean management approach that creates an overall workforce with enhanced skills, supported by information and knowledge technologies.

7.2 TASK PURPOSE

1. Begin identification of known and presumed areas of return on investment (ROI).
2. Begin identification of potential measures of quantitative and qualitative ROI.
3. Begin identification of both BIM program implementation ROI tactics and measures and project ROI tactics and measures.

7.3 APPROACH TO ROI ON AGENCY PROGRAMMATIC BASIS

An underlying question is establishing whether ROI is being examined on a per project basis or on a program/agency basis. Different mechanisms may be employed for each. From an agency program standpoint, Barlish (2011)⁷¹ suggests challenges in valuating BIM continue long after implementation: “Business value of any computer aided collaboration or information systems comprises both monetary and intangible outcomes. The difficulties with the evaluation of the business benefits of information systems can be best categorized into six areas:

1. some of the business benefits may be intangible;
2. organizational changes may occur as a result of the introduction of a new system;
3. business benefits are evolutionary over the life cycle of the system;
4. diverse stakeholders involved will subjectively evaluate the system and may have conflicting opinions;
5. users may feel intimidation or fear of the new system and how it will affect their jobs negatively; and
6. practical difficulties such as improper utilization, interconnected systems, and inability to divide related systems and benefits (Bakis et al., 2006).”

Audrey Schultz (2013) in “The Economics of BIM and added Value of BIM to Construction Sector and Society” notes: “If BIM is to take-off and be adopted holistically by all stakeholders in the AEC (architecture, engineering and construction) industry, then a better understanding of its economic value must be rectified. Currently, there is no standardized methodology or approach in determining its economic value.”

⁷¹ Automation in Construction. Barlish, Kristen, 2012. How to measure the benefits of BIM – A Case Study Approach.

ROI Determination

ROI measures the gains realized from a technology investment relative to the overall cost of implementation, as shown below:

$$\frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}}$$

Figure 7-1: High-Level ROI Equation. (Source: FHWA)

FHWA (Figure 7.1) provides the high-level basis for calculating ROI from technology investments and recognizes the following types of benefits and costs to be considered during benefit-cost Analysis (BCA) and ROI determinations:

1. **Project-level benefits and costs.** These benefits and costs are isolated to the project and can be scaled out either numerically (per project) or by contract value. Labor efficiencies due to technology are benefits that scale linearly across multiple projects and the entire construction program. Full-time equivalent (FTE) costs should be at the normal rates and not reflect the rates of any subject matter experts who are involved in the pilots. The incremental cost difference for subject matter experts should be allocated as one-off costs.
2. **Prorated project-level benefits and costs.** These benefits and costs are scaled across multiple projects (i.e., equipment that depreciates over several construction seasons). A pilot project would capture the full cost of purchasing surveying equipment to take advantage of the 3D models during the construction. However, that cost needs to be prorated in the ROI calculation across the depreciation period. When scaling the ROI across the entire program, another adjustment is needed to account for volume discounts. Purchasing in low quantities is more expensive than making programmatic acquisitions.
3. **Singular and recurring costs.** Pilot projects may incur costs such as training or support that are singular or recurring; these need to be quantified through the pilot process, albeit scaled appropriately in the ROI computation. The cost associated with initial training would be a singular cost scaled across the number of inspectors, and annual maintenance training would occur at a reduced rate (e.g., five days for initial training or two days for annual maintenance skills).
4. **Programmatic costs.** Costs associated with process improvements or policy changes (e.g., upgrading standards and manuals) are difficult to capture through piloting. It is also debatable whether these costs should be included in the ROI analysis or be assigned to baseline costs of doing business. If they are included, these costs need to be allocated over several years. For example, the cost for upgrading software should be distributed over the duration of the enterprise agreement, which is typically three to five years.



Figure 7-2: Benefits Realized During Implementation. (Source: FHWA)

Figure 7.2 reiterates the “investment” is programmatic and gradual—neither fully gained nor expended on any single project nor in any single year. What is not accounted for in the FHWA approach is the Total Cost of Ownership⁷² (TCO) for BIM technology. Lovel, Kirkman 2015 identified⁷³ that “BIM adoption is not just choosing the right technology; agencies must factor in costs related to the culling of failing technologies, refreshing of aging technologies, and responses to disruptive technologies.”

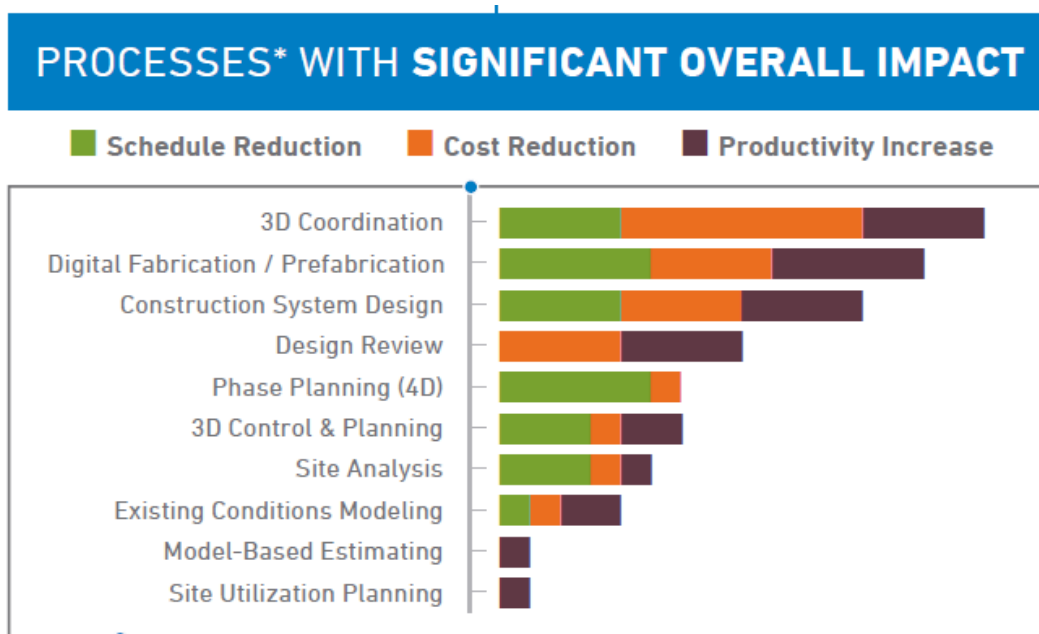


Figure 7-3: Value of BIM Processes to Architecture. (Source: Mortenson Construction)

⁷² TCO is an Information Technology metric and tries to quantify the financial impact of deploying an information technology product over its life cycle. These technologies include hardware, software, maintenance, and training. Frequently, a higher entry fee into a technology can be justified with a lower TCO, yielding a shorter time to recoup the initial investment (also known as the breakeven point).

⁷³ Lovel R., Kirkman R., HDR 2015. MnDOT Destination Innovation – Leveraging Technology to Improve Agency ROI, Strategies for Project Delivery Winona Bridge CMGC Case Study

Justification for BIM technology in the architecture and construction industry has been established and is well known.⁷⁴ It also appears that architecture, transportation engineering design, and construction (AEC) share many similar processes leading to BIM value within the project life cycle. Figure 7.3 provides an example where M.A. Mortenson Companies, a contractor that implements BIM processes, defined value (ROI) in the vertical architecture world; note the number one value process shown is 3D coordination (clash).

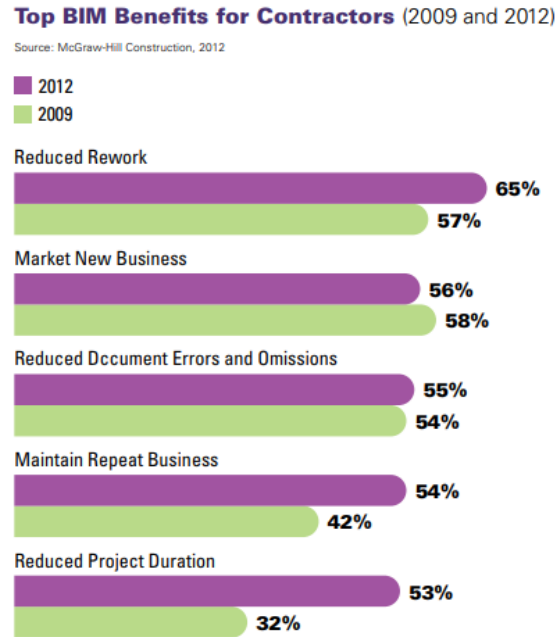


Figure 7-4: Top benefits for contractors. (Source: McGraw Hill)

Coincidentally, the number one BIM value process for transportation design projects has been identified as 3D coordination (referred to as clash or conflict detection). This valuable BIM process correlates across two industries. Figure 7.4 illustrates that due to clash detection/3D coordination taking place during earlier design stages, the value from this process appears later within the construction phase via reduced errors and omissions, lower build costs due to reduction of re-work, and accelerated schedule. On the other hand, pre-fabrication (shown as the second value in Figure 7.3) is currently significantly less valuable to the transportation industry than it is to the vertical world (but expected to increase). These metrics begin to provide baseline insights as to where ROI may be found when using BIM.

⁷⁴ Schultz, Audrey. (2013). The Economics of BIM and added Value of BIM to Construction Sector and Society

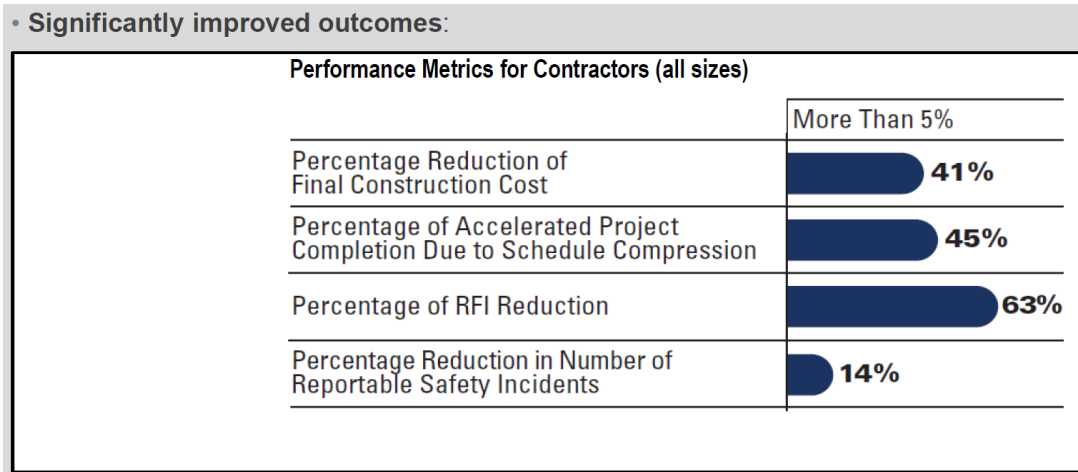


Figure 7-5: Improved Outcomes. (Source: Transformative Innovation for Highways – EDC and Other Initiatives, FHWA, David Unkefer, IHEEP Sept 24, 2017)

The value of BIM processes in civil, mechanical, electrical, and plumbing (MEP) engineering related to facilities (as example) mirror the nature of the architecture field. Mechanical engineers lead their peers with 83% reporting engagement with BIM, followed by electrical engineers at 77% adoption.⁷⁵

Where processes and measure of value begin to diverge is with civil transportation design, partly due the horizontal nature of projects. One goal of this investigation is to begin to identify these areas so that we understand the differences in the application of BIM for civil transportation versus known processes and metrics that provide or measure ROI in architecture and MEP. Figure 7.5 speaks to improved outcomes for the contraction industry by e-Construction and BIM technology. Schedules are shown as accelerated, costs are being reduced, and there is an added benefit to safety. Improvements to safety may include many factors such as less personnel required in harm’s way, 4D construction rehearsals, and 4D logistics planning for workers and materials, or management of traffic. In addition to tracking equipment or materials, RFID tags are now used to track workers in real-time on jobsites⁷⁶ to create real-time awareness, reduce risk, improve performance, and elevate safety. Technologies such as this are likely a contributing factor in the reduction of accidents statistic (Figure 7.6).

FHWA provides the Guide for Determining Return on Investment for using 3D Engineered Models in Highway Construction (2017)⁷⁷ and defines the ROI process by aligning key performance indicators (KPIs) and the mission with planned cost and benefit categories (Figure 7.6).

⁷⁵ The Business Value of BIM in North America: Multi-year Trend Analysis and User Ratings (2007-2012). Smart Market Report, McGraw Hill Construction, 2012.

⁷⁶ Sattineni, Anoop & Azhar, Salman. (2010). Techniques for Tracking RFID Tags in a BIM Model. 10.22260/ISARC2010/0037

⁷⁷ <https://www.fhwa.dot.gov/construction/3d/hif17035.pdf>



Figure 7-6: Flowchart of the ROI Process. (Source: FHWA, 3D Engineered Models ROI)

These same principles are then assigned to pilot projects for implementation so that the correct metrics can collect data for ROI evaluation. Figure 7.7 illustrates this next step.

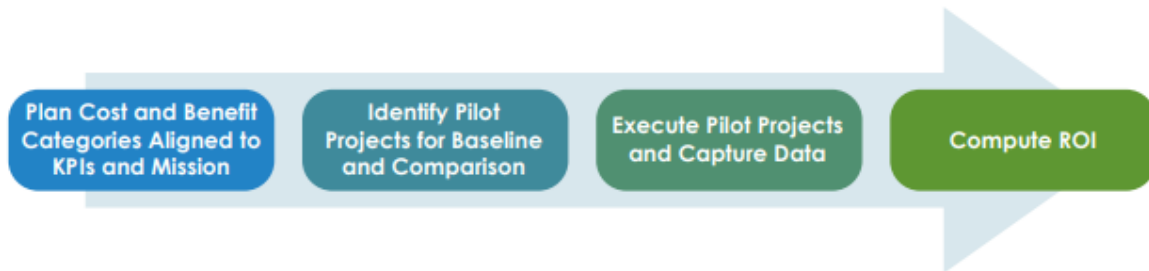


Figure 7-7: Alignment of KPIs with Pilots to Capture ROI Data. (Source: FHWA, 3D Engineered Models ROI)

7.4 APPROACH TO ROI ON PROJECT BASIS

FHWA⁷⁸ concludes “coordinated and strategic investments in 3D engineered models lead to increases in efficiency and effectiveness and to essential enhancements. These investments require a rigorous analysis of the benefits and costs arising from investing in the technology, people, and processes that are influenced by implementing 3D engineered models. Pilot projects offer the opportunity to quantify benefits and costs, provided that the data collection is carefully planned. Executing a deliberate process to categorize the benefits and costs before the pilot project is selected is critical to make a sound investment decision in 3D engineered models. The benefits and costs captured through pilot projects need to be analyzed and manipulated to scale the ROI across a program and across the agency, taking into consideration depreciation cycles and whether the costs scale by time, contract value, and with purchasing power.”

⁷⁸ <https://www.fhwa.dot.gov/construction/3d/hif17035.pdf>



Figure 7-8: Areas of ROI Value for Transportation. (Source: FHWA Guide for Determining the ROI for using 3D Engineered Models in Highway Construction, Summer 2017)

FHWA targeted this document towards State Transportation Agencies (STAs). Therefore, certain assumptions regarding programmatic implementations may be out of context or at inappropriate scale for adoption in county or city transportation agencies (every implementation is unique; dependent upon organization size and goals). Figure 7.8 illustrates areas identified for obtaining value from BIM and the larger digital transformation of the industry.

FHWA’s recommended approach is:

1. Identify Pilot Projects
2. Conduct Pilot and Gather Data
3. Analyze Data and Compute the ROI
4. Independent Review of Analysis

Figure 7.9 illustrates how early phases of the project have higher potential to lower overall project costs versus later phases. This should not be interpreted as there is less value to be realized in later stages of the project life cycle; it demonstrates the value created by activities taking place early in the MacLeamy curve are actually realized during later stages (construction).

The mechanism facilitating this valuable exchange of information is the use of a common data environment (CDE) which (a) allows processes to interact and (b) facilitates models growing in cumulative intelligence (synonymous with value). BIM research for the Minnesota Department of Transportation, Lovel, Kirkman (MnDOT - HDR 2015⁷⁹) notes “the more data and BIM processes are utilized collaboratively throughout a project’s duration, the greater potential increase in ROI to the project.”

⁷⁹ Lovel R., Kirkman R., HDR 2015. MnDOT Destination Innovation – Leveraging Technology to Improve Agency ROI, Strategies for Project Delivery Winona Bridge CMGC Case Study.

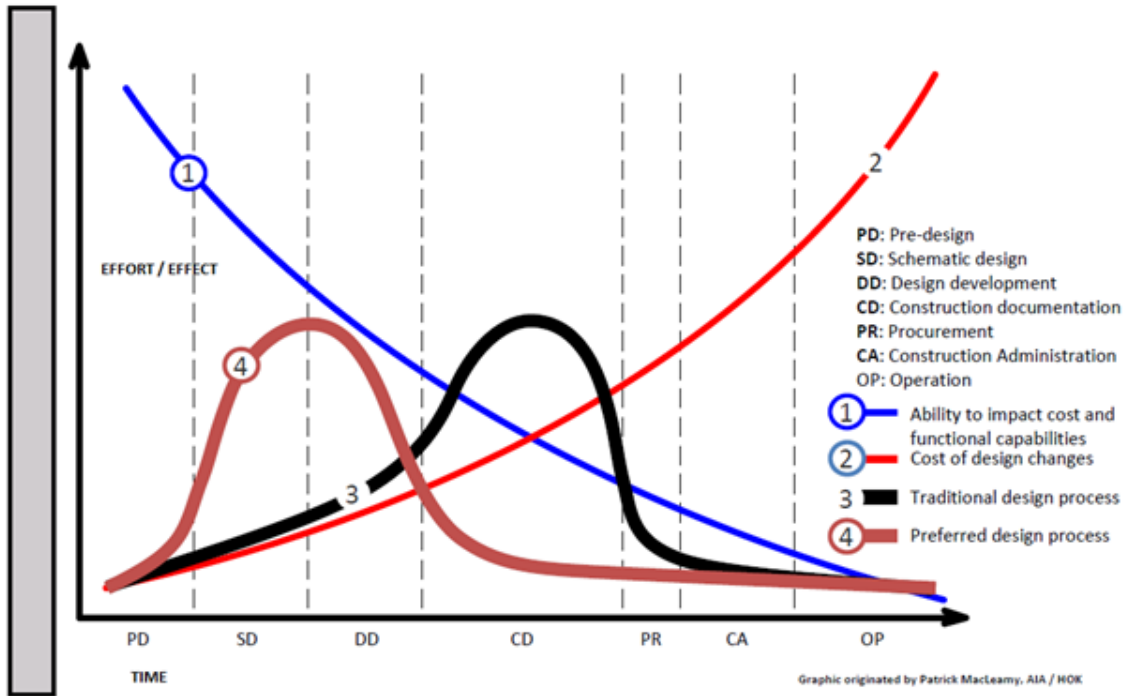


Figure 7-9: MacLeamy Curve – Ability to Influence Project Costs. (Source: HOK)

It is important to fully understand that these benefits resulted from conflict/clash detection process fully understand the potential benefits that 3D modeling could have on large projects. Performing clash detection in advance would have limited the data available to understand the savings in costs of contract change orders and Design Issue Notices (DINs).

Significant to this study, WisDOT estimated that modeling could have saved approximately \$9.5 million on the Mitchell Interchange if 3D modeling had been used during the planning stages. During this comparison, WisDOT did not consider the cost savings of any issues that would be unavoidable regardless of the use of modeling. For example, bad soil types identified during the project were not included as an opportunity for cost savings based on the use of modeling. Rather, WisDOT focused on specific opportunities for ROI within DIN categories. DINs are changes to the design that become necessary due to conflicts or issues identified during construction.

DIN Category	Estimated Percent of Reduction	Total Cost (\$ millions)	Average Cost Per Issue
General Structures	30.5%	6.8	\$45,674
Roadway/Drainage	25.5%	5.7	85,631
Wet Utilities/Drainage	11.1%	2.4	27,120
Bridges	8.0%	1.8	15,557
Noise Wall	8.0%	1.8	125,909
Retaining Wall	7.7%	1.7	21,818
Earthwork	4.5%	1.0	59,220
Electrical/ITS/FTMS	2.6%	0.6	15,557
Traffic	2.1%	0.5	18,174
Sign Structures	0.1%	0.02	738

Figure 7-10: Estimated Cost Impact Reduction using 3D modeling, Mitchell Interchange Project. (Source: FHWA Tech Brief, Lance Parve, WisDOT)

Within several DIN categories, WisDOT identified a percentage of potential cost reduction through comparison of the developed 3D model and the actual results achieved during construction. Figure 8.10 shows the estimated percentage of impact that the use of 3D modeling could have had on each DIN category on the Mitchell Interchange. Figure 7.11 graphically depicts the same information to further demonstrate the estimated percent of impact per each DIN category. Early indications from WisDOT also suggest ~ 3.2% contingency utilization on the project vs the traditional 8% to 10% expectation. Final (updated and more detailed) ROI accounting for this project is expected to be available after the 2019 Transportation Research Board conference. Those results will be included in the final compilation version of this report.

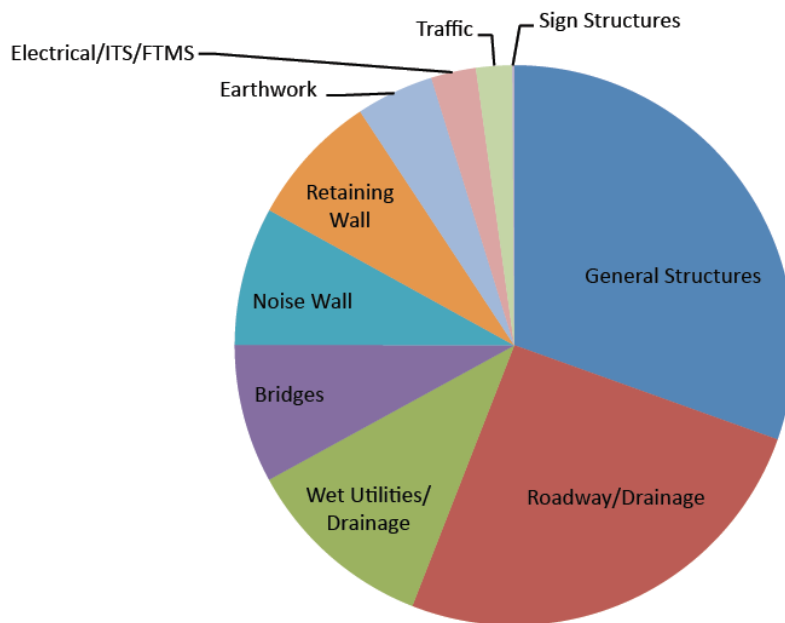


Figure 7-11: Visual Representation of BIM Value in DIN Areas, Mitchell Interchange Project. (Source: FHWA Tech Brief, Lance Parve, WisDOT)

7.5 OTHER FACTORS AND POTENTIAL SOLUTIONS

7.5.1 Creative ROI Solutions to Generate Funds for BIM Adoption

Ben Nolan, a director at forensic analysis consulting firm Berkeley Research Group in Florida, quantified the investment and cost benefit return in the following example. The CBA hypothesis is that BIM visualization (and 4D simulation) of a project adds certainty and mitigates risk, resulting in lower overall costs and a lower expenditure of the contingency funds, which are typically set around 5% of hard costs. Thus, if BIM/4D were implemented, the contingency could predictably be reduced by at least the cost of BIM model/4D. This approach frees up working funds for BIM.

For example, if we assume a \$100 project budget, a 5% or \$5 contingency, and the “cost” is \$1 (or 1% of the overall budget) to implement best practices using BIM on the project. If we further assume the “benefit” is optimizing expenditure of contingency funds (i.e., expending between \$0 and \$4 of the contingency), the real cost savings is in eliminating change orders and claims because project staff can detect and avoid problems identified by BIM. While the “avoided” costs cannot be measured, the results of fewer change orders and claims are lower costs and lower utilization of the contingency. Therefore, measuring contingency utilization is measuring the benefits of the avoided costs. Therefore, the implied strategy is to invest up to \$1 of the \$5 contingency to implement best practices for BIM. Once the project is completed and less than \$4 of contingency is used, then the Cost Benefit Analysis would exceed 1 for a benefit. It is a successful investment attributable to implementing BIM.

7.5.2 Creative Solutions to Measure Performance and ROI

The Stanford Center for Integrated Facility Engineering (CIFE) developed a Virtual Design and Construction (VDC) Scorecard (Figure 7.12) that assesses the maturity of the VDC implementation of a project across four areas, 10 divisions, and 56 measures and deploys the confidence level measured by seven factors to indicate the accuracy of scores.

CIFE: VDC has become a common practice in the AEC industry, but it does not have a scalable framework or management tool to inform and guide owners, architects, engineers and builders on their VDC performances. The VDC Scorecard was created to provide AEC professionals with a holistic, quantitative, practical and adaptive approach to evaluate and track VDC performance. The scoring covers the four major Areas of VDC Planning, Adoption, Technology and Performance, and the overall score is measured on a percentage scale that reflects the project performance relative to the industry’s practice⁸⁰. Variants of this process could potentially be adapted and modified to work for transportation agencies.

⁸⁰ Kam, Calvin and Senaratna, Devini and Xiao, Yao and McKinney, Brian. (2013). WP136: The VDC Scorecard: Evaluation of AEC Projects and Industry Trends. Stanford Digital Repository. Available at: <http://purl.stanford.edu/st437wr3978>

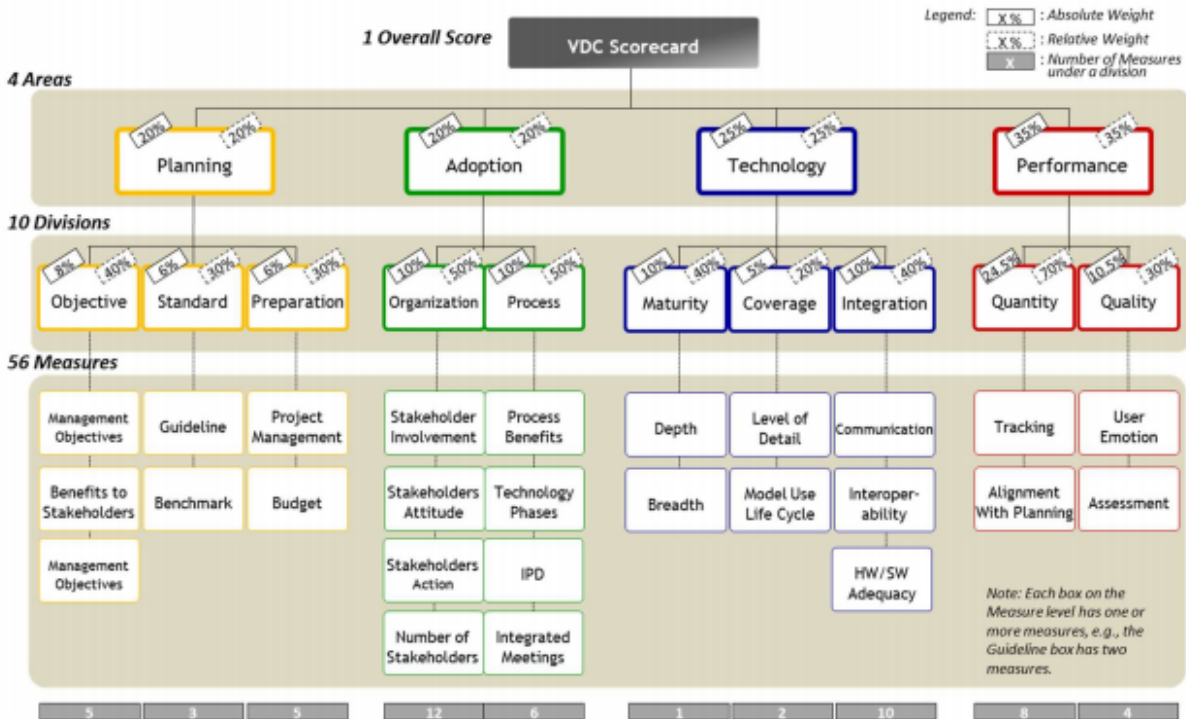


Figure 7-12: VDC Scorecard. (Source: CIFE, Stanford)

VDC has been defined as “the use of integrated multi-disciplinary performance models of design-construction projects to support explicit and public business objectives.” Stanford currently has a VDC certificate program that will be released to an all online format (spring of 2019) and could be one potential resource for transportation agency staff involved in implementations or ROI tracking.

7.5.3 Attention to Human Factors

CIFE (Figure 7.12) eluded to need for change management and attention to the human element. Factors related to human issues that influence realization of ROI on BIM projects include:

1. Definitions of and understanding of BIM from owner/designer/contractor perspectives
2. Definitions of and understanding of BIM from various disciplinary perspective
3. Contract mechanisms (conducive to BIM concepts vs less conducive)
4. Type of project
5. Project challenges
6. Alignment with RFP and Owner goals
7. Use of BIMxp and Project Controls
8. Disconnected (lonely) versus full BIM

Previously in the executive summary the concept of lonely BIM was introduced where BIM processes are implemented to a project piecemeal fashion (such as 3D models only for AMG) or where only a few (but not all) disciplines adopt the common BIM model approach and the implementation tends up not being

consistent with best practices conducive to cumulative value throughout a project life cycle. Figure 7.13 illustrates a study⁸¹ showing the impact of full collaborative process on change orders. Cannistraro examined \$500 million of the firm's past work dividing it into three categories of collaboration (2D, Lonely BIM (partial disciplinary adoption) and Collaborative BIM (full disciplinary adoption)). The resulting data suggests that as more project teams embrace collaborative BIM efforts, 10% to 20% of a project's finances can be saved and possibly reinvested into a project.

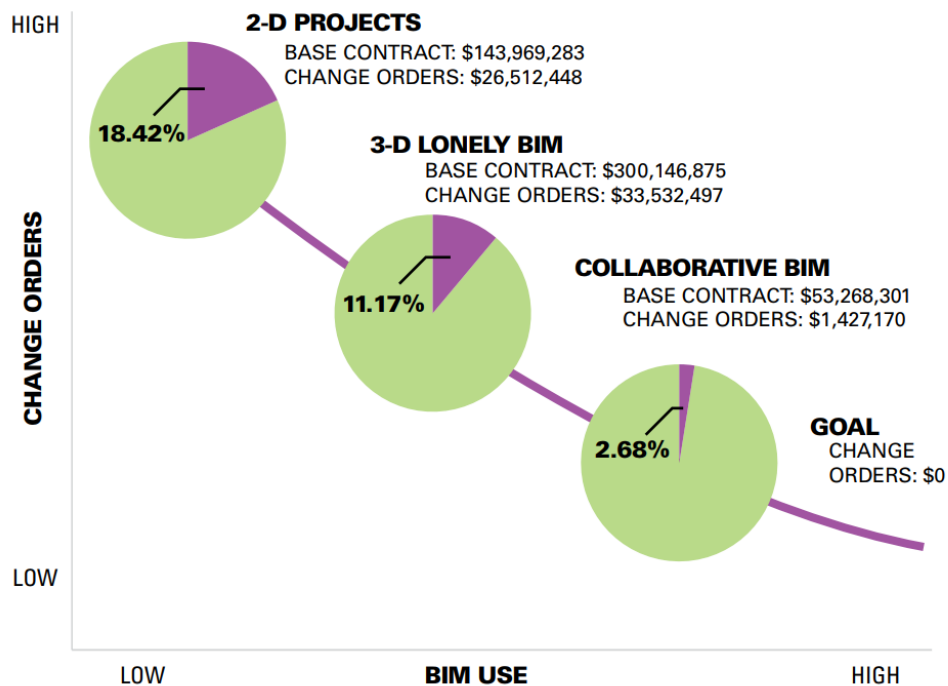


Figure 7-13: Impact of Collaboration on Change Orders. (Source: Michael Cannistraro, Journal of Building Information Systems)

7.6 BENEFITS/SHORTCOMINGS

Potential Benefits:

- Appendix G Project Benefits provides the aggregated inferred qualitative and quantitative value observed during processes conducted (and documented individually) in Chapters 1-7.
- Some findings of BIM process value from the architecture industry correlate with similar findings in transportation (trends in architecture can be a bellwether for transportation).

⁸¹ Cannistraro, Michael, P.E., LEED AP, Savings Through Collaboration: A Case Study on the Value of BIM, Journal of Building Information Modeling, Fall 2010

- Areas benefitting from 3D modeling and BIM processes have been validated and rigorously examined on at least one major project (Mitchell Interchange) identifying that cost gains achieved using 3D modeling can be more significant during general, drainage, structural, and feature design categories than during earthwork and excavation alone.
- This study primarily documented immediate user workflow benefits that result in time savings, rapid alternatives development, improved collaboration, and functionality.
- Many preliminary insights and better understanding of direct project impact of BIM processes was obtained, their relationships to multiple disciplines, and potential contribution to cumulative value.
- Findings should be considered for base-line inclusion in future studies as they provide clues to better understanding of BIM work breakdown structure (WBS) relationships and particularly how the preliminary (survey to 30% design) project stage sets up the remainder of the project to reap the benefits.
- Enough evidence was captured to facilitate other more refined preliminary design studies, to feed further WBS studies, or to build upon these findings when looking at the transition to the next stage of project life (60% to 90%).
- Summation of returns for this effort are primarily relevant to ROI related to software processes, software ecosystem, interoperability with other systems in survey through preliminary design (0% to 30%) project stage.
- Appendix G summation of benefits denoted value by qualitative or quantitative (or in some instances both). Quantitative values for this project include processes that could be measured as well as some processes that were measured.
- Processes that provided ready measures include the cost savings of UAS survey versus traditional survey (Reality Capture Chapter 2) and profile optimization (Chapter 5) (estimated eight-hour savings per alternative not including benefits of quantities and report generation).

Potential Shortcomings

- Scope of work predominantly limited to in-situ use of emerging preliminary design BIM software in the 0% to 30% stages of the project life cycle and should not be construed as an in-depth ROI study of cumulative benefits nor exhaustive use of BIM processes and findings for an entire capital project.
- Some processes observed or performed have potential quantifiable value yet require development of sound mechanisms with repeatable methodology in order to measure.
- The pilot project used for demonstration purposes was predominantly a roadway widening project and may not have been best for some observations about BIM value.
- Long-term benefits of using BIM in processes starting in preliminary design and their impact to later stages of the project life cycle were not reported here.
- This pilot project exercise was restricted to a single project example using a single vendor solution While other vendor's functionality and benefits are similar, this is a narrow focus, emphasizing ROI from workflow optimizations in the preliminary project stage

- BIM process steps adding value and accruing incrementally throughout a project beyond 30% design are not accounted for in this study.
- Lack of documented ROI project studies and methods to measure ROI for transportation BIM across the United States.

7.7 NEXT STEPS

Potential Next Steps Include:

- Drive deeper engagement with BIM, which correlates directly with better ROI. This will help engineers close the gap in ROI benefits that architects and contractors are enjoying⁸².
- Identify pilot projects to measure ROI. Pilot projects need to be carefully selected to capture the benefits and costs associated with predefined categories. The first step is to define pilot project selection criteria. Then, a range of potential baseline and initiative pilot projects should be identified. The best combination of baseline and initiative pilot projects can then be studied to capture the benefits and costs. The degree to which the project team supports the ROI process is an important project selection criterion, as their cooperation will be needed to collect the data.
- Development of standardized Key Performance Indicators
- Initiate Change Management plan conducive to BIM principles
 1. new process adaptation
 2. lean management
 3. common data environment
 4. workforce training and education
- Examine a variety of existing (architecture) ROI mechanisms to determine “best fit” for potential modification or adoption by the industry. Examples of this could be modification of the Stanford VDC scorecard, or other established methodology, to make it work for transportation.

Other areas requiring future study:

1. Ability to influence project costs
2. Presumed benefits to project life cycle
3. Reducing data collection and storage through model and information sharing
4. Compilation of benefits from previous tasks
5. Potential qualitative value versus quantitative measures

⁸² 7 The Business Value of BIM in North America, Multi-year Trend Analysis and User Ratings (2007-2012) McGraw Hill Construction Smart Market Report accessed online:
http://images.marketing.construction.com/Web/DDA/%7Bee68ed67-8a65-413a-b163-dd099e400e43%7D_Business_Value_of_BIM_in_North_America_SMR.pdf

CHAPTER 8: CONCLUSIONS AND NEXT STEPS

8.1 SUMMARY

Transforming civil transportation project delivery in Minnesota from its current condition to paperless BIM delivery presents challenges that will take many years to overcome. Along the way there could be dramatic failures as well as extraordinary positive outcomes. Factors that may influence the success of state, county and city transportation agencies include:

- How broad and tiered of an approach is used to assist institutionalizing the technology
- How comprehensively the human change-management part of the equation is addressed
- Level of openness to understand differences between traditional vs. BIM methods
- Ability to reinvent themselves in lockstep with continuous industry technological advances

Eventually the use of BIM could be mandated for U.S. federally funded transportation projects (as it already is for federal building architecture in the U.S. and both architecture and transportation in the U.K.); arguably Minnesota transportation agencies have incentive to be proactive and start the long cultural change-management process sooner rather than later. Even without mandate, more informed designs attained by BIM process reduce RFI's and accelerate design through construction, which is a compelling enough argument to embrace the technology.

The provided next steps are high-level recommendations for consideration to be leveraged or modified in a customized adoption strategy. The predominant takeaway for readers is that there are years of collective work ahead of the industry; agencies need to just get started. Others have begun their standards development process. Advances in open-standard file formats conducive to collaboration and software interoperability are emerging. Advances in digital signatures for design models are here. Real or perceived challenges (blockers) to adoption are disappearing every day; Minnesota transportation agencies just need to begin the process or risk falling behind. Change is constant yet fear of change is the largest hurdle. The first step is to do something (anything) representing proactive forward action that kickstarts the journey toward the inevitability of BIM for infrastructure.

8.2 TASK PURPOSE

Identify the next steps and roadmap considerations that provide low-risk and high-return on investment (ROI) guidance for city/county/state agencies leading to informed, in-practice deployment of parametric BIM for infrastructure.

8.3 INTRODUCTION

Today, local government is frequently tasked to “do more with less.” Citizens demand transparency and more responsive service(s) while revenues continue to shrink. One solution is for agencies to embrace technology that facilitates efficiencies. Transitioning from Mylar to CAD once provided this as an industry paradigm shift toward efficiency. Now it is time to move on from CAD (drafting) to 3D modeling

and BIM (3D modeling plus information systems plus process), which is a much larger magnitude shift in complexity. Yet with this challenge comes the promise of extraordinary benefits.

Technology alone is not a panacea and there is no “easy button.” Previous chapters introduced stark differences between traditional vs. BIM process. The 3D/4D/5D common data environments (CDE’s) reality capture, and multi-disciplinary collaborative workflows (federated 3D modeling) are not buzzwords but mandated best practices within today’s and tomorrow’s standards. Roles are changing; menial, repetitive tasks are being replaced by state-of-the-art parametric design and expert systems⁸³ running algorithms that optimize design (with your variables and specifications) in the cloud. The “signed plans/paper-in-the-field mindset” is being replaced by virtual models, e-signatures and e-construction. Engineers are now empowered to re-define their role(s) to focus more on engineering and less on drafting and plan production. Eventually, larger volumes of more accurate and efficient designs will be delivered than ever before (with less staff). Reduced siloes, embedded visualization, transparent collaboration, data re-use, and accelerated design and construction ultimately will optimize the use of public infrastructure tax dollars.

So how do we reach this BIM nirvana? The approach and additional assumptions sections include considerations examined when determining actions for the recommended next steps and provide logical options for agencies to proceed. Investments in the areas of education, training, tools, evolving standards and processes are required. One industry challenge is the need to embrace new methods that replace or modify years of siloed workflows; owners and practitioners must now rethink the project delivery life cycle from planning through survey, design, and construction into operations and maintenance. Employers face retraining their entire workforce with new methods; some will reject change insisting “if it’s not broke, don’t fix it.” Yet posing an even larger threat may be those who try to force “new tools into old work siloes,” effectively negating the ROI benefits of the BIM process and potentially giving the technology a black eye and introducing risk (possibly generating more damage to progress than those rejecting adoption outright). Financial and professional liability risk with BIM are real; effectively managing human tendencies to revert to old behavior(s) up-front will reduce this risk and maximize benefits.

8.4 APPROACH

Minnesota transportation design and construction practitioners avoid starting from scratch and benefit from early adopter knowledge. The architecture industry has established principles and lessons learned with applicability (via adaption) to horizontal and vertical transportation design. Scandinavia, Asia, and the U.K. were early civil transportation BIM adopters. Utah, Wisconsin, Michigan, Iowa, Oregon (and other DOTs) are demonstrating BIM process benefits. In yet other areas of the U.S., it is the contractors currently leading the way in demonstrating benefits. Minnesota must leverage all this knowledge via

⁸³ In artificial intelligence, an expert system is a computer system that emulates the decision-making ability of a human expert.

Jackson, P. (1998). *Introduction to Expert Systems*, 3rd ed (p. 2). Boston: Addison Wesley, ISBN 978-0-201-87686-4

outreach and embrace these hard-fought lessons learned. Additional research in Minnesota feeds a growing knowledge base. In 2017-18 under a program development contract⁸⁴ for MnDOT, SRF Consulting Inc. conducted a literature review of four most recent and relevant BIM research documents (including *Modernizing Road Construction Plans and Documentation*, LRRB Research MN/RC 2016-29). A Strengths, Weaknesses, Opportunities and Threats (SWOT) matrix was compiled, which is shown in Figure 8.1. Highly relevant to the development of next steps, it provides clues for areas to leverage (strengths and opportunities) while simultaneously illustrating the need for strategies to overcome challenges (weaknesses and threats).

	Positive	Negative
Internal Factors	<p>Strengths</p> <ul style="list-style-type: none"> • Federated (single) source of truth (model-centric) process • Quality improvements, reduced errors, RFIs, and risk • Enhanced communication and transparency • Accelerated project schedules • Predictable project outcomes 	<p>Weaknesses</p> <ul style="list-style-type: none"> • Culture (disciplinary and organizational) • Interoperability • Lack of pilot studies • Few ROI metrics, studies, or performance measures • No identified processes or methods to enhance collaboration and communication
External Factors	<p>Opportunities</p> <ul style="list-style-type: none"> • Better use of budgets and public funds • Alt Del/CMGC conducive to BIM • Engagement with Contractors • Redefined workflow processes • Staff education- promotion of innovation throughout agency 	<p>Threats</p> <ul style="list-style-type: none"> • Entrenched culture/workflows • Piecemeal implementations • Restricted & scattered data processes • Lack of Standards • Legal challenges

Figure 8-1: MnDOT BIM Research SWOT Analysis. (Source: MnDOT/SRF Consulting Group)

8.5 ADDITIONAL ASSUMPTIONS

Lack of case studies, ROI measures, or KPI's and standards also appear as threats and weaknesses in Figure 8.1. Industry outreach will be one key ingredient as everyone is relearning new processes and tools together. Project owners, contractors, and consultants all benefit and advance BIM practice more efficiently through collaboration and learning from the successes and challenges of others.

⁸⁴ MnDOT. (SRF 2018). Civil Information Management (CIM) Framework (Contract No. 1029210)

When considering the next steps, a stratified approach that recognizes different strategies could be adopted to on-board and educate at different levels since each presumably has different needs, goals, concerns, and timelines, including:

- Organizational
- Disciplinary
- Design-team
- Individual staff
- Stakeholders (local government, funding sources, and cooperative agencies)

Recommendations provide high-level “first steps” for potential consideration within the generalized categories and hierarchies illustrated in Figure 8.2. The intent is to balance progress with minimization of risk and disruption. Individual agencies can choose different steps depending on the priorities within that organization. Currently, several Minnesota counties have begun the process, while other counties and cities are beginning engagement in a variety of ways. Every agency has unique circumstances that will affect its approach to adoption.

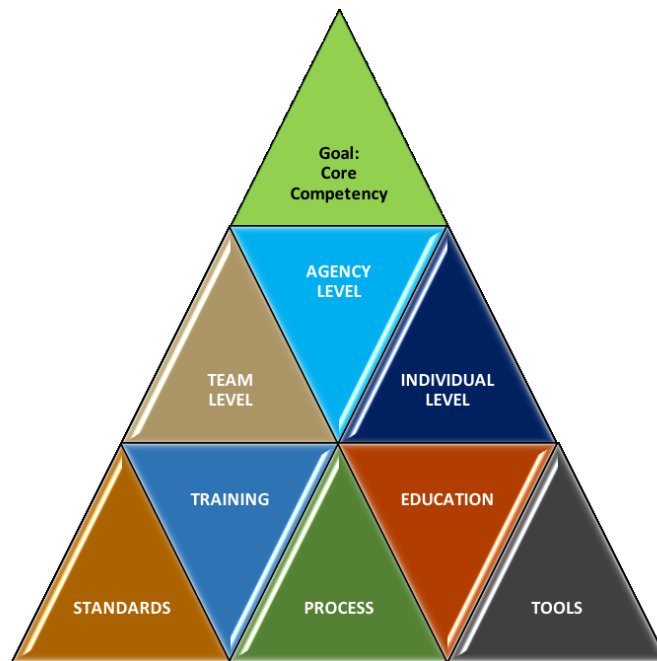


Figure 8-2: Elements of Adoption. (Source: SRF Consulting Group)

Therefore, next-steps recommendations are not:

- A. A one-size fit-all recipe
- B. Exclusive to preliminary design
- C. An all-inclusive list of potential actions
- D. Definitively in order

8.6 NEXT STEPS (PRELIMINARY DESIGN)

Recommended next steps for preliminary design are noted near the end of each chapter in this document. For further reference and convenience, these are compiled in Appendix H. It is evident that preliminary design is a critical study area requiring further investigation because acceleration and advancement at early project stages has more ability to positively affect critical project success factors (financial, schedule, and stakeholder consensus) than later stages of a project. Appendix H provides agencies and researchers with a list of potential actions that can be prioritized based on individual agencies' interests and perceived needs.

While much work can be accomplished now for reassessing the preliminary design process (in particularly with culture/reduction of siloes), preliminary design tools are also rapidly evolving. Both predominant vendors (Bentley and Autodesk) continue maturing their toolkits and cloud analysis services in this area requiring consumers to consistently stay abreast of features and functionality of new releases.

The transportation industry's shift to BIM design and e-construction will transpire over many years. Each state DOT, county, city and municipality will proceed at its own pace. As mentioned previously, some Minnesota entities have started their own transition process; regardless of late or early adoption status, there is a vast amount of work in many areas at many different organizational levels. The transition of an entire industry's culture, adoption of new tools, processes, and best practices and standards is daunting and chipping away at tasks needs to begin now. Therefore, while preliminary design requires continued investigation, agencies should also simultaneously consider a programmatic roadmap approach to begin the adoption process. Some high-level recommendations are provided below as potential action/outcomes for consideration.

8.7 NEXT STEPS (BROAD PROGRAM ADOPTION)

Action # 1

Start a BIM design practice:

- a. Designate a small design team (or individuals) to be educated on preliminary and final design BIM who can then become internal BIM subject matter experts (SME's).
- b. Evaluate hardware/software specifications to ensure that the correct resources are in place
- c. Educate/train a BIM project manager.
- d. Invest equally in process training and understanding of the cumulative value of lifecycle "BIM uses" not just tools.
- e. Train at least one staff from disciplines such as drainage or utilities to leverage high-value BIM activities such as clash detection.
- f. Keep it compartmentalized.
- g. Prepare the team for a future pilot project.

Expected Outcomes: Once the project manager SME or design team SMEs reach a certain level of competency, they will:

- ✓ Complete a pilot on their own (see Action #3) (or collaborate with a consultant using BIM concepts on a joint project)
- ✓ Begin best practices documentation and development
- ✓ Begin sharing their knowledge throughout their internal organization to grow agency core competency and expand a depth chart
- ✓ Start the agency on a journey to paperless project design and delivery

When coupled with best-fit projects, this approach maximizes ROI while minimizing exposure to financial or professional risk. Overall this represents a gradual change strategy that brings forward progress to the agency with minimum disruption.

Action # 2

Kick off change-management efforts that lead to a measurable success framework:

- a. Identify agency BIM champion
- b. Develop a mission statement and goals
- c. Conduct agency self-assessment including a capabilities maturity matrix (CMM)
- d. Develop program-level key performance indicators (KPI's)
- e. Engage with industry outreach (agencies in states beyond Minnesota)
- f. Reach out to identify contractors' needs
- g. Revise outdated RFP language to facilitate innovation
- h. Incentivize innovation by consultants and contractors
- i. Identify funding sources to support adoption of innovative practices

Expected Outcomes: These changes will provide critical vision and foundation to support maturity and further development of a BIM roadmap.

Action # 3

Identify and prepare to deploy BIM methods on a pilot project:

- a. Develop selection criteria and identify "best-fit" BIM project opportunities
- b. Develop BIM execution plan templates for a couple of different types of projects
- c. Proactively conduct pre-project technology needs assessments
- d. Establish quantitative and qualitative project measures to gauge return on investment
- e. Deploy internal design team/PM on pilot project (or collaborate with consultant)
- f. Document lessons learned

Expected Outcomes: Nothing builds experience like putting innovation into practice. Each successive pilot strengthens the core competency of the agency and generates best practices that lead to new standards. The lessons learned will provide efficiencies for each subsequent project:

- ✓ Reusable BIM project scorecards and project level KPIs
- ✓ Collaboration with consultants, contractors, stakeholders; educate/learn together
- ✓ Best practices development
- ✓ Standards development

APPENDIX A: EXAMPLE BIMXP TEMPLATE

BIM PROJECT EXECUTION PLAN (BIMxp)
EXAMPLE TEMPLATE VERSION FOR ILLUSTRATION PURPOSES ONLY
SRF CONSULTING GROUP INC.



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SECTION A: BIMXP OVERVIEW

To successfully implement Building Information Modeling (BIM) on a project, the project team has developed this detailed BIM Project Execution Plan. The BIM Project Execution Plan defines uses for BIM on the project (e.g. design authoring, cost estimating, and design coordination), along with a detailed design of the process for executing BIM throughout the project lifecycle.

SECTION B: PROJECT INFORMATION

This section defines basic project reference information and determined project milestones.

1. **PROJECT OWNER:**
2. **PROJECT NAME:**
3. **PROJECT LOCATION AND ADDRESS:**
4. **CONTRACT TYPE / DELIVERY METHOD:**
5. **BRIEF PROJECT DESCRIPTION:**
6. Additional Project Information:
7. **PROJECT NUMBERS:**

PROJECT INFORMATION	NUMBER
CONTRACT NUMBER:	
TASK ORDER:	
PROJECT NUMBER:	

8. PROJECT SCHEDULE / PHASES / MILESTONES:

Include BIM milestones, pre-design activities, major design reviews, stakeholder reviews, and any other major events which occur during the project life cycle.

PROJECT PHASE / MILESTONE	ESTIMATED START DATE	ESTIMATED COMPLETION DATE	OBJECT STAKEHOLDERS INVOLVED
referred Alternative Selection			

30% Plan Submittal			
60% Plan Submittal			
95% Plan Submittal			

SECTION C: KEY PROJECT CONTACTS

List of lead BIM contacts for each organization on the project. Additional contacts can be included later in the document.

ROLE	ORGANIZATION	CONTACT NAME	LOCATION	E-MAIL	PHONE
Project Manager(s)					
Project Manager(s)					
QAQC					
BIM Manager(s)					
BIM Coordination					
BIM Bridge Type Study					
Roadway Design					
Drainage					
Reality Capture LIDAR Survey					
Utilities					

General Requirements

BIM Goals (example)

- Capture Work plan information in models and leverage this to help with overall Project Management.
- BIM implementation shall allow for a final deliverable of an as-built model issued to the owner for use in operations.

SECTION D: PROJECT GOALS / POTENTIAL BIM USES

Describe how the BIM Model and other Data are leveraged to maximize project value (e.g. design alternatives, life-cycle analysis, scheduling, estimating, material selection, pre-fabrication opportunities, site placement, etc.) Reference www.engr.psu.edu/bim/download for BIM Goal & Use Analysis Worksheet.

1. MAJOR BIM GOALS / OBJECTIVES:

State Major BIM Goals and Objectives

PRIORITY (HIGH/ MED/ LOW)	GOAL DESCRIPTION	POTENTIAL BIM USES

2. BIM USE ANALYSIS WORKSHEET: ATTACHMENT 1

Reference www.engr.psu.edu/bim/download for BIM Goal & Use Analysis Worksheet. Attach BIM Use analysis Worksheet as Attachment 1.

3. BIM USES:

Highlight and place an X next to the additional BIM Uses to be developed by the use of the BIM model as selected by the project team using the BIM Goal & Use Analysis Worksheet. See BIM Project Execution Planning Guide at www.engr.psu.edu/BIM/BIM_Uses for Use descriptions. Include additional BIM Uses as applicable in empty cells.

X	PLAN	X	DESIGN	X	CONSTRUCT	X	OPERATE

SECTION E: ORGANIZATIONAL ROLES / STAFFING

Determine the project's BIM Roles/Responsibilities and BIM Use Staffing

1. BIM ROLES AND RESPONSIBILITIES:

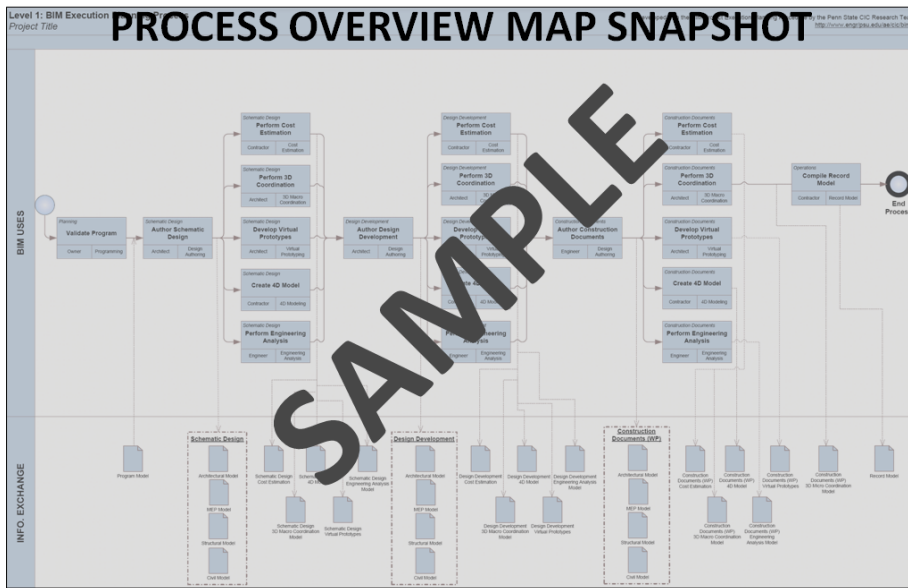
Describe BIM roles and responsibilities such as BIM Managers, Project Managers, Draftspersons, etc.

BIM ROLE	ORGANIZATION	RESPONSIBILITIES	ESTIMATED WORKER HOURS	LOCATION(S)	LEAD CONTACT
BIM Manager					
BIM Coordinator					
BIM Concept Designers					
Project Manager					

SECTION F: BIM PROCESS DESIGN

Provide process maps for each BIM Use selected in section D: Project Goals/BIM Objectives. These process maps provide a detailed plan for execution of each BIM Use. They also define the specific Information Exchanges for each activity, building the foundation for the entire execution plan. The plan includes the Overview Map (Level 1) of the BIM Uses, a Detailed Map of each BIM Use (Level 2), and a description of elements on each map, as appropriate. Level 1 and 2 sample maps are available for download at www.engr.psu.edu/BIM/download. (Please note that these are sample maps and should be modified based on project specific information and requirements). Please reference Chapter Three: Designing BIM Project Execution Process in the BIM Project Execution Planning Guide found at www.engr.psu.edu/BIM/PxP

1. LEVEL ONE PROCESS OVERVIEW MAP: ATTACHMENT 2



LIST OF LEVEL TWO – DETAILED BIM USE PROCESS MAP(S): ATTACHMENT 3

The following are examples. Modify for specific project. Some Process Maps may need to be removed, while some process maps may need to be added.

- a. Existing Conditions Modeling
 - b. Cost Estimation
 - c. Phase Planning (4D Modeling)
 - d. Programming
 - e. Site Analysis
 - f. Design Reviews
 - g. Design Authoring
 - h. Energy Analysis
 - i. Structural Analysis
 - j. Lighting Analysis
 - k. 3D Coordination
 - l. Site Utilization Planning
 - m. 3D Control and Planning
 - n. Record Modeling
 - o. Maintenance Scheduling
 - p. Building System Analysis
- [Delete unused or add additional process maps from list]

SECTION G: BIM INFORMATION EXCHANGES

Model elements by discipline, level of detail, and any specific attributes important to the project are documented using information exchange worksheet. See Chapter Four: Defining the Requirements for Information Exchanges in the BIM Project Execution Planning Guide for details on completing this template.

1. LIST OF INFORMATION EXCHANGE WORKSHEET(S): ATTACHMENT 4

The following are examples. Modify for specific project. Some Information Exchanges may need to be removed, while some Information Exchanges may need to be added.

- a. Existing Conditions Modeling
- b. Cost Estimation
- c. Phase Planning (4D Modeling)
- d. Programming
- e. Site Analysis
- f. Design Reviews
- g. Design Authoring
- h. Energy Analysis
- i. Structural Analysis
- j. Lighting Analysis
- k. 3D Coordination
- l. Site Utilization Planning
- m. 3D Control and Planning
- n. Record Modeling
- o. Maintenance Scheduling
- p. Building System Analysis
- q. [Delete unused information exchanges from list]

INFORMATION EXCHANGE (IE)															
Information		Responsible Party													
A	Architect Data & Conditions, includes materials and object parameters	ARCH	Architect	CON	Contractor	CE	Cost Estimator	PM	Project Manager	MEP	Mechanical Engineer	SE	Structural Engineer		
B	General Data & Conditions, includes parameter data	CE	Cost Estimator	PM	Project Manager	MEP	Mechanical Engineer	SE	Structural Engineer	TS	Trade Contractors				
C	Schematic Data & Location														
BIM Use Title		Programming	Design Authoring	Existing Conditions Modeling	Cost Estimation	3D Coordination	Design Reviews								
Project Phase		Planning	Design	Design	Design	Design	Design Reviews								
Time of Exchange (SD, DD, CD, Construction)															
Responsible Party (Information Receiver)															
Receiver File Format															
Application & Versions															
Model Element Breakdown	Info	Resp Part	Additional Info	Info	Resp Part	Additional Info	Info	Resp Part	Notes	Info	Resp Part	Notes	Info	Resp Part	Notes
A SUBSTRUCTURE															
Foundations															
	Standard Foundations														
	Special Foundations														
	Slab on Grade														
Basement Construction															
	Basement Excavation														
	Basement Walls														
B SHELL															
Superstructure															
	Floor Construction														
	Roof Construction														
Exterior Enclosure															
	Exterior Walls														
	Exterior Windows														
	Exterior Doors														
Flooring															
	Floor Coverings														
	Roof Openings														
C INTERIORS															
Interior Construction															
	Partitions														
	Interior Doors														
	Fittings														
Stairs															
	Stair Construction														
	Stair Finishes														
Interior Finishes															
	Wall Finishes														
	Floor Finishes														
	Ceiling Finishes														
D SERVICES															
Conveying Systems															
	Elevators & Lifts														
	Elevators & Moving Walks														
	Escalators & Moving Walks														

MODEL DEFINITION WORKSHEET:

Future

The number of coordination efforts has yet to be defined. But the intent is to involve all project disciplines even if those disciplines are not contributing 3D geometry to the model.

2. MEETING PROCEDURES:

The following are examples of meetings that should be considered.

MEETING TYPE	PROJECT STAGE	FREQUENCY	PARTICIPANTS	LOCATION
BIM REQUIREMENTS KICK-OFF				
BIM EXECUTION PLAN DEMONSTRATION				
DESIGN COORDINATION				
DESIGN COORDINATION				
CONSTRUCTION OVER-THE-SHOULDER PROGRESS REVIEWS				
ANY OTHER BIM MEETINGS THAT OCCURS WITH MULTIPLE PARTIES				

3. MODEL DELIVERY SCHEDULE OF INFORMATION EXCHANGE FOR SUBMISSION AND APPROVAL:

Document the information exchanges and file transfers that will occur on the project.

INFORMATION EXCHANGE	FILE SENDER	FILE RECEIVER	ONE-TIME or FREQUENCY	DUE DATE or START DATE	MODEL FILE	MODEL SOFTWARE	NATIVE FILE TYPE	FILE EXCHANGE TYPE

4. WORKSPACE

The project team will utilize local network storage for the project

5. ELECTRONIC COMMUNICATION PROCEDURES:

(Note: File Naming and Folder Structure will be discussed in Section L: Model Structure).

The following document management issues should be resolved, and a procedure should be defined for each: Permissions / access, File Locations, FTP Site Location(s), File Transfer Protocol, File / Folder Maintenance, etc.

FILE LOCATION	FILE STRUCTURE / NAME	FILE TYPE	PASSWORD PROTECT	FILE MAINTAINER	UPDATED

SECTION J: QUALITY CONTROL

1. OVERALL STRATEGY FOR QUALITY CONTROL:

Describe the strategy to control the quality of the model.

2. QUALITY CONTROL CHECKS:

The following checks should be performed to assure quality.

CHECKS	DEFINITION	RESPONSIBLE PARTY	SOFTWARE PROGRAM(S)	FREQUENCY
VISUAL CHECK	Ensure there are no unintended model components and the design intent has been followed			
INTERFERENCE CHECK	Detect problems in the model where two design components are clashing including soft (visual) and hard (geometry) clash			
STANDARDS CHECK	Ensure that the BIM and AEC CADD Standard have been followed (fonts, dimensions, line styles, levels/layers, etc)			
MODEL INTEGRITY CHECKS	Describe the QC validation process used to ensure that the Project Facility Data set has no undefined, incorrectly defined or duplicated elements and the reporting process on non-compliant elements and corrective action plans			

3. MODEL ACCURACY AND TOLERANCES:

Models should include all appropriate dimensioning as needed for design intent, analysis, and construction. Level of detail and included model elements are provided in the Information Exchange Worksheet.

PHASE	DISCIPLINE	TOLERANCE
DESIGN DOCUMENTS	ROADWAY	ACCURATE TO +/- [#] OF ACTUAL SIZE AND LOCATION
DESIGN DOCUMENTS	Drainage	ACCURATE TO +/- [#] OF ACTUAL SIZE AND LOCATION
DESIGN DOCUMENTS	Structures	
SHOP DRAWINGS	MECH CONTRACTOR	

SECTION K: TECHNOLOGICAL INFRASTRUCTURE NEEDS

1. SOFTWARE:

List software used to deliver BIM. Remove software that is not applicable.

	DISCIPLINE (if applicable)	SOFTWARE	VERSION
DESIGN AUTHORING			
DESIGN AUTHORING			
DESIGN AUTHORING			

2. COMPUTERS / HARDWARE:

Understand hardware specification becomes valuable once information begins to be shared between several disciplines or organizations. It also becomes valuable to ensure that the downstream hardware is not less powerful than the hardware used to create the information. To ensure that this does not happen, choose the hardware that is in the highest demand and most appropriate for majority of BIM Uses.

BIM USE	HARDWARE	OWNER OF HARDWARE	SPECIFICATIONS
DESIGN AUTHORING	XXX COMPUTER SYSTEM	Engineer/Technician	PROCESSOR, OPERATING SYSTEM, MEMORY STORAGE, GRAPHICS, NETWORK CARD, ETC.

3. MODELING CONTENT AND REFERENCE INFORMATION

Identify items such as families, workspaces, and databases.

BIM USE	DISCIPLINE (if applicable)	MODELING CONTENT / REFERENCE INFORMATION	VERSION
DESIGN AUTHORING	ARCH	XYZ APP FAMILIES	VER. X.X. (YEAR)
ESTIMATING	CONTRACTOR	PROPRIETARY DATABASE	VER. X.X (YEAR)

SECTION L: MODEL STRUCTURE

1. FILE NAMING STRUCTURE:

Determine and list the structure for model file names.

FILE NAMES FOR MODELS SHOULD BE FORMATTED AS:	
DISCIPLINE - PROJECT NUMBER – BUILDING NUMBER.XYZ (example: ARCH-11111-BL001.xyz)	
CIVIL MODEL	CIVIL-
ELECTRICAL MODEL	ELEC-
STRUCTURAL MODEL	STRUCT-
Visual Aesthetics MODEL	LA-
COORDINATION MODEL	COORD-

2. MODEL STRUCTURE:

Describe and diagram how the Model is separated, e.g., by zone, by areas, and/or discipline.

3. MEASUREMENT AND COORDINATE SYSTEMS:

Xxx County State Plane u.s. FEET

4. BIM AND CAD STANDARDS:

Identify items such as the BIM and CAD standards, content reference information, and the version of IFC, etc.

STANDARD	VERSION	BIM USES APPLICABLE	ORGANIZATIONS APPLICABLE
Bentley DGN			
Autodesk DWG			
IFC			

SECTION N: DELIVERY STRATEGY / CONTRACT

1. DELIVERY AND CONTRACTING STRATEGY FOR THE PROJECT:

What additional measures need to be taken to successfully use BIM with the selected delivery method and contract type?

2. TEAM SELECTION PROCEDURE:

How will you select future team members in regard to the above delivery strategy and contract type?

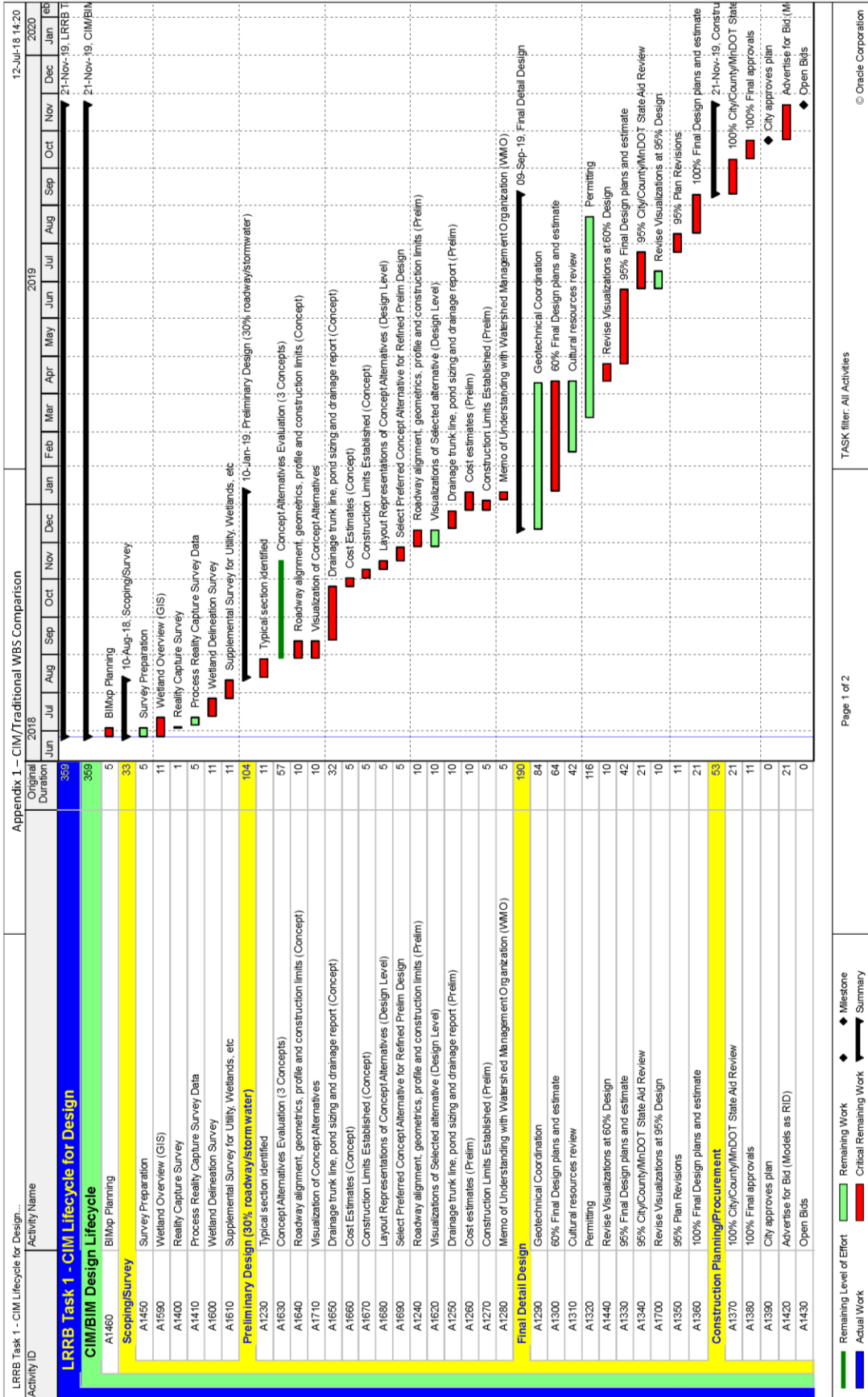
3. BIM CONTRACTING PROCEDURE:

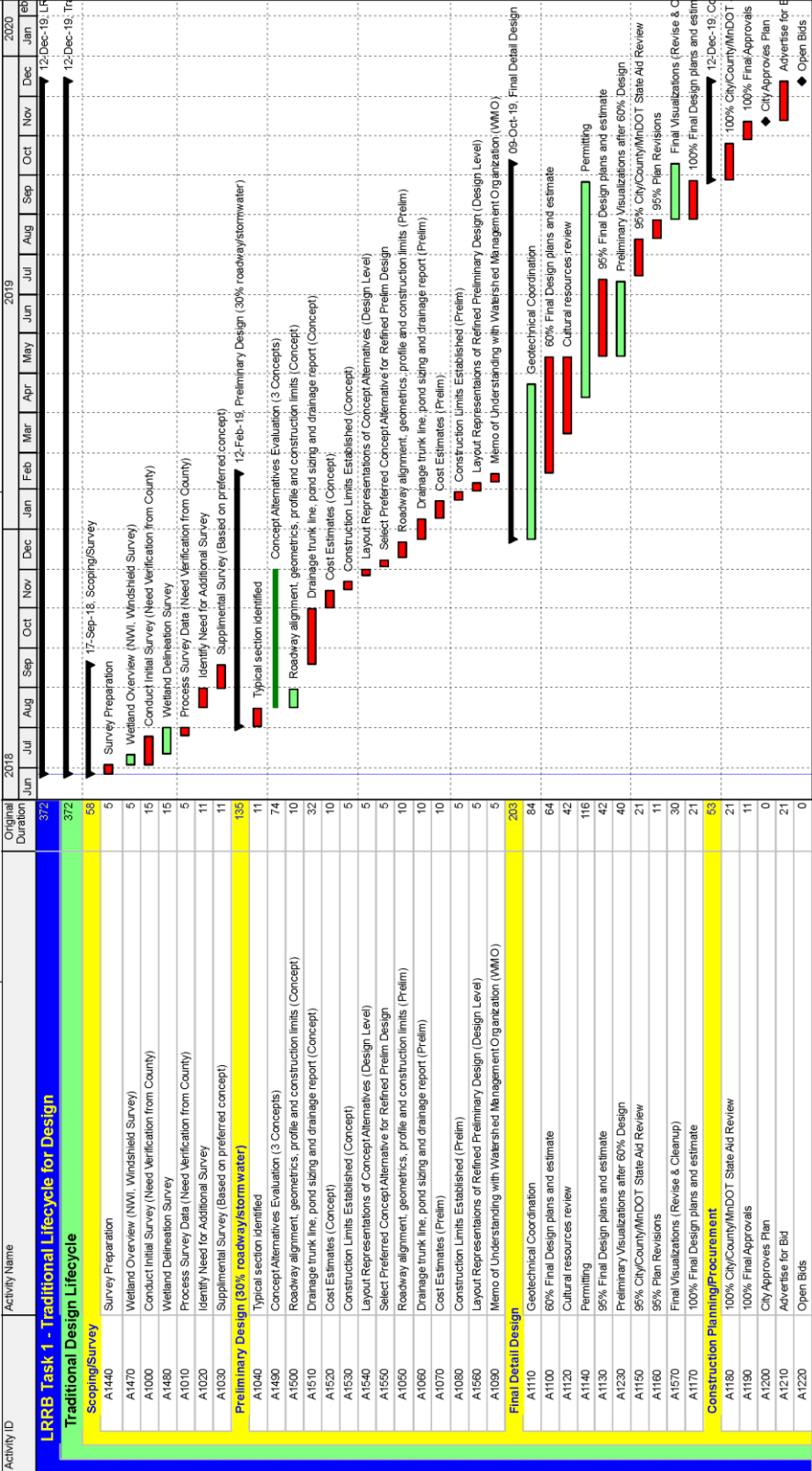
How should BIM be written into the future contracts? (If documents / contracts are developed, please attach as attachment 6)

SECTION O: ATTACHMENTS

- 1. BIM USE SELECTION WORKSHEET [FROM SECTION D]**
- 2. LEVEL 1 PROCESS OVERVIEW MAP [FROM SECTION F]**
- 3. LEVEL 2 DETAILED BIM USE PROCESS MAP(S) [FROM SECTION F]**
- 4. INFORMATION EXCHANGE REQUIREMENT WORKSHEET(S) [FROM SECTION G]**
- 5. MODEL DEFINITION WORKSHEET [FROM SECTION G]**
- 6. DEVELOPED DOCUMENTS / CONTRACTS [FROM SECTION H]**

**APPENDIX B:
TRADITIONAL VS. BIM WBS**





**APPENDIX C:
COLLINS ENGINEERING GCP REPORT**

propeller aeropoints

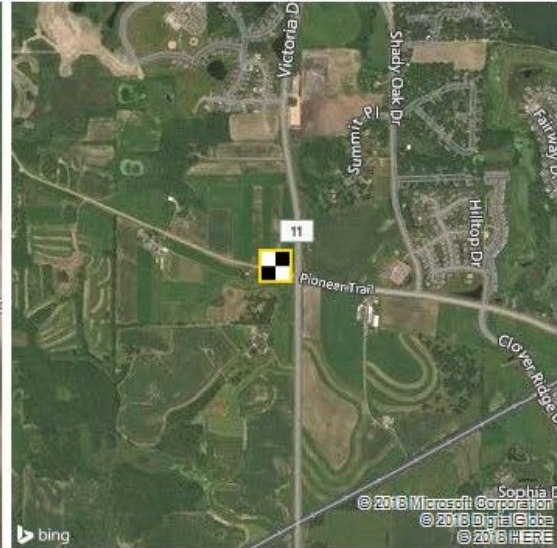
Ground Control Report

Chaska, MN



Survey ID as81f475b4
Aeropoint Set Maverick Drone Systems AeroPoints #2
Date captured 10 May 2018 7:46 AM CDT
Points captured 10
Processing method Propeller network correction
Document generated 14 May 2018 11:49 AM CDT

Point 1



Point Number 1
Global ID acbe0a68a3
AeroPoint ID 8364368

Capture start 10 May 2018 7:46 AM CDT
Capture end 10 May 2018 12:45 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.82554228° (44° 49' 31.95220" N)
Longitude -93.65305186° (93° 39' 10.98668" W)
Ellipsoid height 899.976 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2714682.454 ft (US)
Northing 993759.518 ft (US)

NAVD88 height

Height 987.879 ft (US)

Quality

Data points 1796
Points used 1762 (98.1%)
Baseline distance 27.84 km
Data variance 4.6 mm / 2.0 mm / 4.2 mm

Point 2



Point Number 2
Global ID ace9ddb826
AeroPoint ID 8365082

Capture start 10 May 2018 7:53 AM CDT
Capture end 10 May 2018 12:52 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.826629° (44° 49' 35.86439" N)
Longitude -93.65760316° (93° 39' 27.37139" W)
Ellipsoid height 905.278 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2713499.963 ft (US)
Northing 994150.722 ft (US)

NAVD88 height

Height 993.208 ft (US)

Quality

Data points 1796
Points used 1713 (95.4%)
Baseline distance 27.46 km
Data variance 5.0 mm / 4.7 mm / 8.4 mm

Point 3



Point Number 3
Global ID acdf63d3e9
AeroPointID 8365909

Capture start 10 May 2018 7:56 AM CDT
Capture end 10 May 2018 12:55 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.82778417° (44° 49' 40.02303" N)
Longitude -93.66171571° (93° 39' 42.17656" W)
Ellipsoid height 916.867 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2712431.244 ft (US)
Northing 994567.42 ft (US)

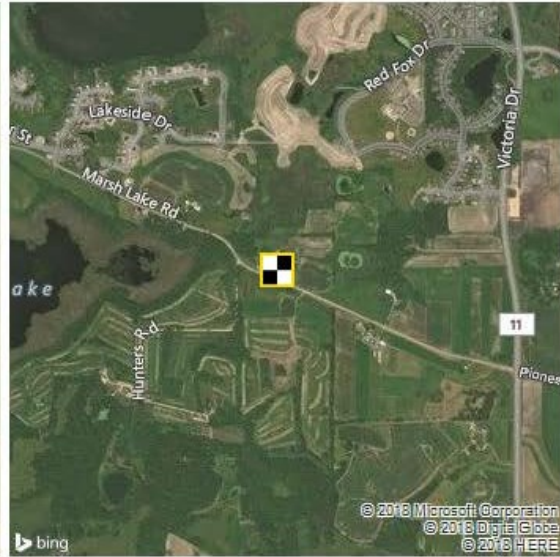
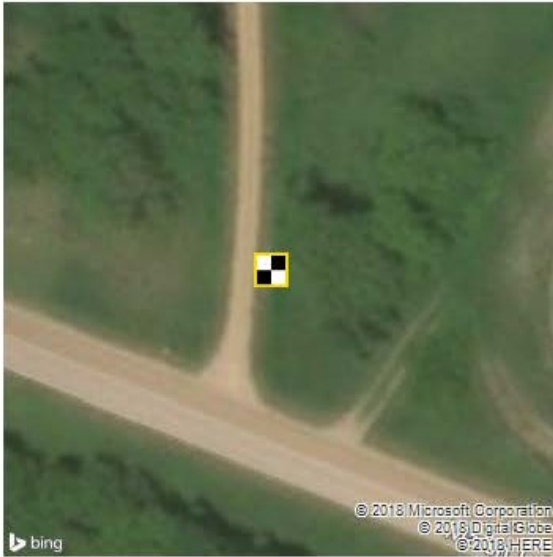
NAVD88 height

Height 1004.825 ft (US)

Quality

Data points 1794
Points used 1627 (90.7%)
Baseline distance 1.84 km
Data variance 6.5 mm / 3.1 mm / 10.9 mm

Point 4



Point Number 4
Global ID ace61975e6
AeroPointID 8366674

Capture start 10 May 2018 7:59 AM CDT
Capture end 10 May 2018 12:58 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.8290479° (44° 49' 44.57244" N)
Longitude -93.66484597° (93° 39' 53.44548" W)
Ellipsoid height 895.97 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2711617.246 ft (US)
Northing 995024.79 ft (US)

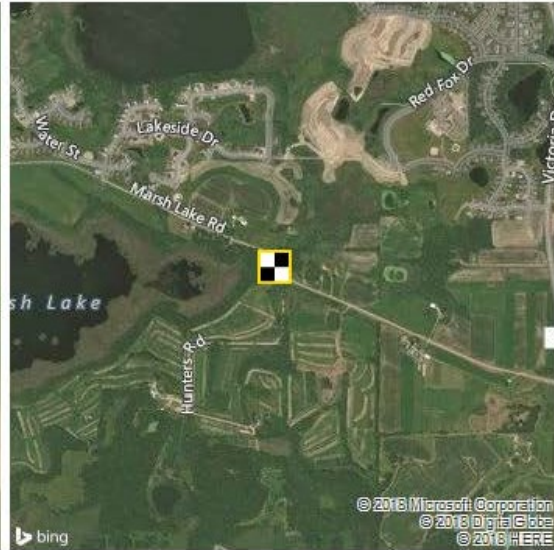
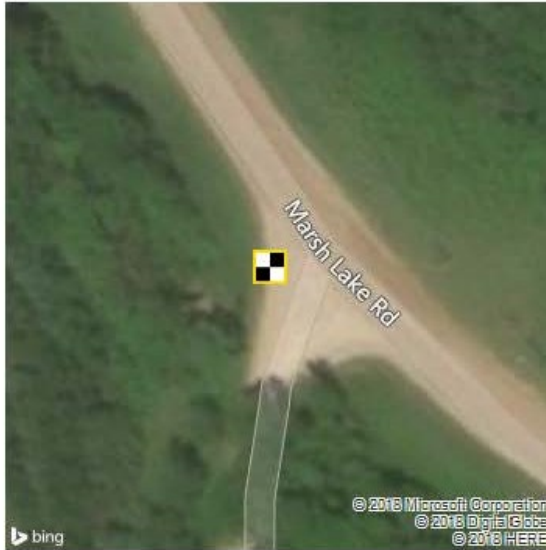
NAVD88 height

Height 983.95 ft (US)

Quality

Data points 1797
Points used 1724 (95.9%)
Baseline distance 26.83 km
Data variance 3.1 mm / 2.2 mm / 24.3 mm

Point 5



Point Number 5

Global ID ac922fe7f9

AeroPoint ID 8364842

Capture start 10 May 2018 8:02 AM CDT

Capture end 10 May 2018 1:01 PM CDT

Duration 4:59

Uploaded 10 May 2018 6:33 PM CDT

NAD83(2011)

Latitude 44.82973007° (44° 49' 47.02825" N)

Longitude -93.66755678° (93° 40' 3.20440" W)

Ellipsoid height 888.031 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2710912.96 ft (US)

Northing 995270.615 ft (US)

NAVD88 height

Height 976.031 ft (US)

Quality

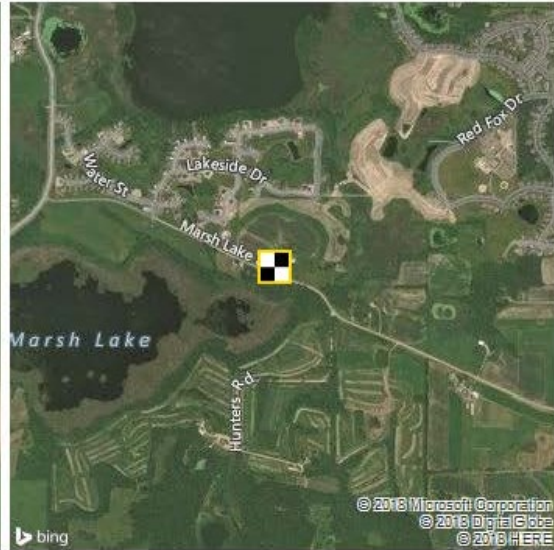
Data points 1796

Points used 1657 (92.3%)

Baseline distance 1.33 km

Data variance 2.7 mm / 3.5 mm / 9.2 mm

Point 6



Point Number 6
Global ID acce677a28
AeroPoint ID 8364998

Capture start 10 May 2018 8:05 AM CDT
Capture end 10 May 2018 1:04 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.83114196° (44° 49' 52.11107" N)
Longitude -93.67020721° (93° 40' 12.74596" W)
Ellipsoid height 905.542 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2710223.281 ft (US)
Northing 995782.562 ft (US)

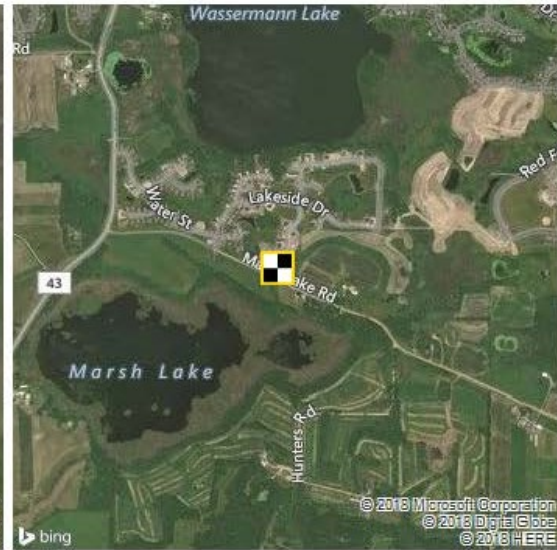
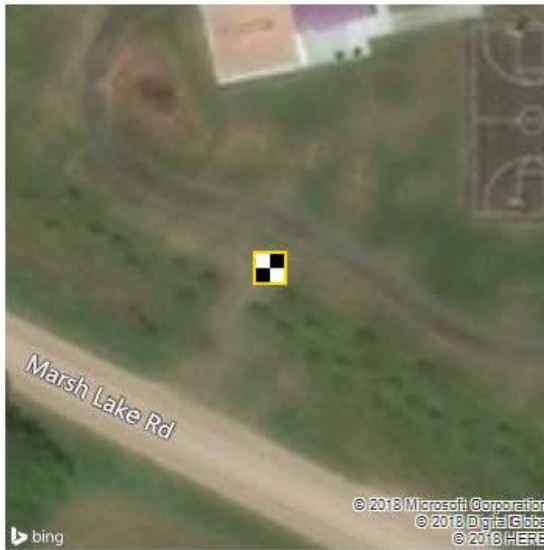
NAVD88 height

Height 993.564 ft (US)

Quality

Data points 1797
Points used 1639 (91.2%)
Baseline distance 26.36 km
Data variance 22.9 mm / 6.2 mm / 21.5 mm

Point 7



Point Number 7
Global ID acdf870d2e
AeroPoint ID 8368090

Capture start 10 May 2018 8:08 AM CDT
Capture end 10 May 2018 1:08 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.83236334° (44° 49' 56.50804" N)
Longitude -93.67350407° (93° 40' 24.61464" W)
Ellipsoid height 900.806 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2709366.219 ft (US)
Northing 996224.406 ft (US)

NAVD88 height

Height 988.855 ft (US)

Quality

Data points 1798
Points used 1793 (99.7%)
Baseline distance 26.07 km
Data variance 4.6 mm / 6.9 mm / 9.2 mm

Point 8



Point Number	8	Capture start	10 May 2018 8:12 AM CDT
Global ID	ac915dc124	Capture end	10 May 2018 1:12 PM CDT
AeroPoint ID	8365399	Duration	4:59
		Uploaded	10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude	44.8332855° (44° 49' 59.82781" N)
Longitude	-93.67741487° (93° 40' 38.69354" W)
Ellipsoid height	896.781 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting	2708350.357 ft (US)
Northing	996556.569 ft (US)

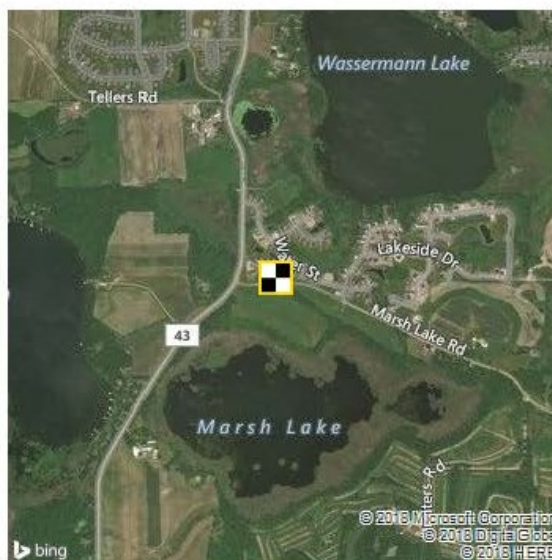
NAVD88 height

Height	984.863 ft (US)
---------------	-----------------

Quality

Data points	1796
Points used	1790 (99.7%)
Baseline distance	25.74 km
Data variance	2.9 mm / 7.3 mm / 7.5 mm

Point 9



Point Number 9
Global ID acecc0a734
AeroPoint ID 8364394

Capture start 10 May 2018 8:15 AM CDT
Capture end 10 May 2018 1:15 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.83400907° (44° 50' 2.43266" N)
Longitude -93.6806193° (93° 40' 50.22948" W)
Ellipsoid height 908.108 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2707518.051 ft (US)
Northing 996817.095 ft (US)

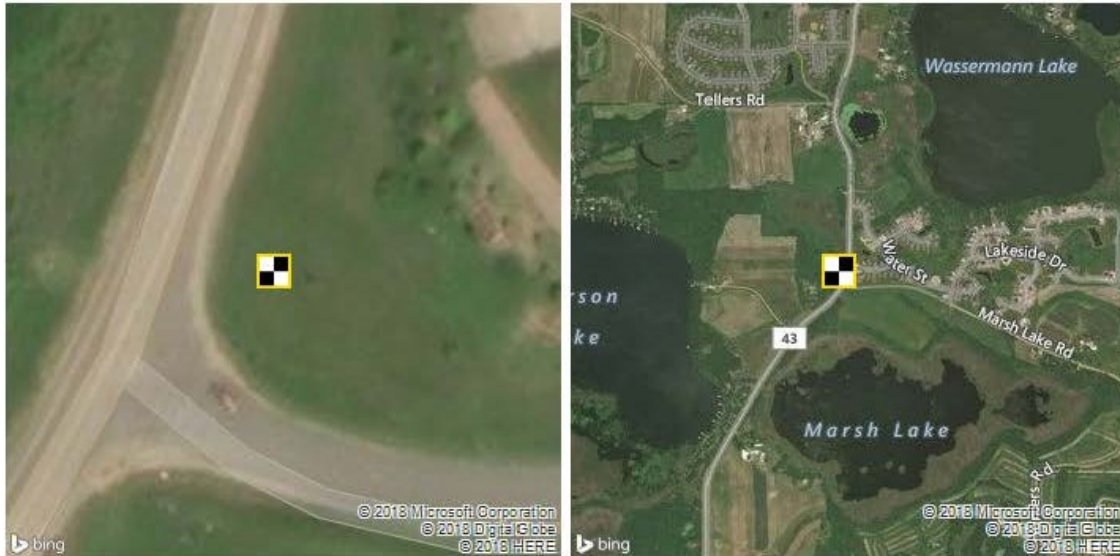
NAVD88 height

Height 996.217 ft (US)

Quality

Data points 1796
Points used 1774 (98.8%)
Baseline distance 25.48 km
Data variance 2.8 mm / 6.8 mm / 12.3 mm

Point 10



Point Number 10
Global ID ac59ed3afa
AeroPoint ID 8365961

Capture start 10 May 2018 8:18 AM CDT
Capture end 10 May 2018 1:17 PM CDT
Duration 4:59
Uploaded 10 May 2018 6:34 PM CDT

NAD83(2011)

Latitude 44.83435846° (44° 50' 3.69045" N)
Longitude -93.68302006° (93° 40' 58.87221" W)
Ellipsoid height 901.45 ft (US)

NAD83(2011) / Minnesota South (ftUS)

Easting 2706894.773 ft (US)
Northing 996942.046 ft (US)

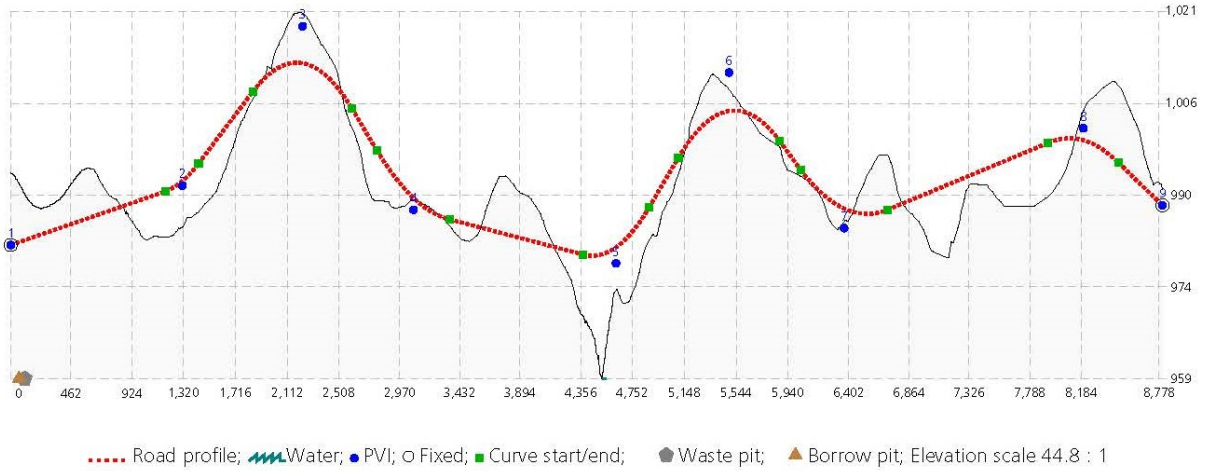
NAVD88 height

Height 989.579 ft (US)

Quality

Data points 1798
Points used 1791 (99.6%)
Baseline distance 25.28 km
Data variance 0.2 mm / 0.3 mm / 1.1 mm

**APPENDIX D:
AUTODESK CORRIDOR OPTIMIZATION DOCUMENTATION**



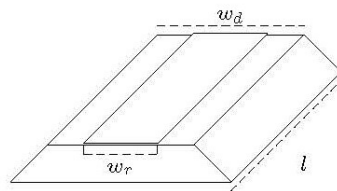
1. PROFILE INFORMATION

Total project cost:	\$1,973,731	Number of PVI's:	9
Linear unit:	foot	Maximum grade:	5.00 %
Design speed:	55	Required drainage grade:	0.00 %
Length:	8,805.16	Minimum PVI spacing:	600.00

2. CONSTRUCTION INFORMATION

Total construction cost: ¹	\$1,196,688	Use bridges:	No
Number of bridges:	0	Use tunnels:	No
Number of tunnels:	0	Sample line distance:	50.00
Number of retainings:	0		

2.1. Road Assembly Information. The construction cost for a sample line subsection with a road assembly is l times the road cost per linear unit.



l : Sample line distance
 w_r : Road width
 w_d : Datum width

Road cost per linear foot: ²	\$135.82	Daylight cut slope:	0.50
Road width: ³	24.00	Daylight fill slope:	0.50
Datum width:	99.64		

¹The construction costs are computed at every sample line, using a selected assembly or style, and a sample line distance for the length of a construction subsection. Individual cost computations for the different assemblies are explained below. The total construction cost is the sum of the individual subsection costs.

²The road cost per linear unit is $w_r \cdot (0.3 \cdot C + 0.7 \cdot A) + D + S + L + G$, where C is the cement pavement cost per square unit, A is the asphalt pavement cost per square unit, D is the cost for drainage, S for signing, L for lighting, and G for signaling per linear unit.

³The road width is the number of road lanes multiplied by the width of a road lane. It does not include the width of medians, sidewalks, etc.

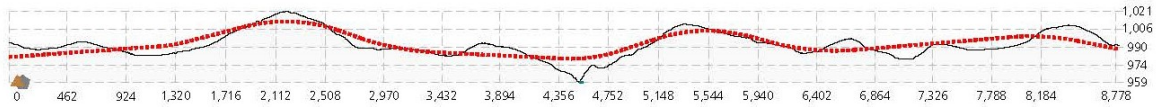
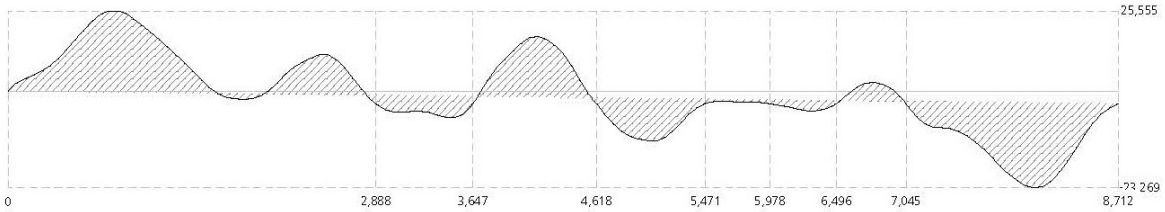
3. EARTHWORK INFORMATION

Total earthwork cost:	\$777,044	Max section length:	594.00
Num earthwork sections:	20	Num waste pits:	1
Num earthwork sub-sections:	133	Num borrow pits:	1
Num. stratum:	1	Swath width:	116.60

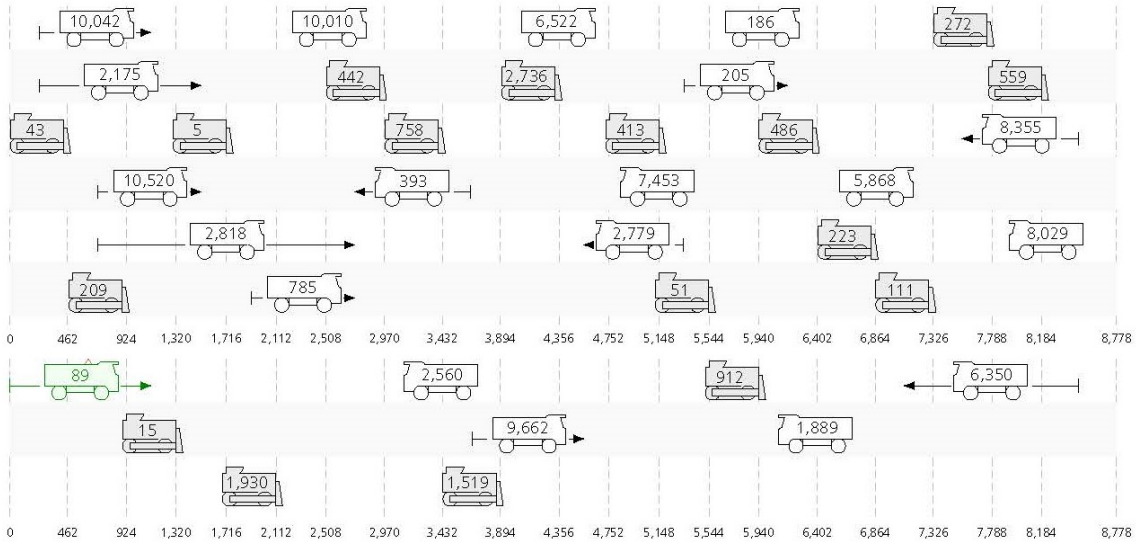
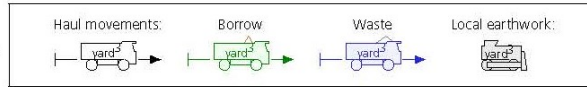
3.1. Earthwork for Strata Layer 1.

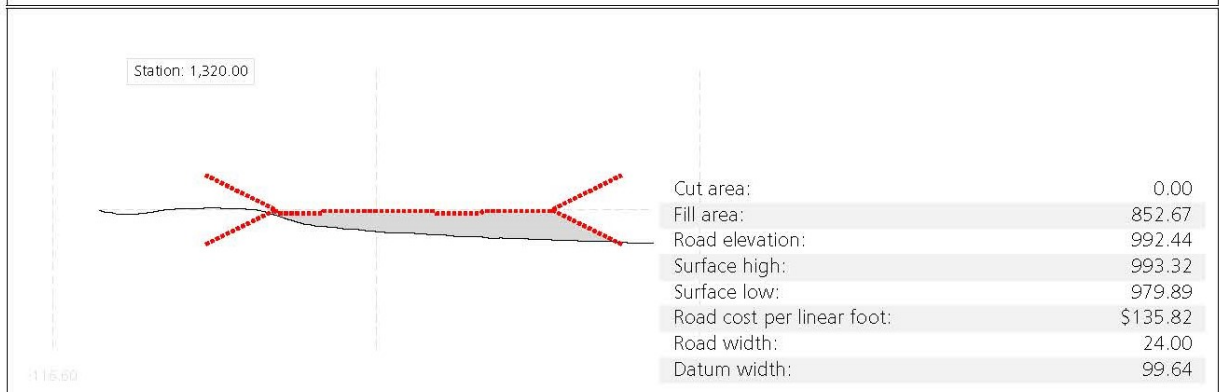
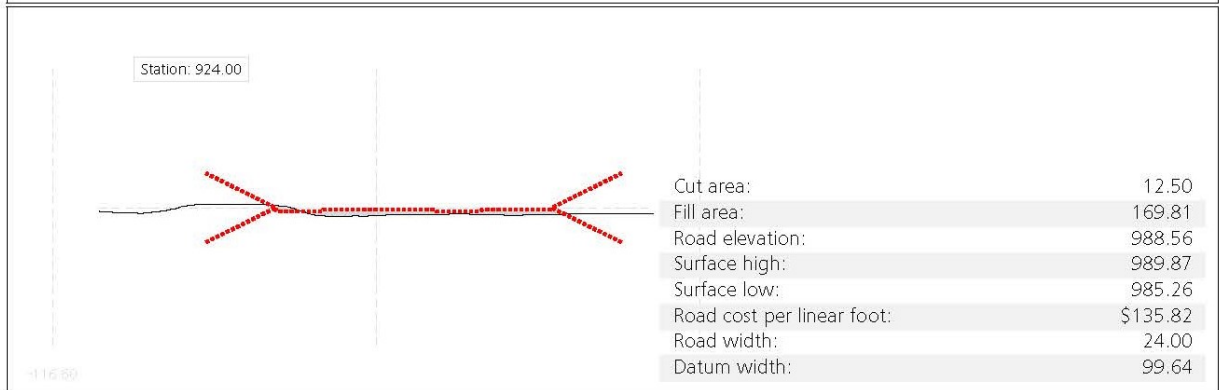
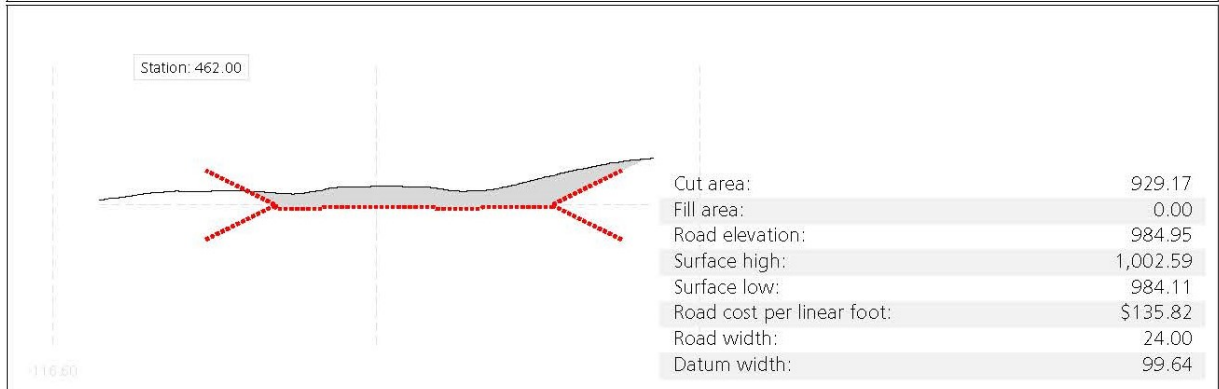
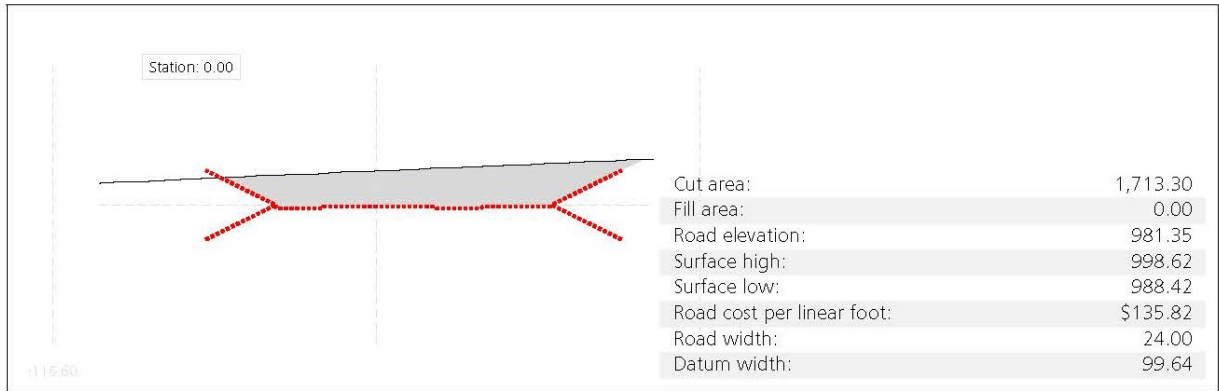
Cum. cut:	107,288.19	Excavation cost:	\$2.34
Cum. fill:	107,377.61	Load cost:	\$1.43
Net volume:	-89.42	Haul cost (per mile):	\$1.84
Volume unit:	cubic yard	Embankment cost:	\$3.37
Layer name:		Waste cost:	\$.75
Reusability factor:	1.00	Borrow cost:	\$2.10

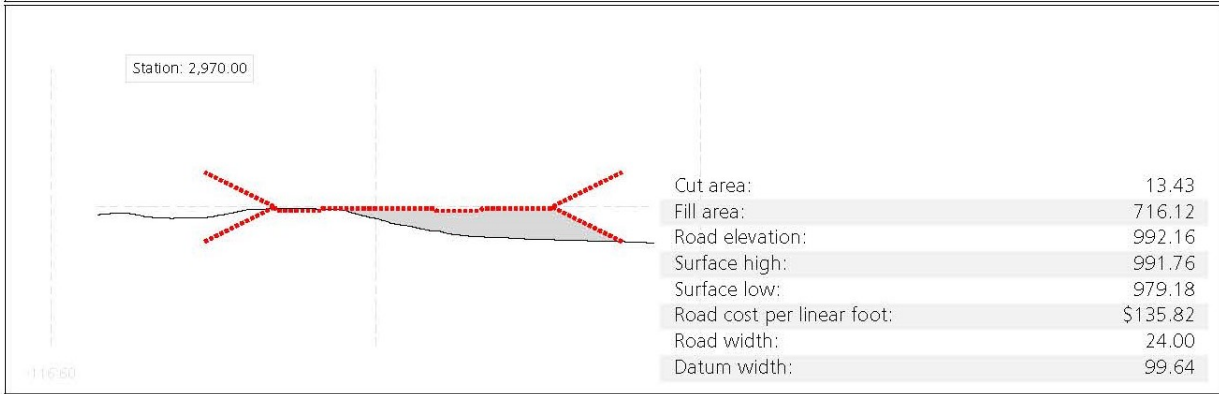
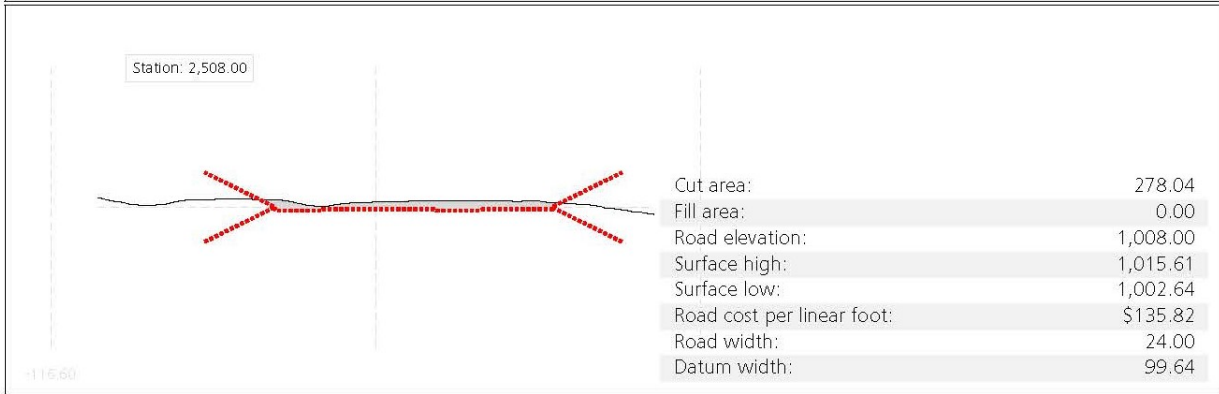
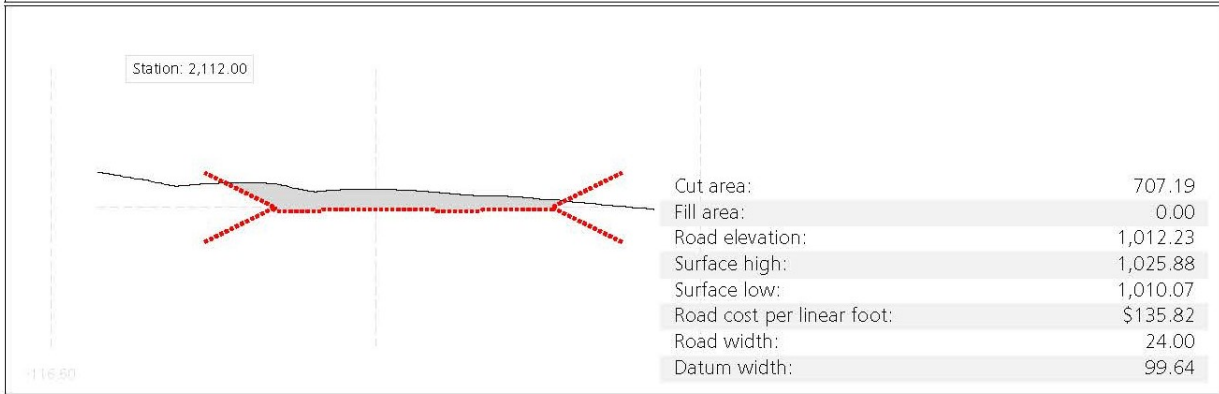
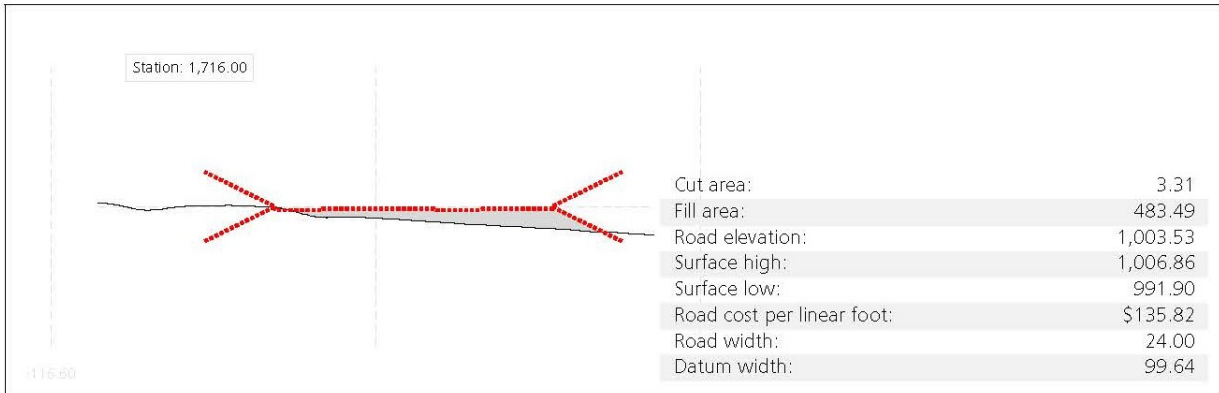
3.1.1. Mass diagram for strata layer 1.

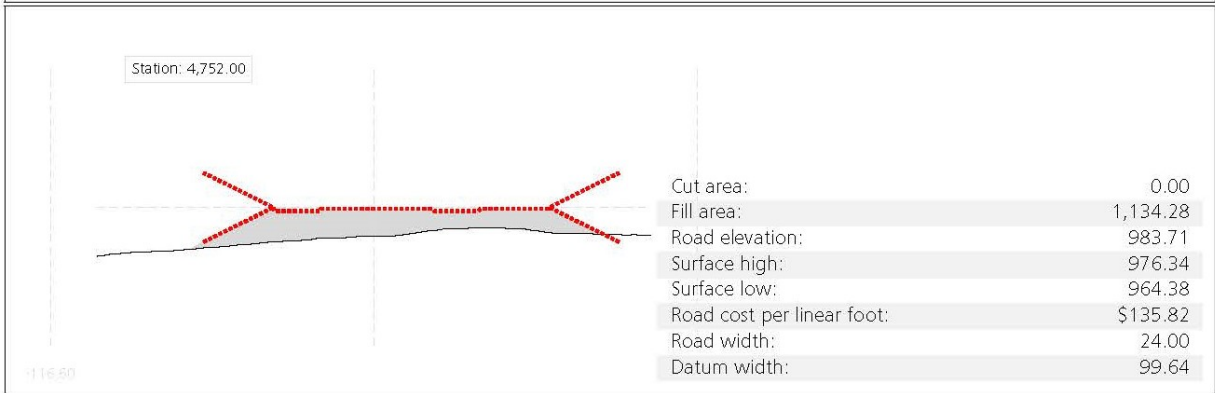
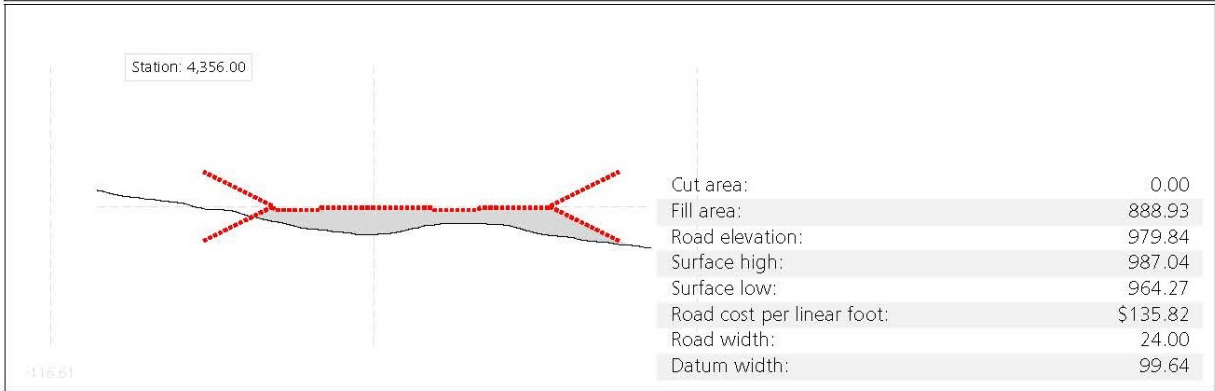
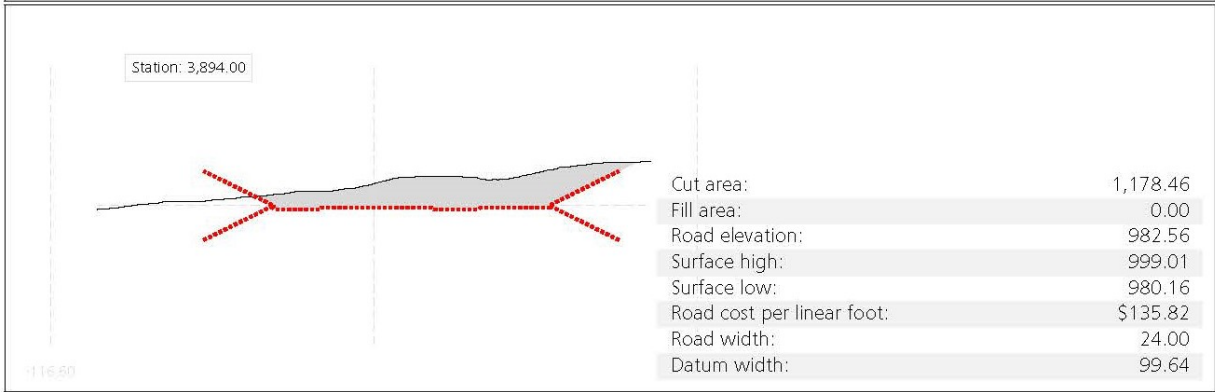
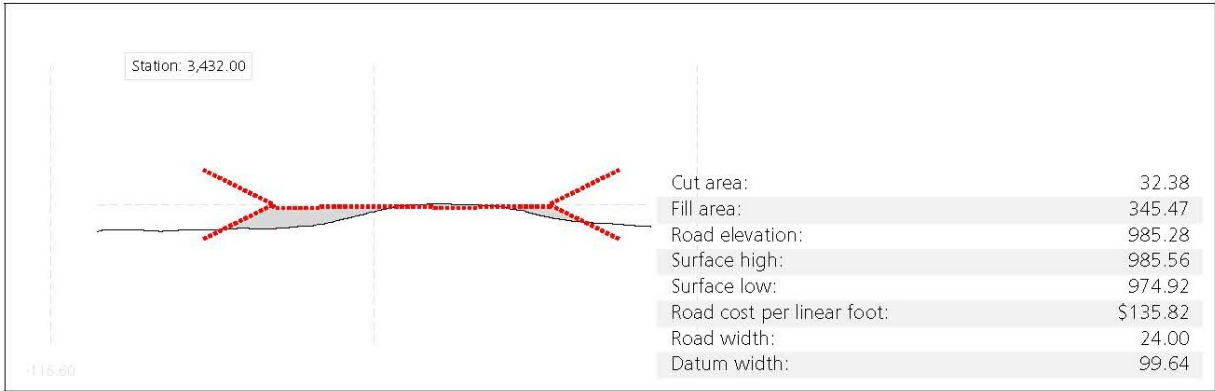


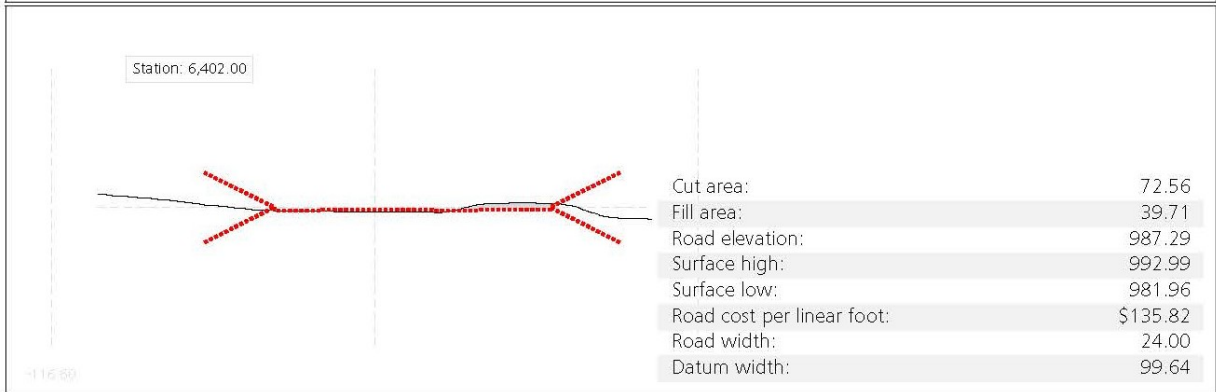
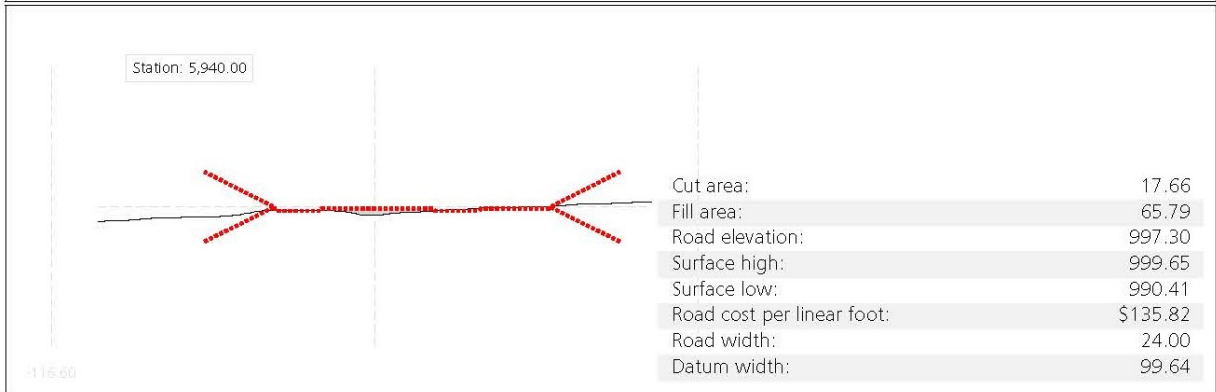
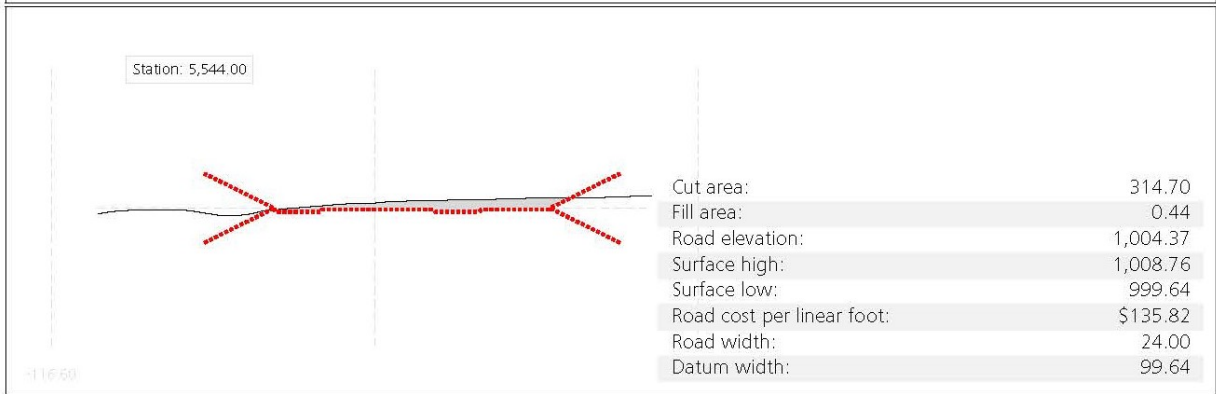
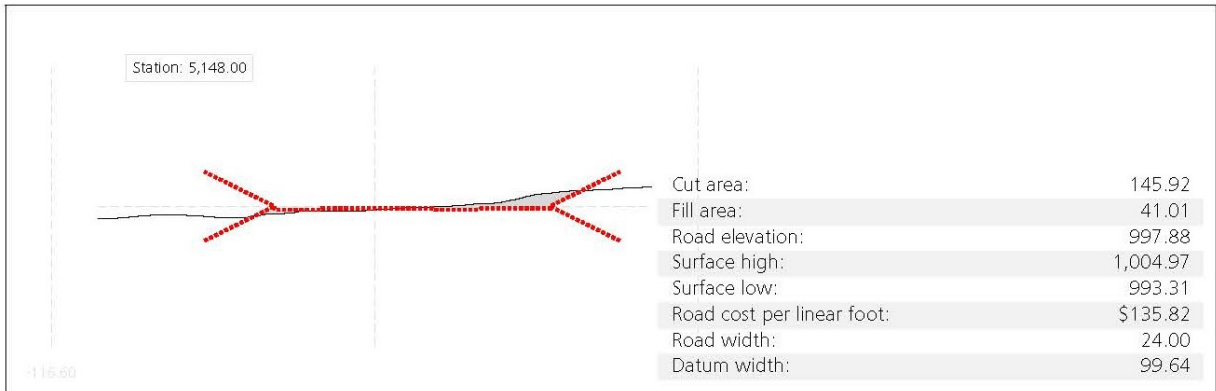
3.1.2. Hauling Scheme for strata layer 1.

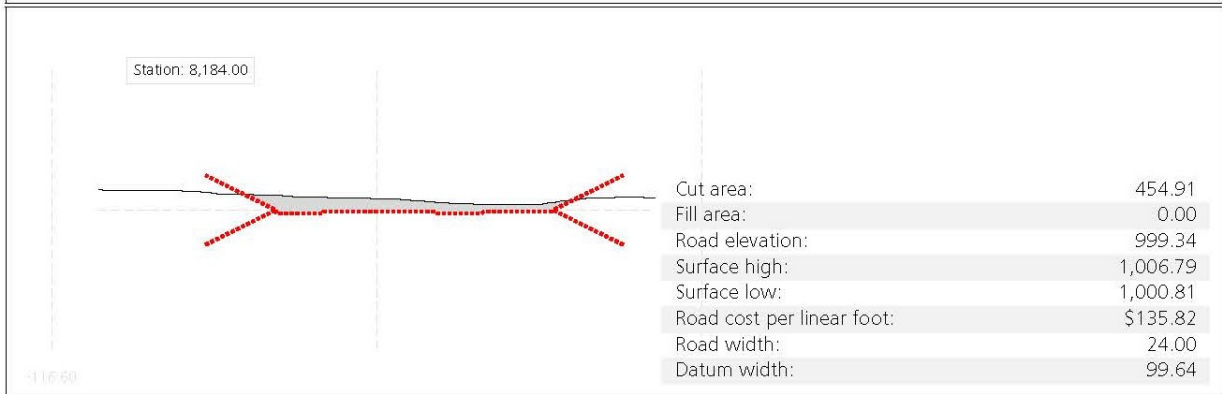
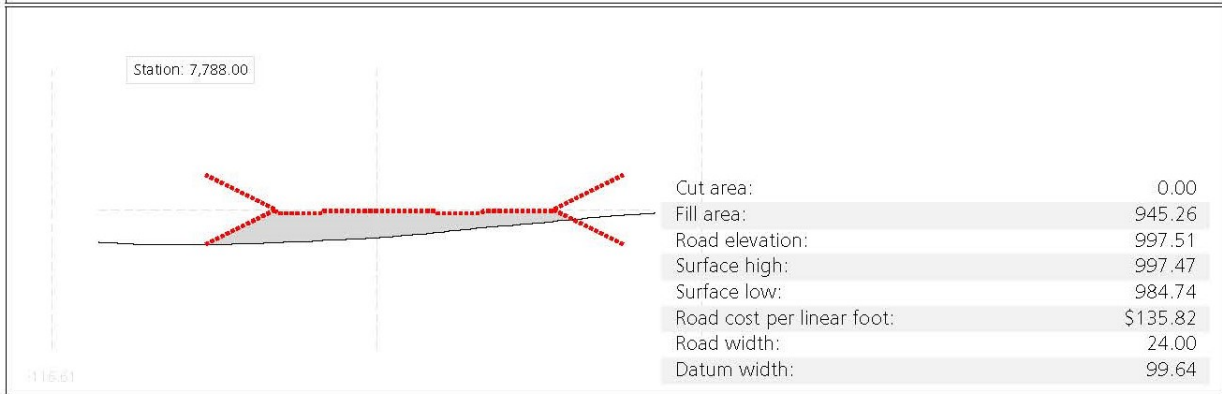
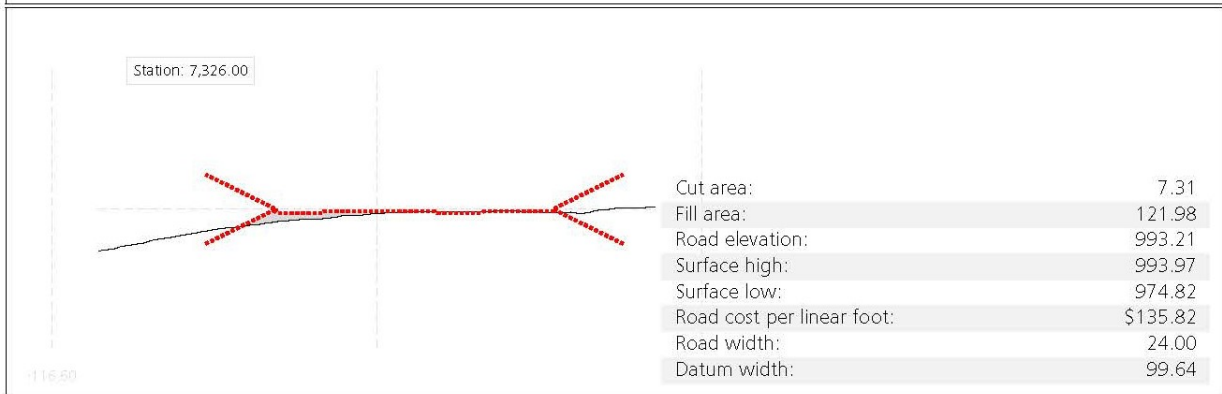
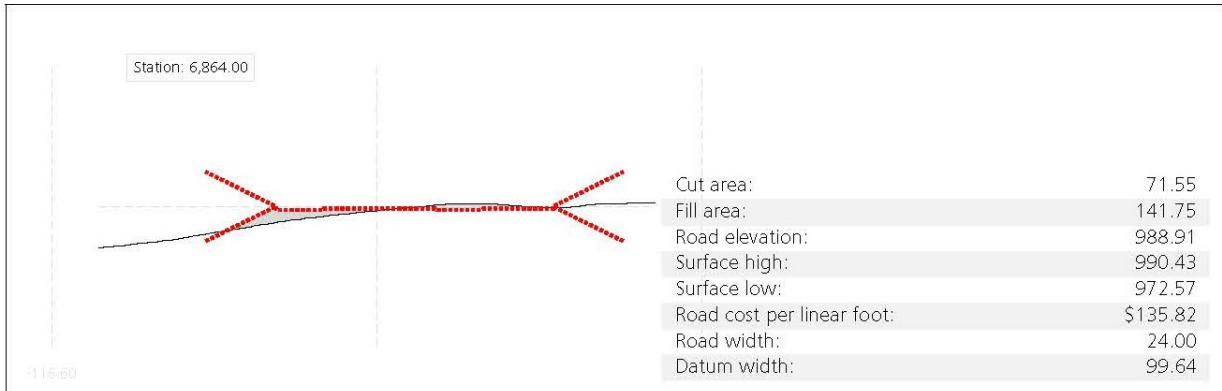


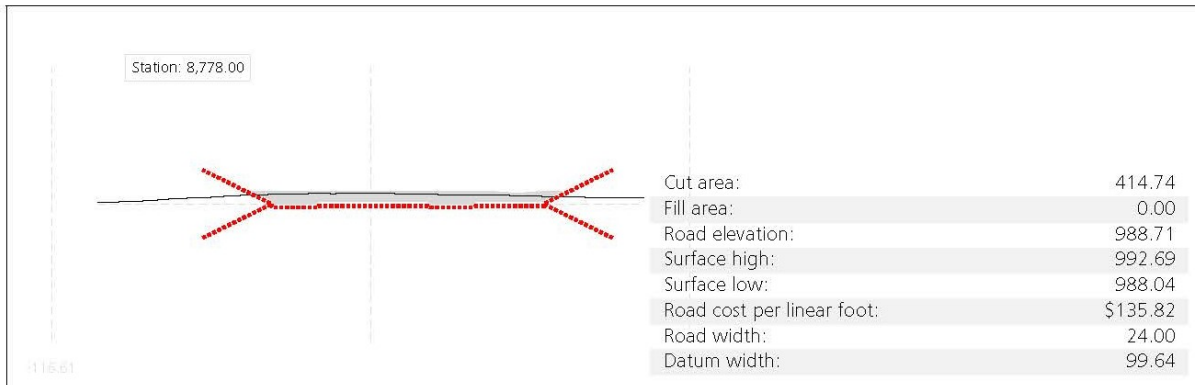












4. VOLUME REPORT

Station:	Cut area: (ft ²)	Cut vol: (yd ³)	Fill area: (ft ²)	Fill vol. (yd ³)	Cum. cut: (yd ³)	Cum. fill: (yd ³)	Cum. net: (yd ³)
0.00	1,713.30	0.00	0.00	0.00	0.00	0.00	0.00
462.00	929.17	12,260.76	0.00	43.41	12,260.76	43.41	12,217.35
924.00	12.50	13,546.86	169.81	209.07	25,807.62	252.48	25,555.14
1,320.00	0.00	15.28	852.67	10,146.96	25,822.90	10,399.45	15,423.46
1,716.00	3.31	4.63	483.49	12,699.52	25,827.53	23,098.97	2,728.56
2,112.00	707.19	2,714.83	0.00	1,930.33	28,542.36	25,029.30	3,513.06
2,508.00	278.04	10,010.03	0.00	0.00	38,552.40	25,029.30	13,523.10
2,970.00	13.43	442.12	716.12	14,447.50	38,994.52	39,476.80	-482.29
3,432.00	32.38	758.46	345.47	3,318.04	39,752.98	42,794.84	-3,041.87
3,894.00	1,178.46	14,134.21	0.00	1,519.30	53,887.18	44,314.14	9,573.04
4,356.00	0.00	9,258.10	888.93	2,736.09	63,145.28	47,050.23	16,095.05
4,752.00	0.00	0.00	1,134.28	18,963.89	63,145.28	66,014.12	-2,868.84
5,148.00	145.92	412.94	41.01	7,866.14	63,558.23	73,880.26	-10,322.03
5,544.00	314.70	10,488.00	0.44	50.66	74,046.22	73,930.91	115.31
5,940.00	17.66	1,098.18	65.79	912.12	75,144.40	74,843.04	301.37
6,402.00	72.56	485.97	39.71	2,765.97	75,630.37	77,609.01	-1,978.64
6,864.00	71.55	7,981.02	141.75	223.36	83,611.40	77,832.37	5,779.03
7,326.00	7.31	111.42	121.98	12,330.18	83,722.82	90,162.54	-6,439.72
7,788.00	0.00	272.18	945.26	8,627.15	83,995.00	98,789.69	-14,794.69
8,184.00	454.91	559.16	0.00	8,587.92	84,554.16	107,377.61	-22,823.45
8,778.00	461.52	22,734.02	0.00	0.00	107,288.19	107,377.61	-89.42

5. LIST OF PVI'S

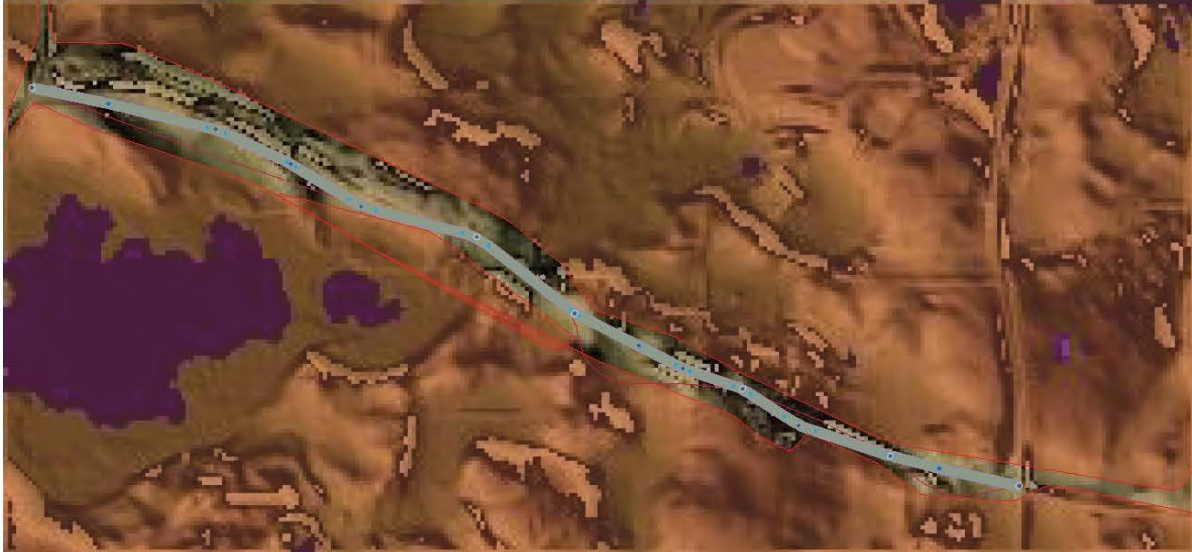
PVI	Station	Elevation	Curve length
*1	0.00	981.35	0.00
2	1,310.73	991.58	251.34
3	2,230.99	1,018.71	758.99
4	3,078.08	987.36	554.15
5	4,625.42	978.25	503.87

PVI	Station	Elevation	Curve length
6	5,489.14	1,010.84	773.88
7	6,372.01	984.33	659.16
8	8,200.73	1,001.35	539.57
*9	8,805.16	988.11	0.00

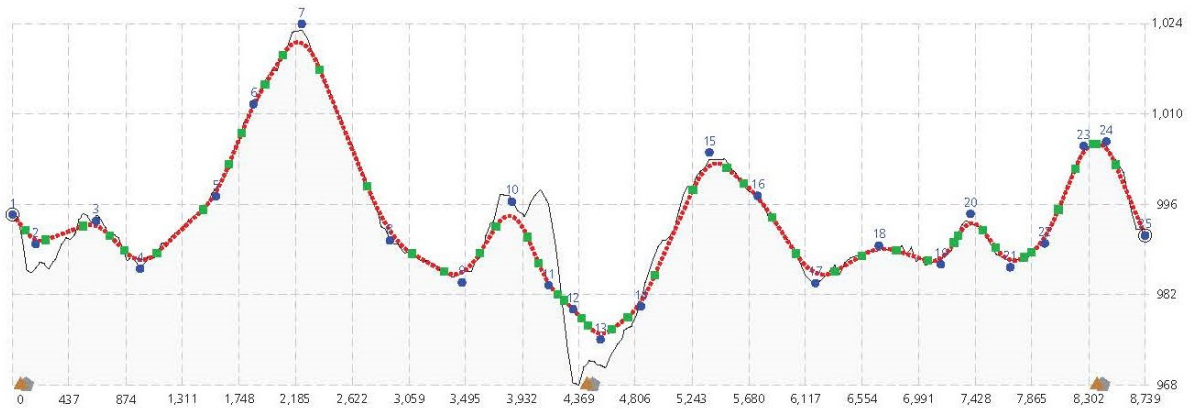
6. LEGAL REMINDER

All data and data files contained in the Profile Optimization Results are created as a result of your use of Profile Optimization for InfraWorks and are subject to the Autodesk InfraWorks Software License Agreement and the Autodesk 360 Terms of Service you accepted prior to your use of Profile Optimization.

**APPENDIX E:
CORRIDOR OPTIMIZATION REPORT**



— Final alignment; — Starting alignment; ● PVI; ○ Fixed; ● PC/PT; ■ Avoidance zone; ● Waste pit; ▲ Borrow pit;



--- Road profile; ● PVI; ○ Fixed; ■ Curve start/end; ● Waste pit; ▲ Borrow pit; Elevation scale 49.8 : 1

1. ALIGNMENT INFORMATION

Linear unit:	foot	Minimum radius:	420.90
Design speed:	35	Minimum super elevation:	4.00 %
Swath width:	70.01	Number of PIs and Curves:	14

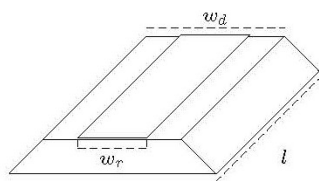
2. PROFILE INFORMATION

Total project cost:	\$1,279,040	Number of PVI's:	25
Linear unit:	foot	Maximum grade:	5.00 %
Design speed:	35	Required drainage grade:	0.00 %
Length:	8,738.61	Minimum PVI spacing:	105.00

3. CONSTRUCTION INFORMATION

Total construction cost: ¹	\$1,178,958	Maximum fill height before bridge:	N/A
Number of bridges:	0	Maximum cut depth before tunnel:	N/A
Number of tunnels:	0	Sample line distance:	50.00
Number of retainings:	0		

3.1. **Road Assembly Information.** The construction cost for a sample line subsection with a road assembly is l times the road cost per linear unit.



l : Sample line distance
 w_r : Road width
 w_d : Datum width

Road cost per linear foot: ²	\$134.62	Daylight cut slope:	0.25
Road width: ³	23.62	Daylight fill slope:	0.25
Datum width:	40.03		

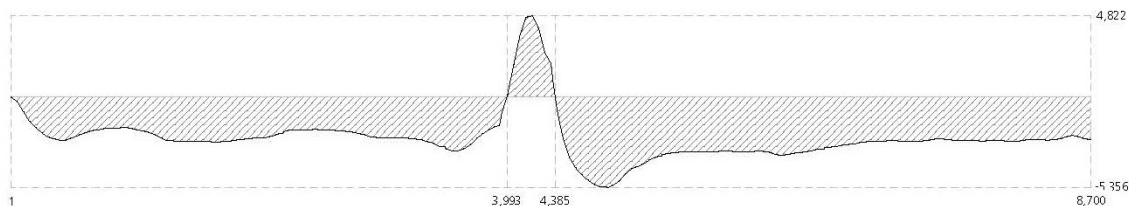
4. EARTHWORK INFORMATION

Total earthwork cost:	\$100,082	Max section length:	436.93
Num earthwork sections:	20	Num waste pits:	3
Num earthwork sub-sections:	194	Num borrow pits:	3
Num. stratum:	1	Swath width:	70.01

4.1. Earthwork for Strata Layer 1.

Cum. cut:	6,890.15	Excavation cost:	\$2.34
Cum. fill:	6,890.15	Load cost:	\$1.43
Net volume:	0.00	Haul cost (per mile):	\$1.84
Volume unit:	cubic yard	Embankment cost:	\$3.37
Layer name:		Waste cost:	\$.75
Reusability factor:	1.00	Borrow cost:	\$2.10

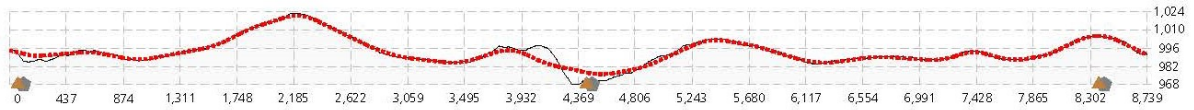
4.1.1. Mass diagram for strata layer 1.



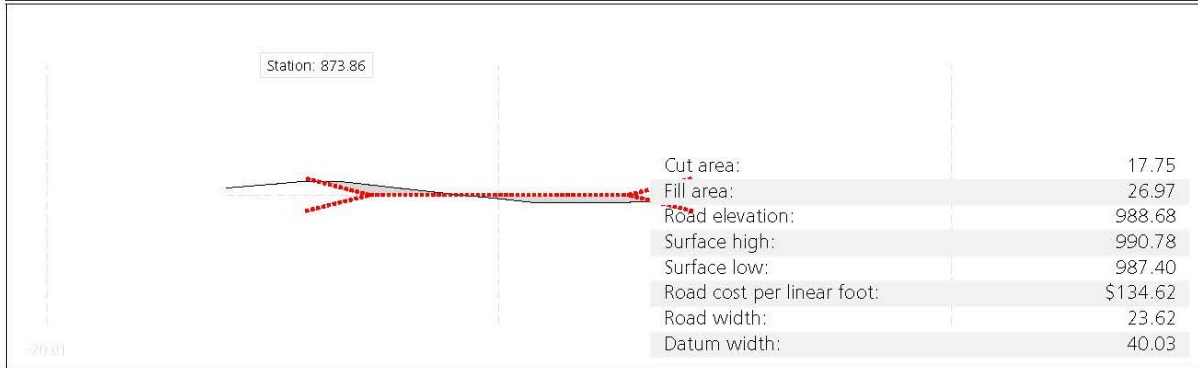
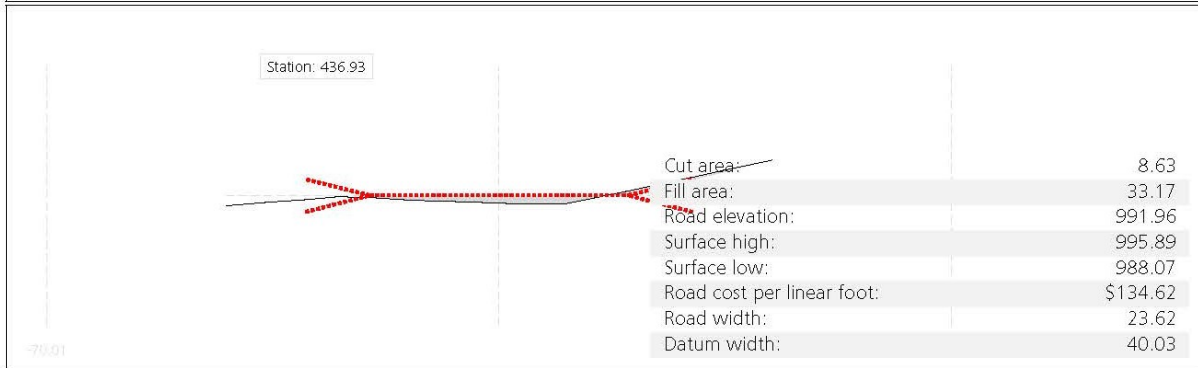
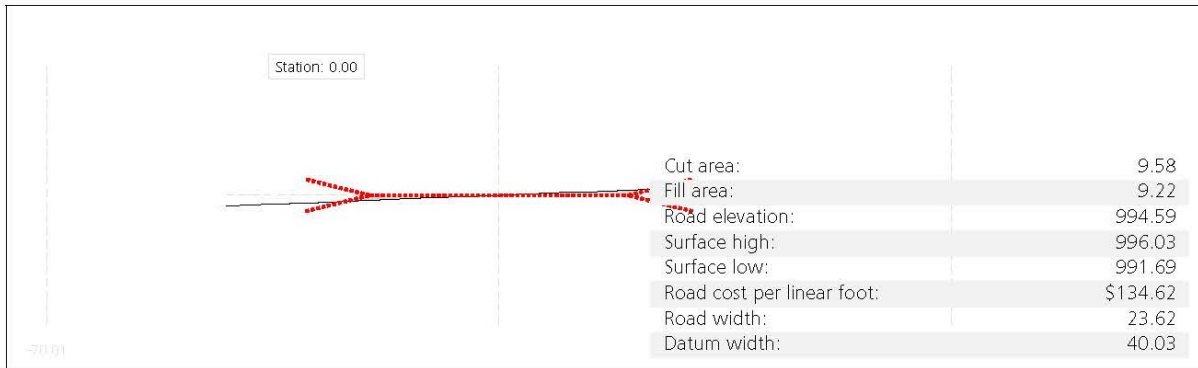
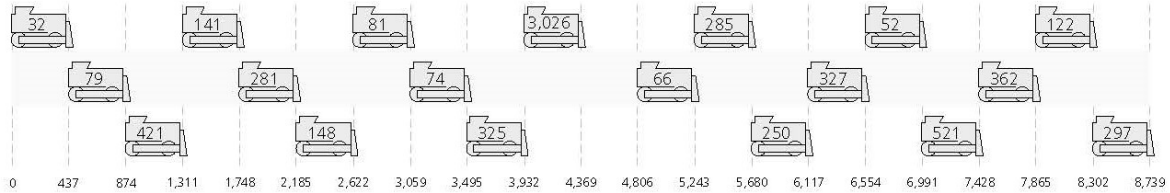
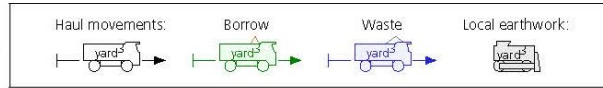
¹The construction costs are computed at every sample line, using a selected assembly or style, and a sample line distance for the length of a construction subsection. Individual cost computations for the different assemblies are explained below. The total construction cost is the sum of the individual subsection costs.

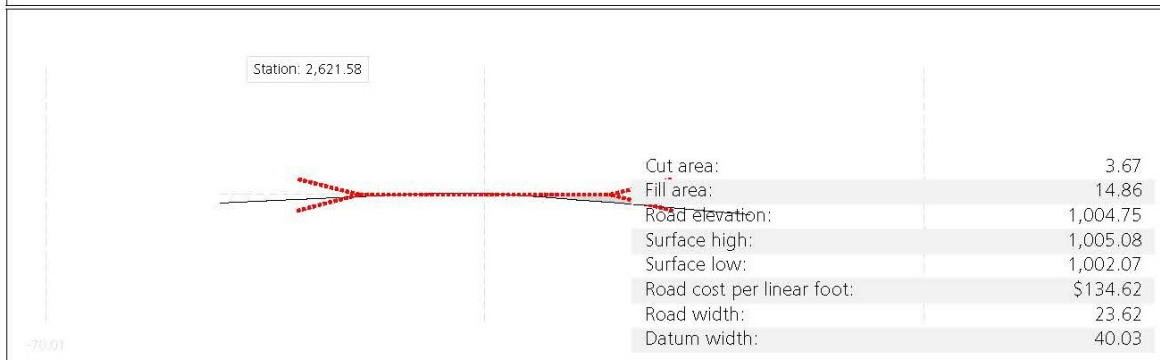
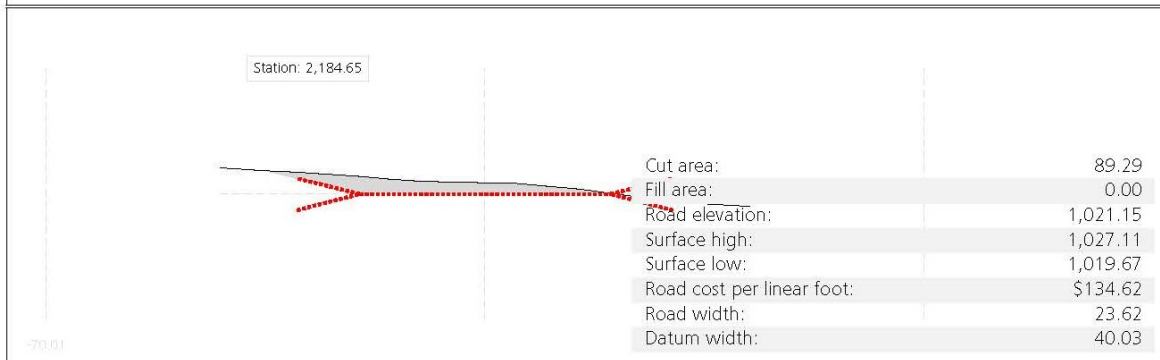
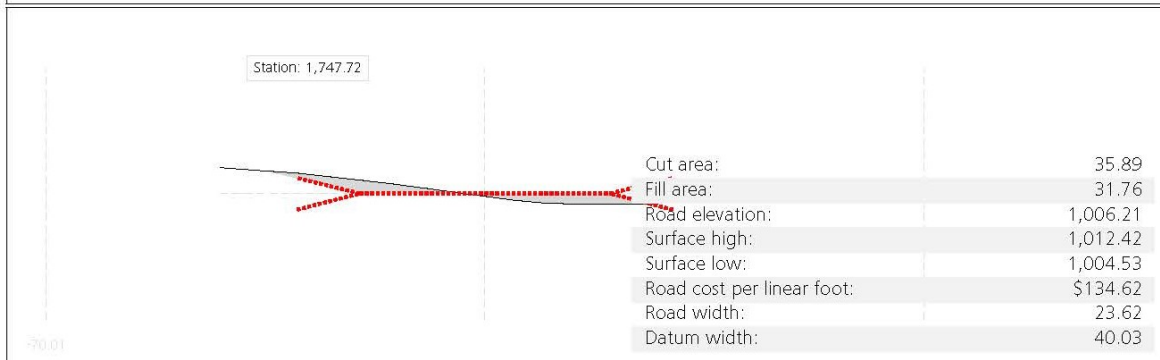
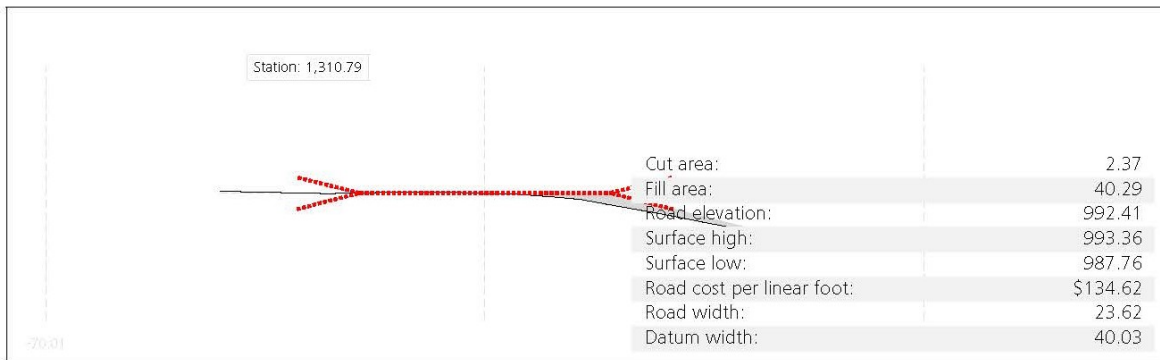
²The road cost per linear unit is $w_r \cdot (0.3 \cdot C + 0.7 \cdot A) + D + S + L + G$, where C is the cement pavement cost per square unit, A is the asphalt pavement cost per square unit, D is the cost for drainage, S for signing, L for lighting, and G for signaling per linear unit.

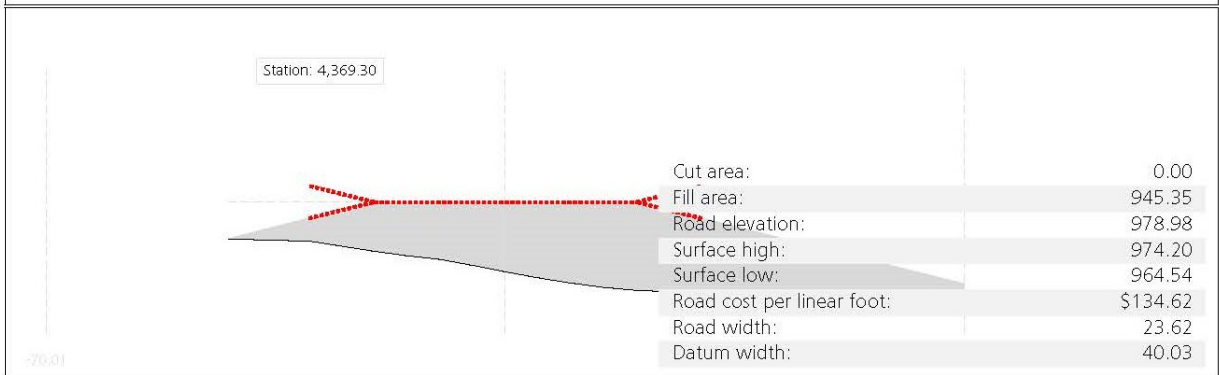
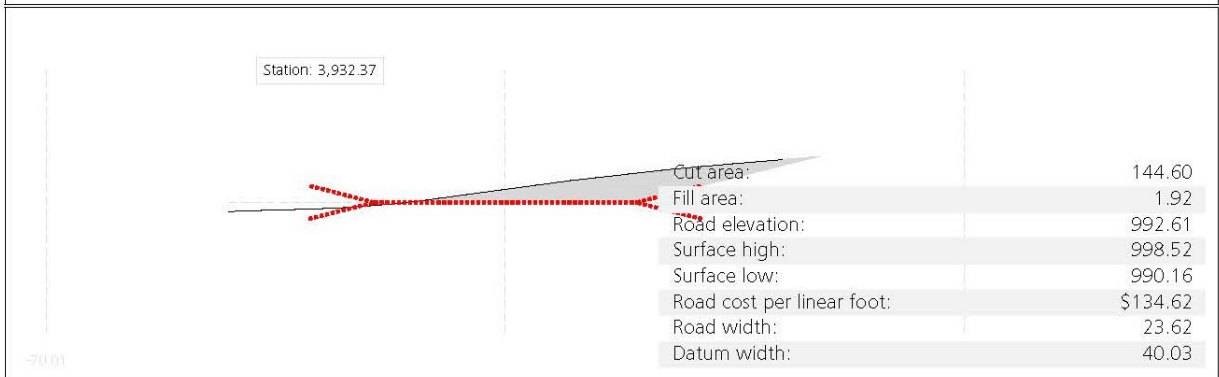
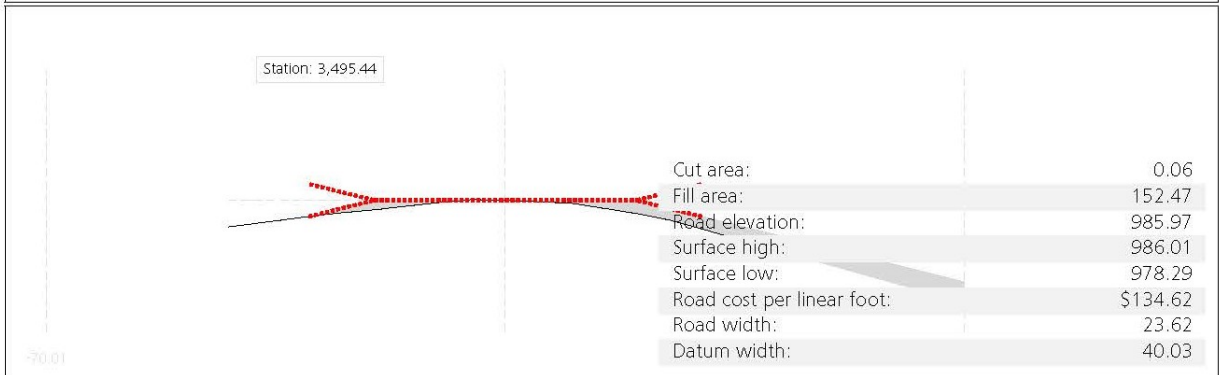
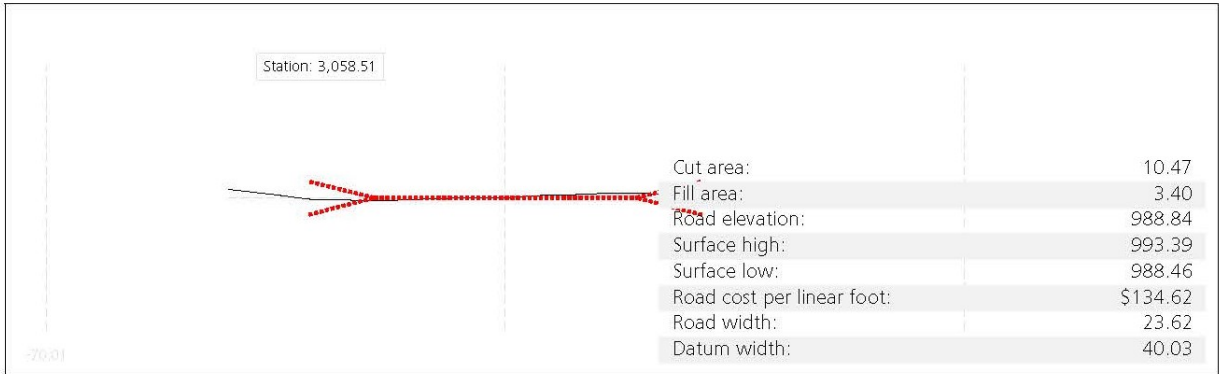
³The road width is the number of road lanes multiplied by the width of a road lane. It does not include the width of medians, sidewalks, etc.

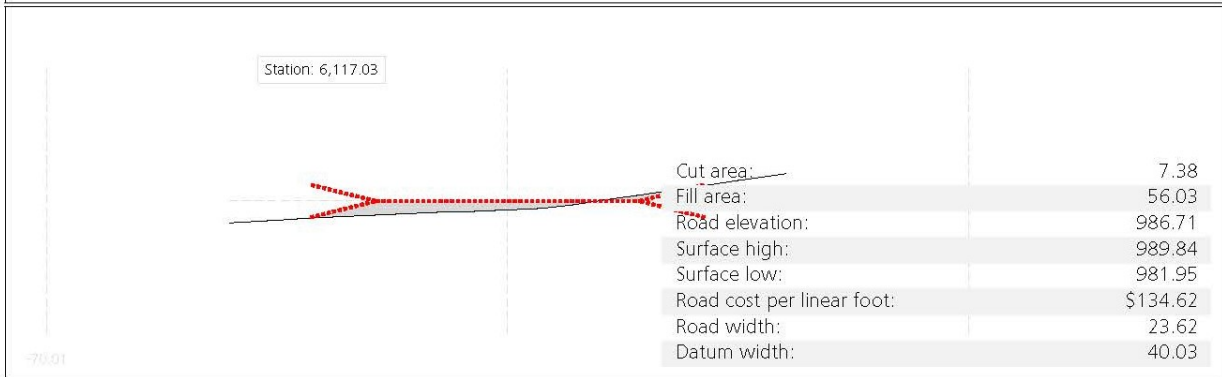
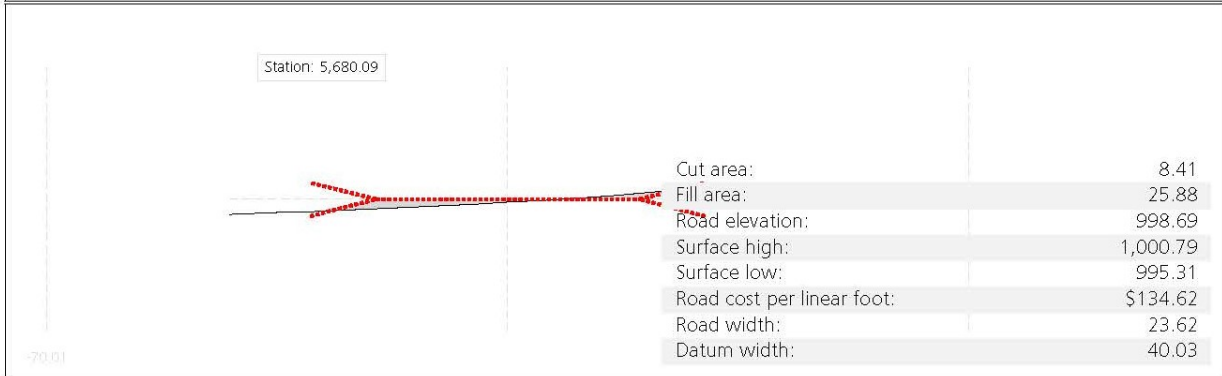
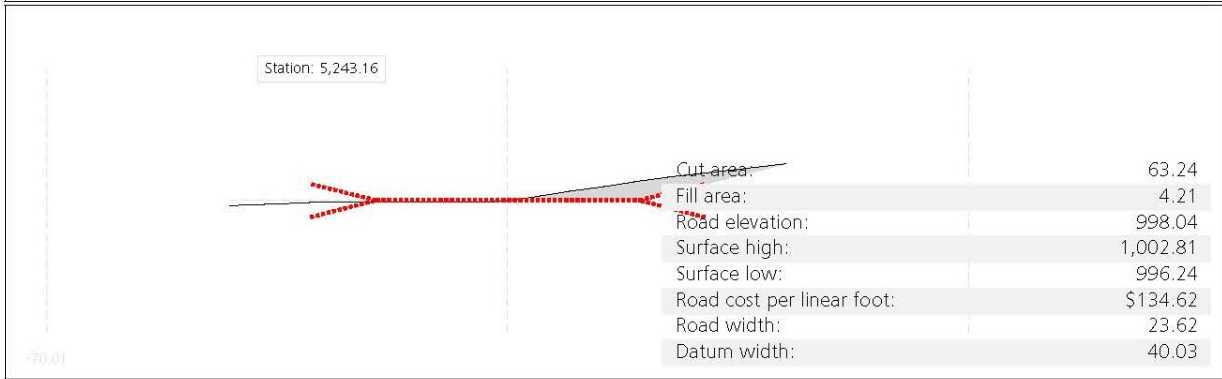
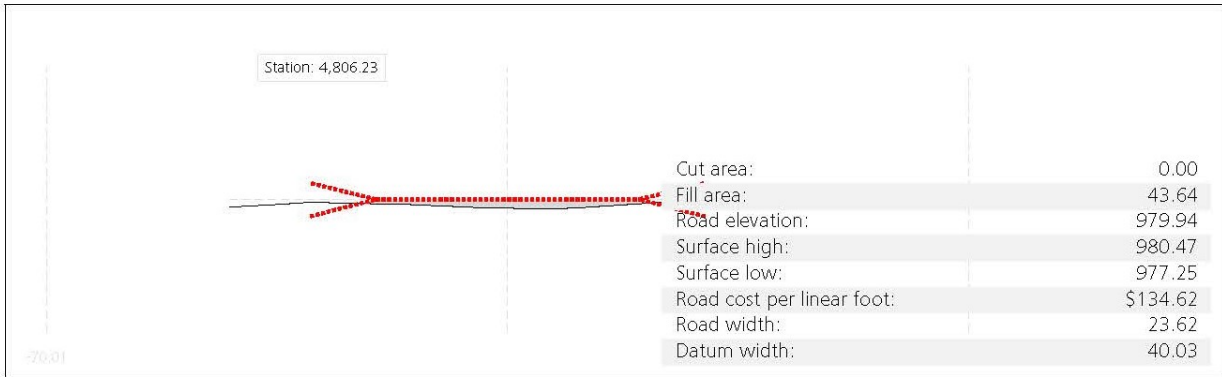


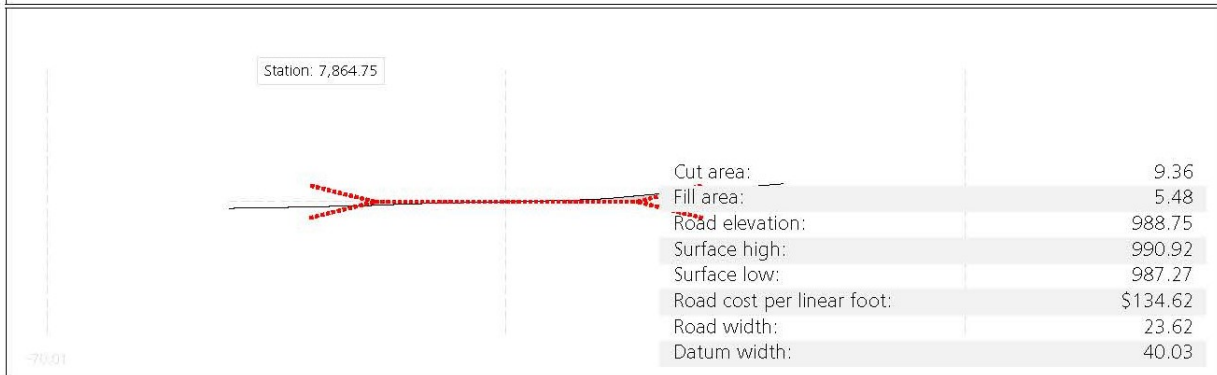
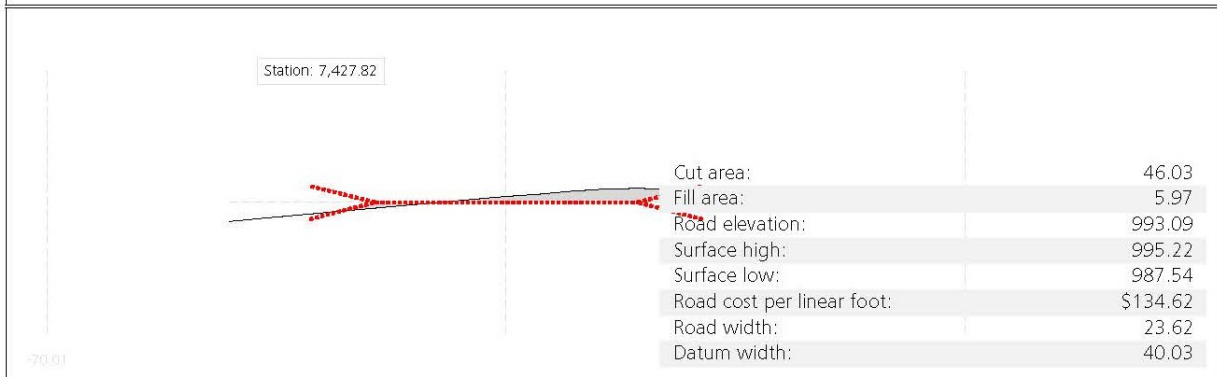
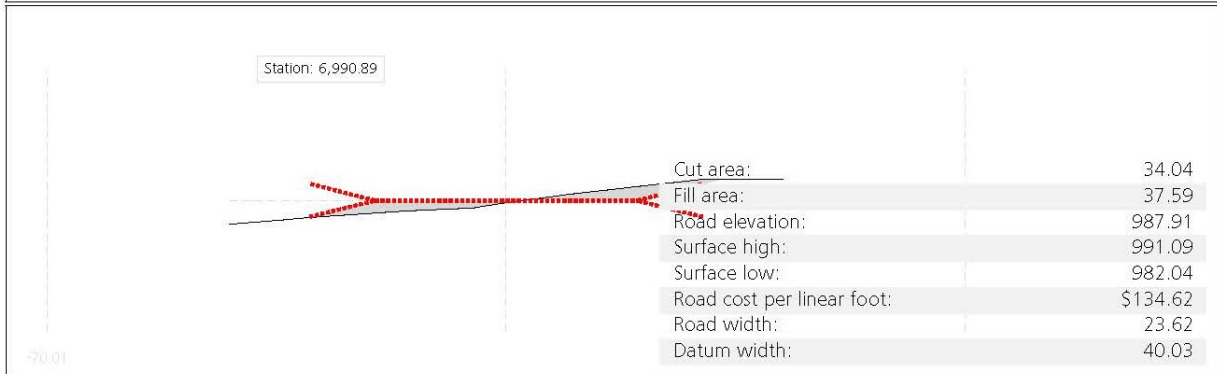
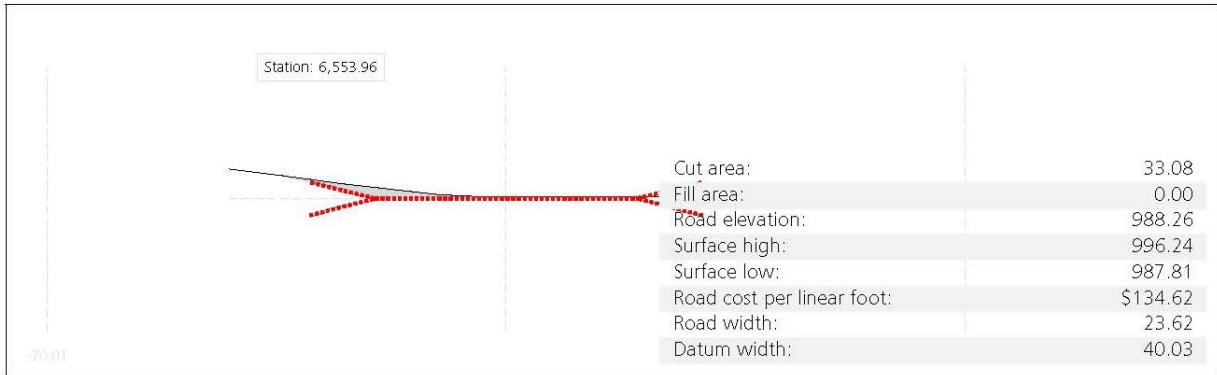
4.1.2. Hauling Scheme for strata layer 1.

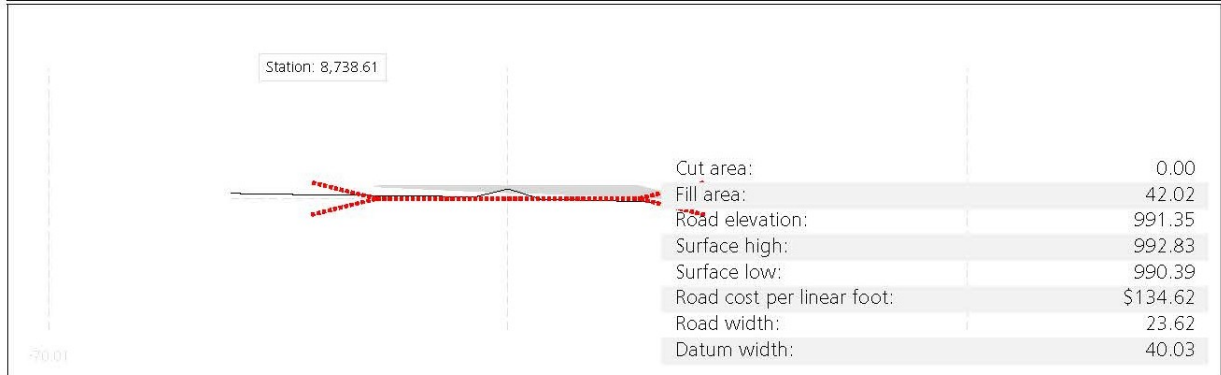
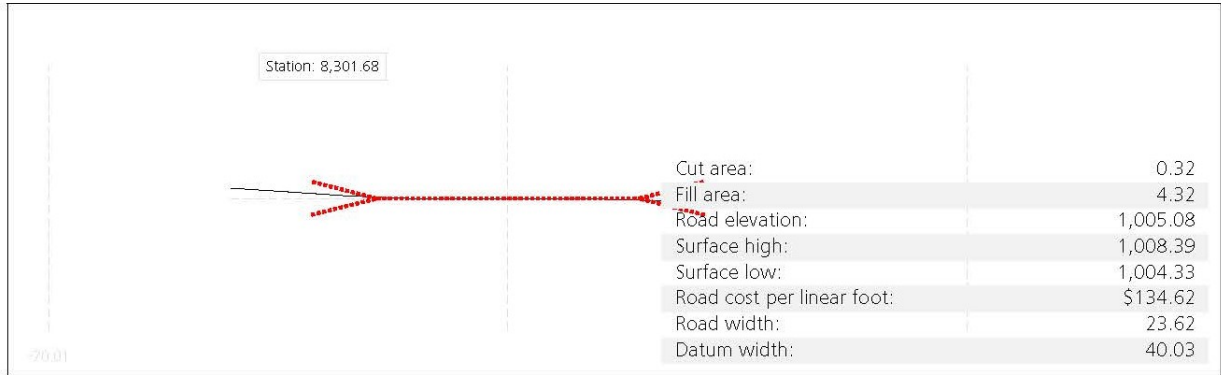












5. VOLUME REPORT

Station:	Cut area: (ft ²)	Cut vol: (yd ³)	Fill area: (ft ²)	Fill vol. (yd ³)	Cum. cut: (yd ³)	Cum. fill: (yd ³)	Cum. net: (yd ³)
0.00	9.58	0.00	9.22	0.00	0.00	0.00	0.00
436.93	8.63	32.44	33.17	2,578.67	32.44	2,578.67	-2,546.22
873.86	17.75	810.07	26.97	78.60	842.51	2,657.26	-1,814.76
1,310.79	2.37	421.31	40.29	1,170.88	1,263.81	3,828.15	-2,564.33
1,747.72	35.89	141.07	31.76	237.32	1,404.89	4,065.47	-2,660.58
2,184.65	89.29	750.32	0.00	281.40	2,155.20	4,346.87	-2,191.67
2,621.58	3.67	369.46	14.86	148.22	2,524.66	4,495.09	-1,970.43
3,058.51	10.47	81.37	3.40	556.51	2,606.03	5,051.61	-2,445.57
3,495.44	0.06	74.02	152.47	548.11	2,680.05	5,599.71	-2,919.66
3,932.37	144.60	1,481.33	1.92	324.90	4,161.39	5,924.62	-1,763.23
4,369.30	0.00	6,743.36	945.35	3,026.18	10,904.74	8,950.79	1,953.95
4,806.23	0.00	0.00	43.64	7,279.95	10,904.74	16,230.74	-5,326.00
5,243.16	63.24	1,861.08	4.21	65.82	12,765.82	16,296.56	-3,530.73
5,680.09	8.41	564.16	25.88	285.43	13,329.98	16,581.99	-3,252.01
6,117.03	7.38	250.03	56.03	260.60	13,580.01	16,842.58	-3,262.57
6,553.96	33.08	514.42	0.00	327.01	14,094.43	17,169.59	-3,075.16
6,990.89	34.04	522.43	37.59	51.57	14,616.86	17,221.17	-2,604.31
7,427.82	46.03	570.25	5.97	520.59	15,187.11	17,741.76	-2,554.64
7,864.75	9.36	361.61	5.48	400.34	15,548.72	18,142.09	-2,593.37
8,301.68	0.32	180.44	4.32	121.72	15,729.16	18,263.81	-2,534.65
8,738.61	12.99	310.37	5.25	296.86	16,039.53	18,560.67	-2,521.14

6. SURFACE INFORMATION

Name:	N/A	Planar unit:	foot
Surface width:	295	Horizontal resolution:	32.81
Surface height:	137	Vertical resolution:	32.81
Coordinate system:	UTM84-15N	Elevation unit:	foot
SW Corner (Long, Lat):	445,922.563319, 4,963,604.567829	Minimum elevation:	946.26
NE Corner (Long, Lat):	448,872.563319, 4,964,974.567829	Maximum elevation:	1,050.98

7. LIST OF PI/CURVES

PI	Longitude	Latitude	Radius
*1	448,435.397449	4,963,772.6794	0.00
2	448,238.737757	4,963,816.2839	774.07
*3	448,117.843285	4,963,847.3255	859.25
4	447,889.682098	4,963,922.0757	1,048.45
*5	447,751.211108	4,964,013.0224	651.23
6	447,603.582542	4,964,063.0782	837.83
7	447,495.556047	4,964,119.8057	773.01

PI	Longitude	Latitude	Radius
*8	447,336.384472	4,964,199.5104	443.44
*9	447,094.070662	4,964,388.4597	576.94
10	446,808.764988	4,964,463.4580	807.26
11	446,634.160724	4,964,567.5441	755.58
12	446,449.105007	4,964,653.3930	751.74
13	446,182.275564	4,964,717.4076	988.78
*14	445,992.182911	4,964,757.2462	0.00

8. LIST OF PVI'S

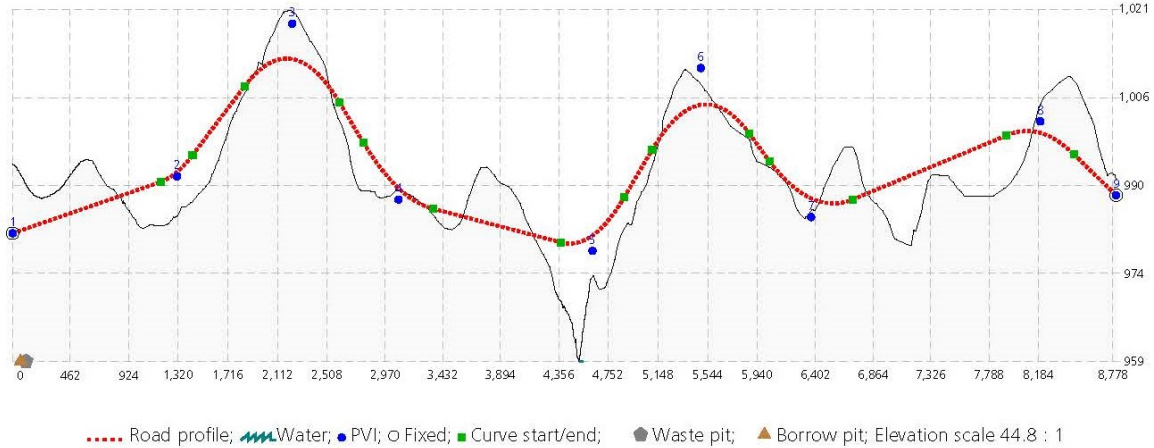
PVI	Station	Elevation	Curve length
*1	0.00	994.59	0.00
2	177.55	990.01	159.80
3	648.02	993.55	202.38
4	986.64	986.23	250.07
5	1,568.19	997.32	203.10
6	1,857.25	1,011.63	180.08
7	2,229.91	1,024.05	287.48
8	2,910.36	990.52	341.63
9	3,468.29	984.08	278.50
10	3,850.52	996.62	242.06
11	4,134.68	983.57	151.15
12	4,326.22	979.96	136.19
13	4,534.24	975.25	187.22

PVI	Station	Elevation	Curve length
14	4,850.68	980.42	210.93
15	5,379.19	1,004.14	259.06
16	5,752.27	997.43	217.89
17	6,194.75	983.98	300.71
18	6,682.78	989.80	266.55
19	7,164.00	986.84	199.41
20	7,391.90	994.64	191.41
21	7,695.55	986.42	219.47
22	7,965.47	990.13	207.60
23	8,268.04	1,005.16	141.40
24	8,435.64	1,005.85	150.85
*25	8,738.61	991.35	0.00

9. LEGAL REMINDER

All data and data files contained in the Corridor Optimization Results are created as a result of your use of Corridor Optimization for InfraWorks and are subject to the Autodesk InfraWorks Software License Agreement and the Autodesk 360 Terms of Service you accepted prior to your use of Corridor Optimization.

**APPENDIX F:
VERTICAL PROFILE OPTIMIZATION REPORT**



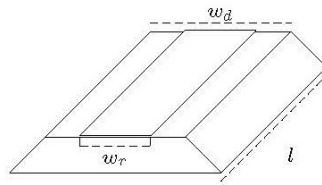
1. PROFILE INFORMATION

Total project cost:	\$1,973,731	Number of PVI's:	9
Linear unit:	foot	Maximum grade:	5.00 %
Design speed:	55	Required drainage grade:	0.00 %
Length:	8,805.16	Minimum PVI spacing:	600.00

2. CONSTRUCTION INFORMATION

Total construction cost: ¹	\$1,196,688	Use bridges:	No
Number of bridges:	0	Use tunnels:	No
Number of tunnels:	0	Sample line distance:	50.00
Number of retainings:	0		

2.1. **Road Assembly Information.** The construction cost for a sample line subsection with a road assembly is l times the road cost per linear unit.



l : Sample line distance
 w_r : Road width
 w_d : Datum width

Road cost per linear foot: ²	\$135.82	Daylight cut slope:	0.50
Road width: ³	24.00	Daylight fill slope:	0.50
Datum width:	99.64		

¹The construction costs are computed at every sample line, using a selected assembly or style, and a sample line distance for the length of a construction subsection. Individual cost computations for the different assemblies are explained below. The total construction cost is the sum of the individual subsection costs.

²The road cost per linear unit is $w_r \cdot (0.3 \cdot C + 0.7 \cdot A) + D + S + L + G$, where C is the cement pavement cost per square unit, A is the asphalt pavement cost per square unit, D is the cost for drainage, S for signing, L for lighting, and G for signaling per linear unit.

³The road width is the number of road lanes multiplied by the width of a road lane. It does not include the width of medians, sidewalks, etc.

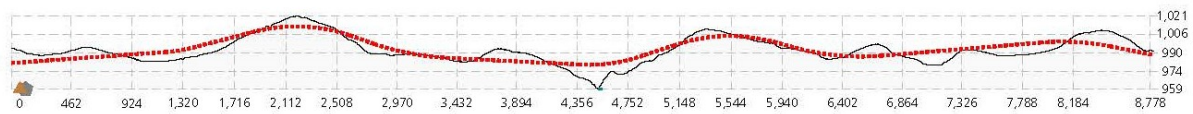
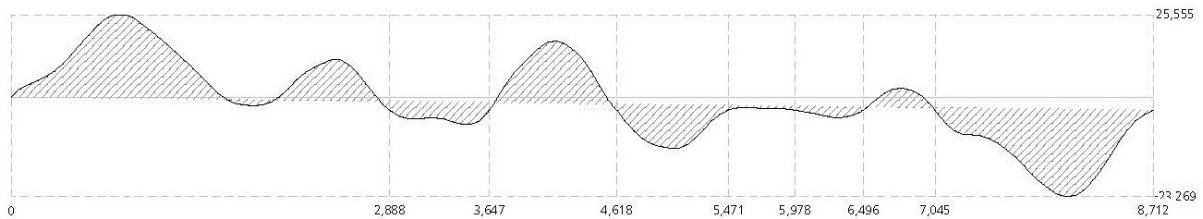
3. EARTHWORK INFORMATION

Total earthwork cost:	\$777,044	Max section length:	594.00
Num earthwork sections:	20	Num waste pits:	1
Num earthwork sub-sections:	133	Num borrow pits:	1
Num. stratum:	1	Swath width:	116.60

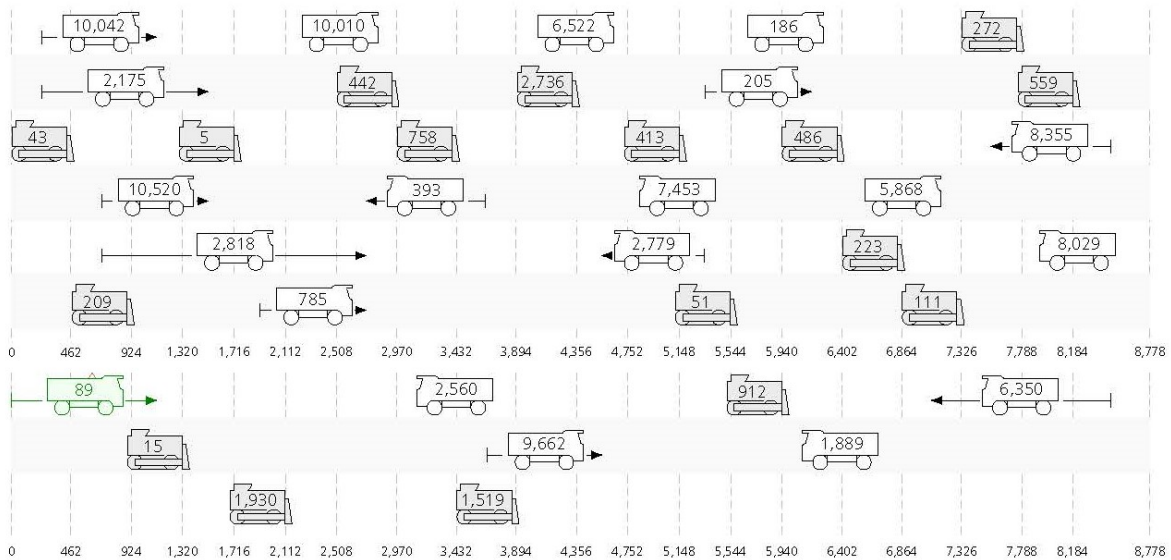
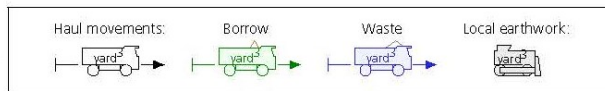
3.1. Earthwork for Strata Layer 1.

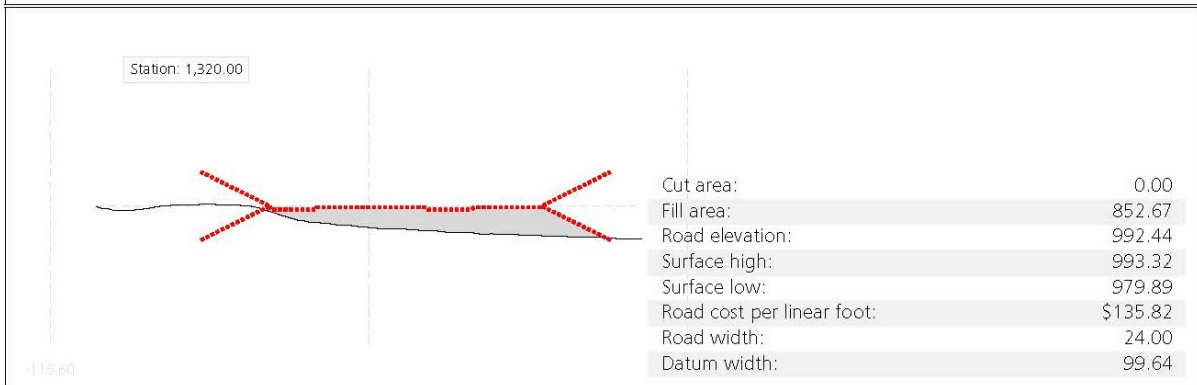
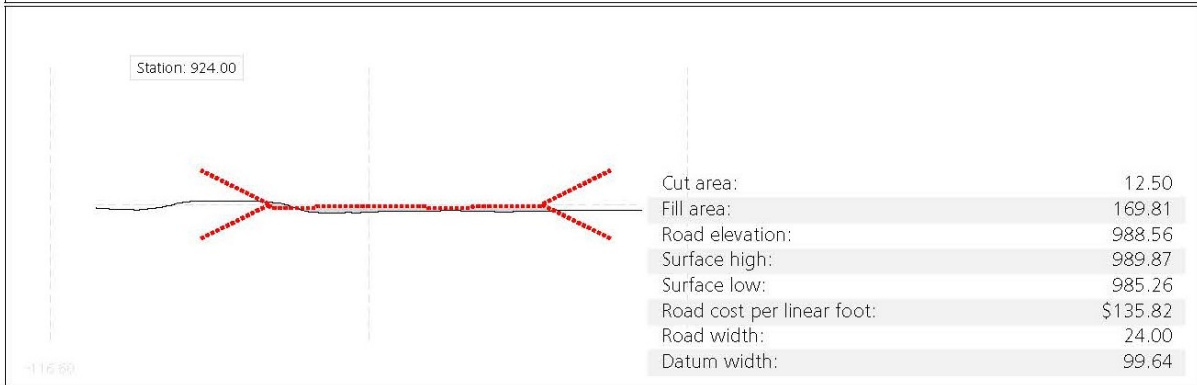
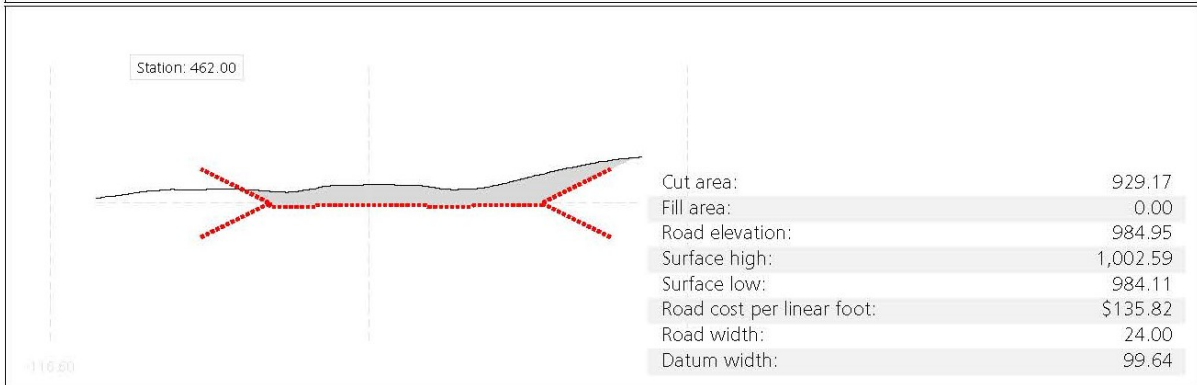
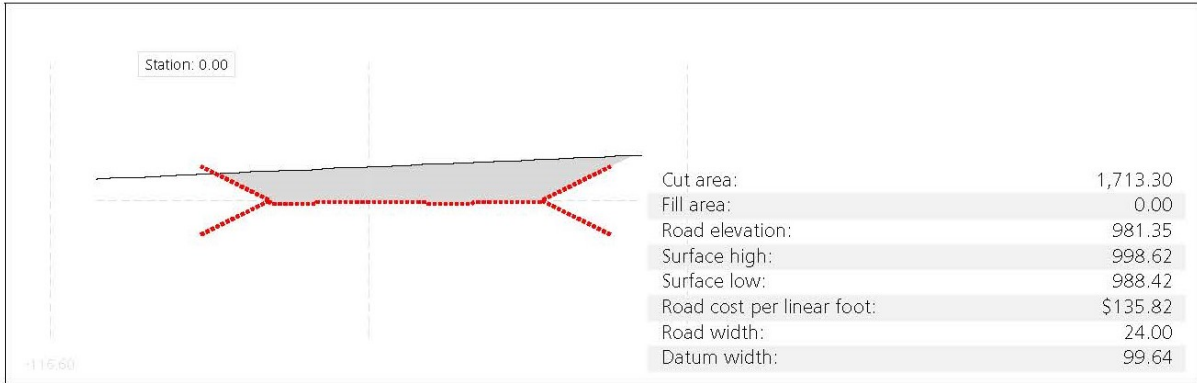
Cum. cut:	107,288.19	Excavation cost:	\$2.34
Cum. fill:	107,377.61	Load cost:	\$1.43
Net volume:	-89.42	Haul cost (per mile):	\$1.84
Volume unit:	cubic yard	Embankment cost:	\$3.37
Layer name:		Waste cost:	\$.75
Reusability factor:	1.00	Borrow cost:	\$2.10

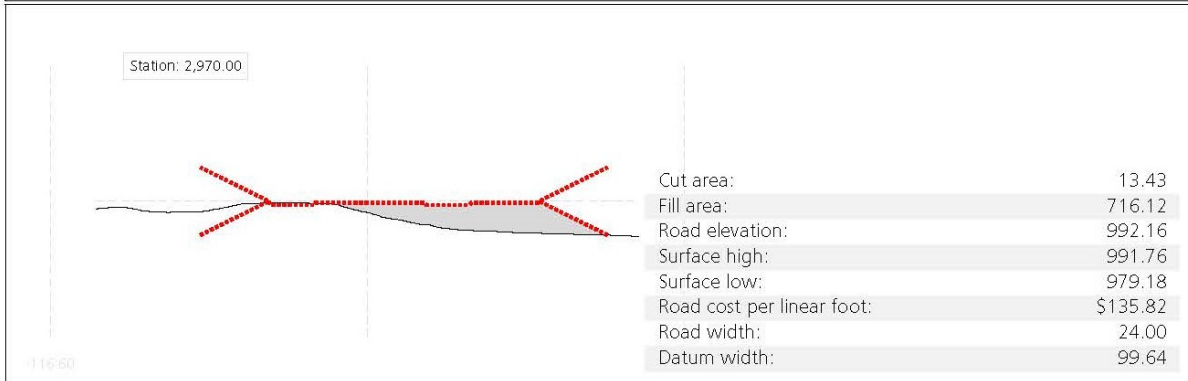
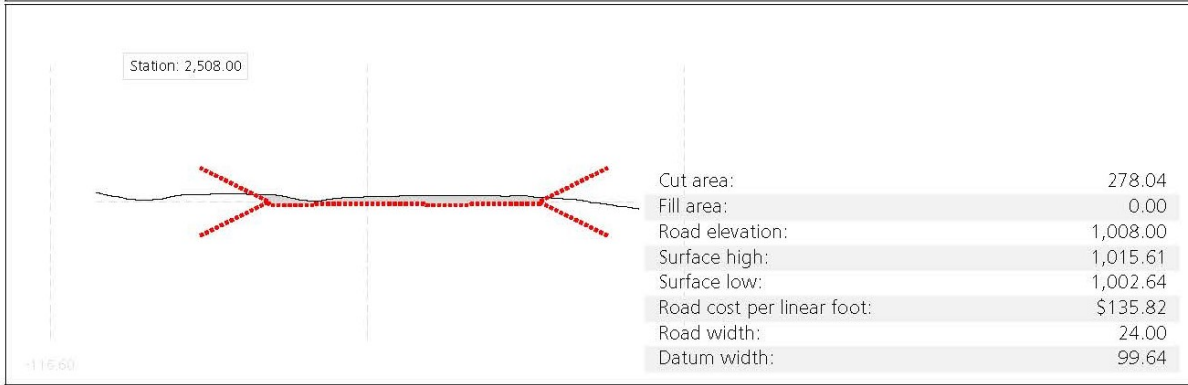
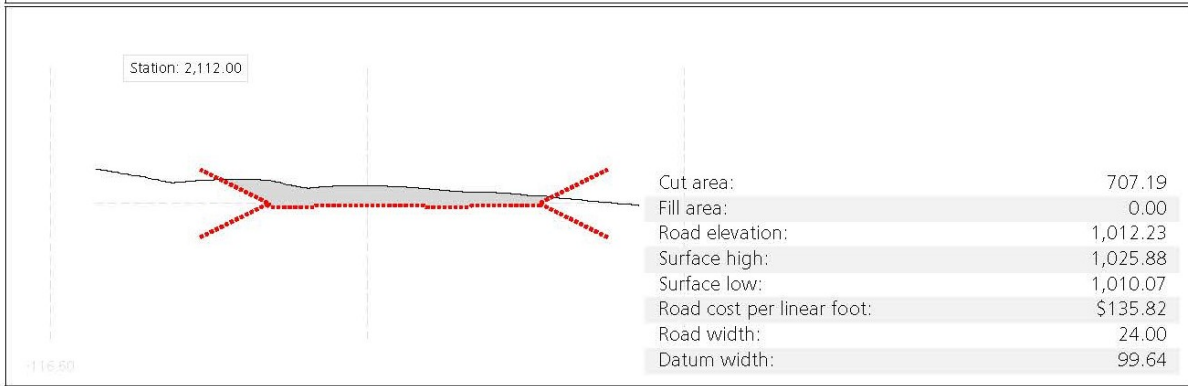
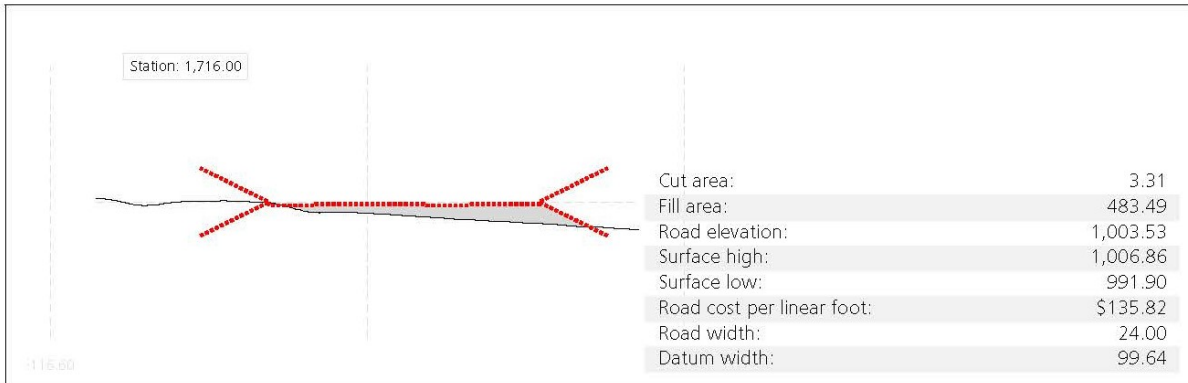
3.1.1. Mass diagram for strata layer 1.

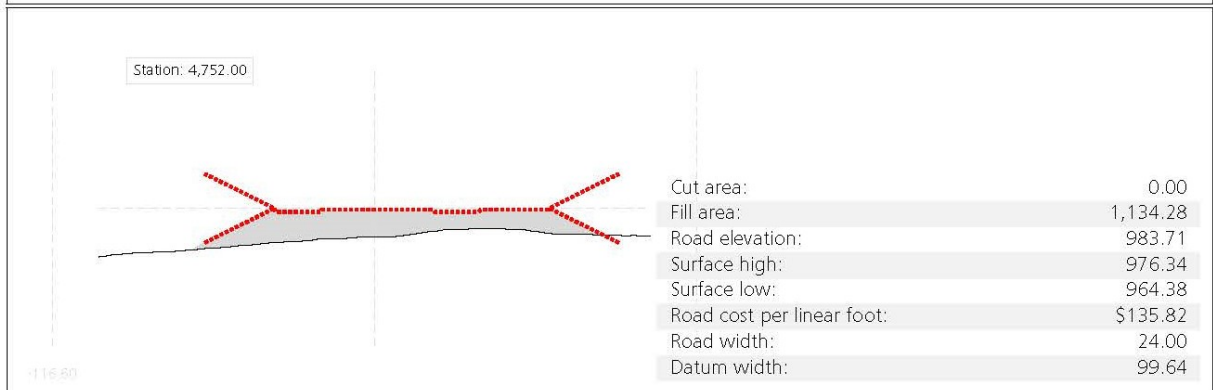
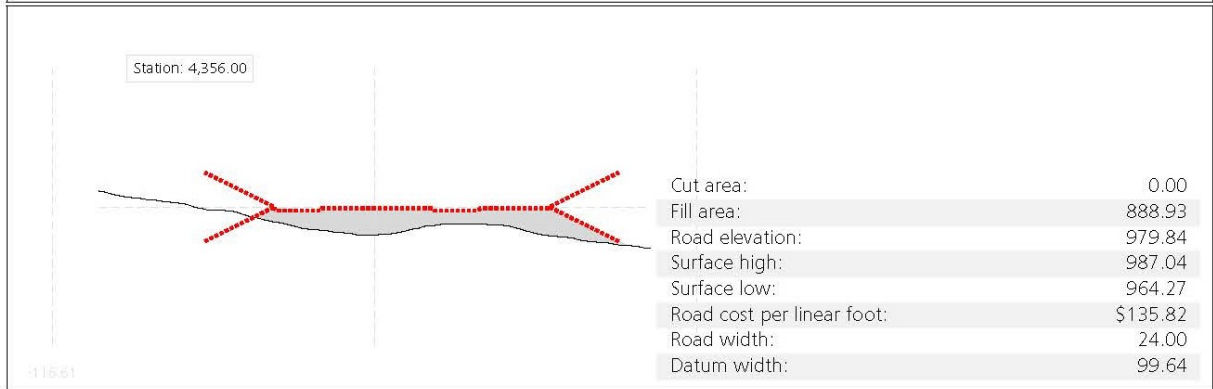
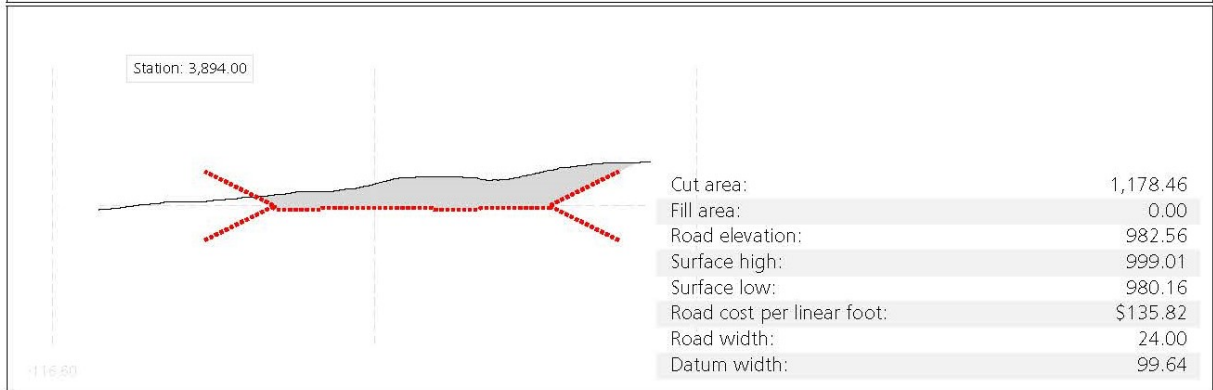
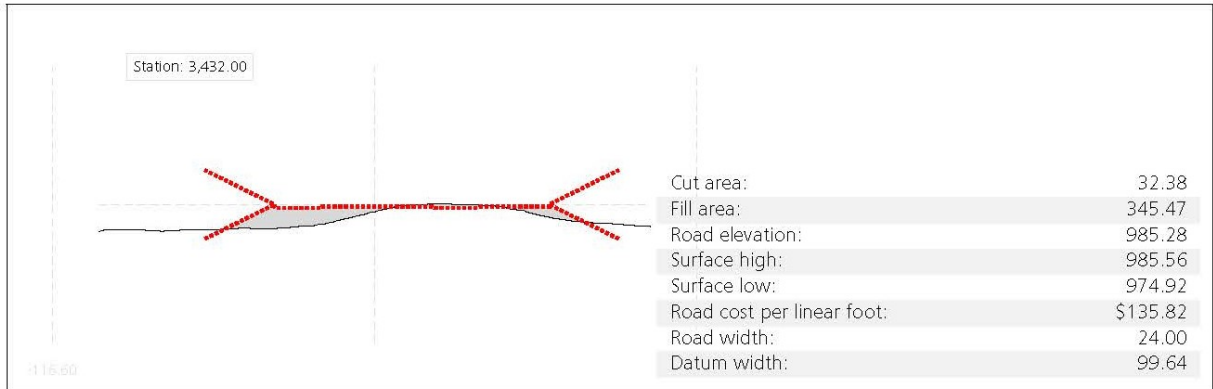


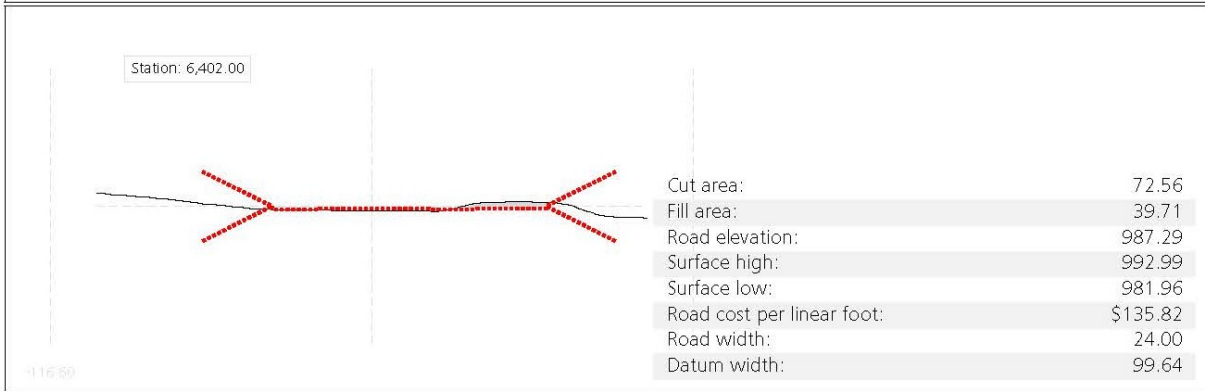
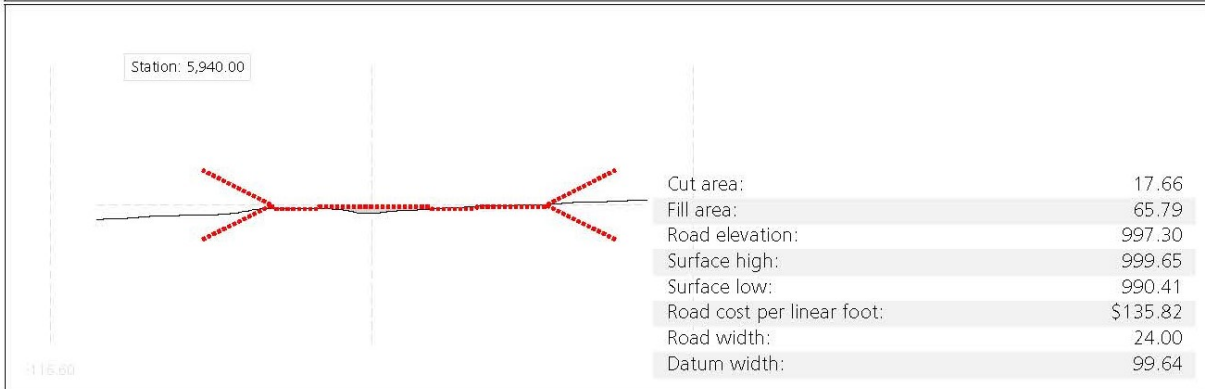
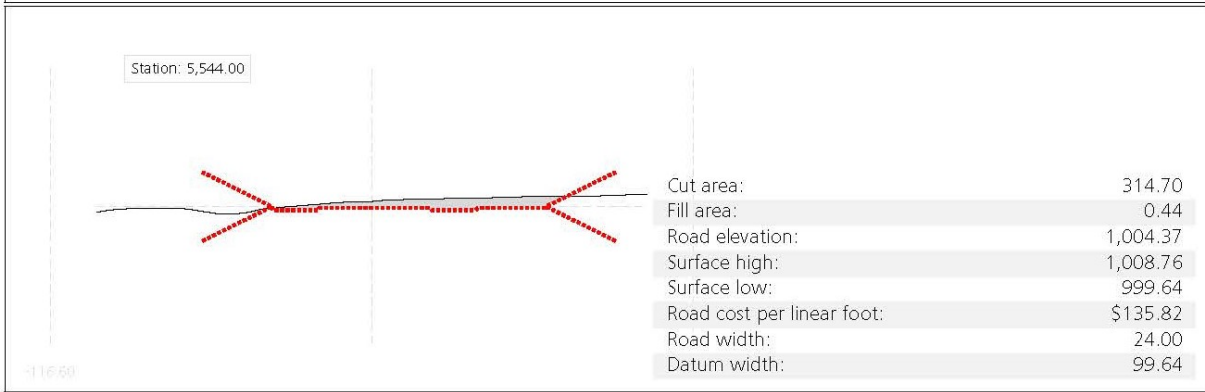
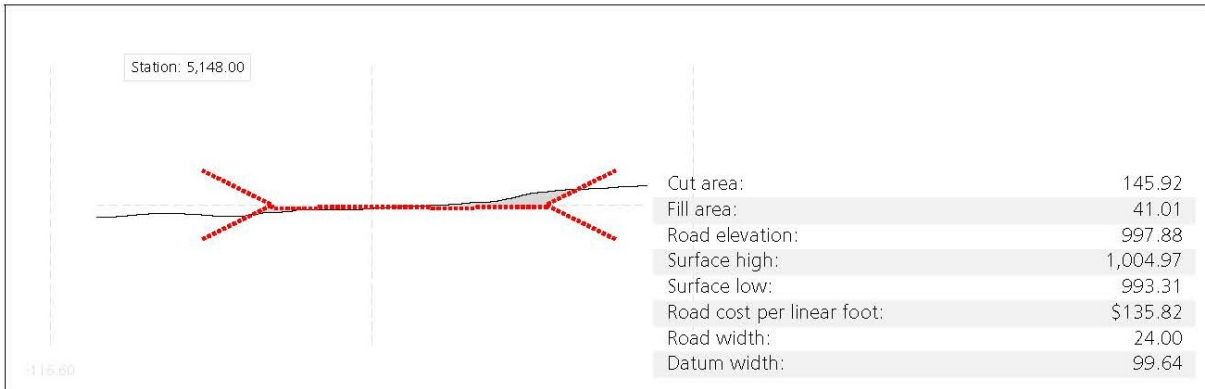
3.1.2. Hauling Scheme for strata layer 1.

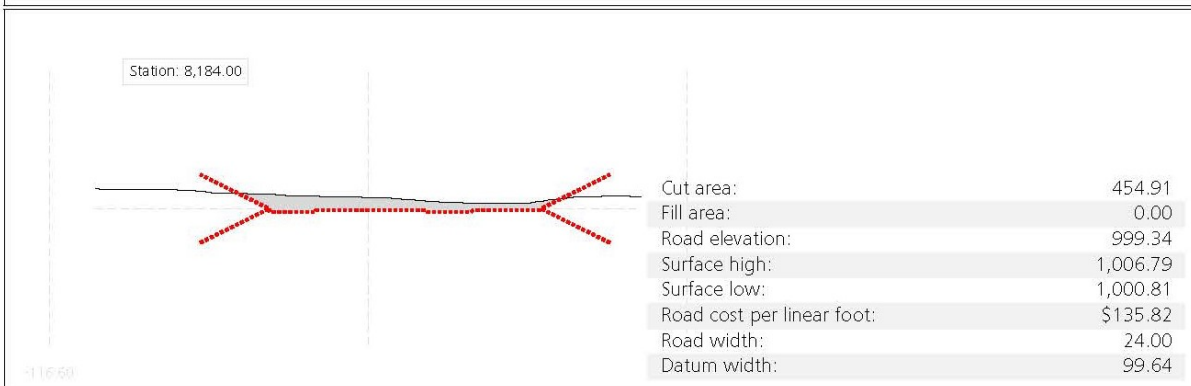
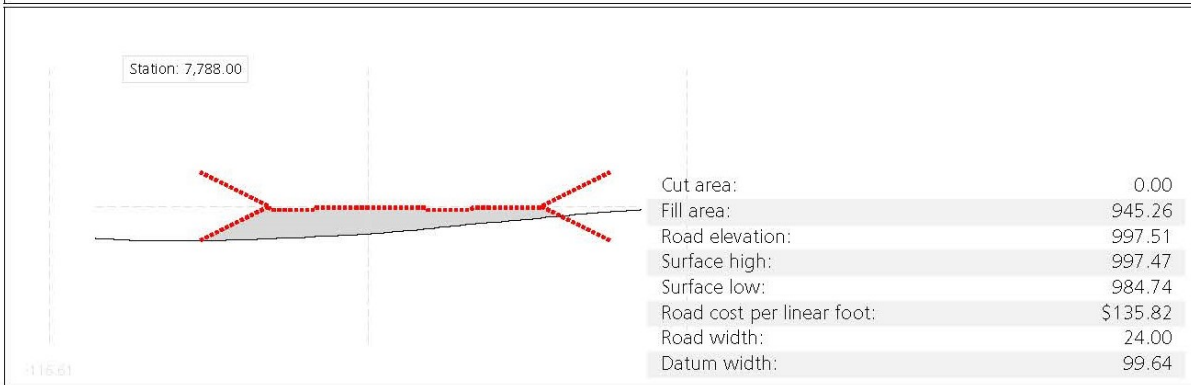
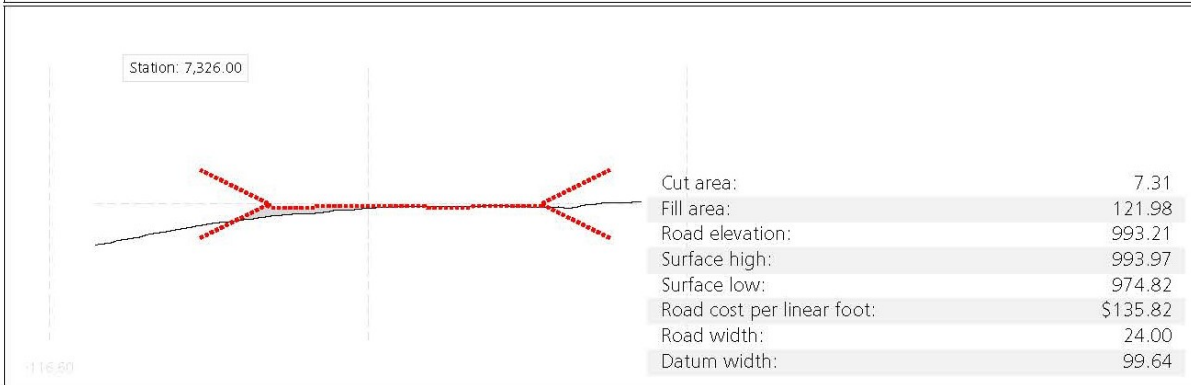
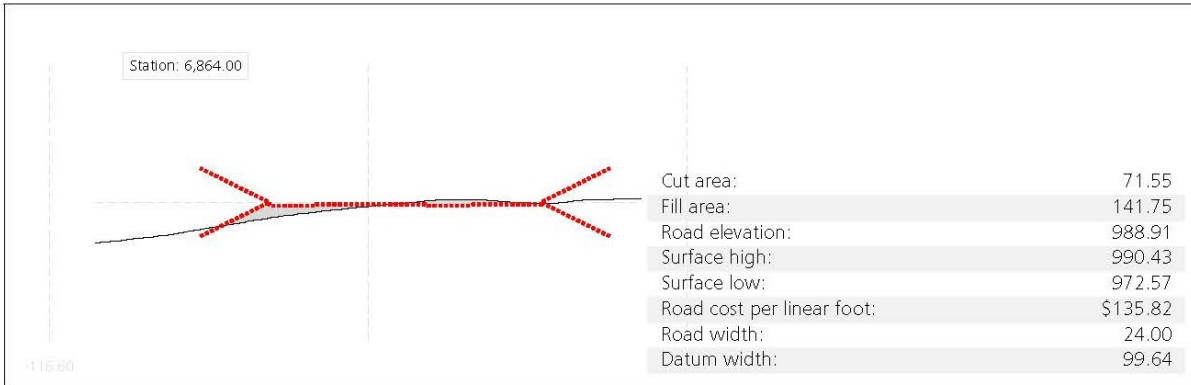


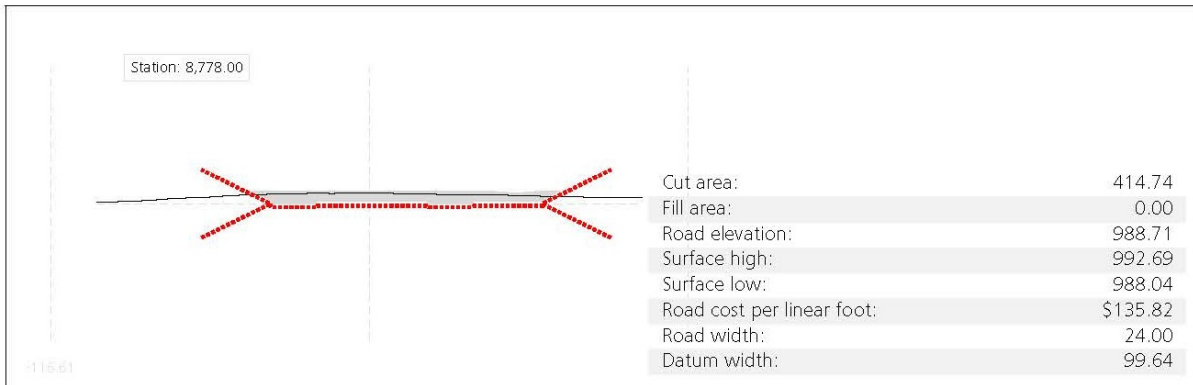












4. VOLUME REPORT

Station:	Cut area: (ft ²)	Cut vol: (yd ³)	Fill area: (ft ²)	Fill vol. (yd ³)	Cum. cut: (yd ³)	Cum. fill: (yd ³)	Cum. net: (yd ³)
0.00	1,713.30	0.00	0.00	0.00	0.00	0.00	0.00
462.00	929.17	12,260.76	0.00	43.41	12,260.76	43.41	12,217.35
924.00	12.50	13,546.86	169.81	209.07	25,807.62	252.48	25,555.14
1,320.00	0.00	15.28	852.67	10,146.96	25,822.90	10,399.45	15,423.46
1,716.00	3.31	4.63	483.49	12,699.52	25,827.53	23,098.97	2,728.56
2,112.00	707.19	2,714.83	0.00	1,930.33	28,542.36	25,029.30	3,513.06
2,508.00	278.04	10,010.03	0.00	0.00	38,552.40	25,029.30	13,523.10
2,970.00	13.43	442.12	716.12	14,447.50	38,994.52	39,476.80	-482.29
3,432.00	32.38	758.46	345.47	3,318.04	39,752.98	42,794.84	-3,041.87
3,894.00	1,178.46	14,134.21	0.00	1,519.30	53,887.18	44,314.14	9,573.04
4,356.00	0.00	9,258.10	888.93	2,736.09	63,145.28	47,050.23	16,095.05
4,752.00	0.00	0.00	1,134.28	18,963.89	63,145.28	66,014.12	-2,868.84
5,148.00	145.92	412.94	41.01	7,866.14	63,558.23	73,880.26	-10,322.03
5,544.00	314.70	10,488.00	0.44	50.66	74,046.22	73,930.91	115.31
5,940.00	17.66	1,098.18	65.79	912.12	75,144.40	74,843.04	301.37
6,402.00	72.56	485.97	39.71	2,765.97	75,630.37	77,609.01	-1,978.64
6,864.00	71.55	7,981.02	141.75	223.36	83,611.40	77,832.37	5,779.03
7,326.00	7.31	111.42	121.98	12,330.18	83,722.82	90,162.54	-6,439.72
7,788.00	0.00	272.18	945.26	8,627.15	83,995.00	98,789.69	-14,794.69
8,184.00	454.91	559.16	0.00	8,587.92	84,554.16	107,377.61	-22,823.45
8,778.00	461.52	22,734.02	0.00	0.00	107,288.19	107,377.61	-89.42

5. LIST OF PVI'S

PVI	Station	Elevation	Curve length
*1	0.00	981.35	0.00
2	1,310.73	991.58	251.34
3	2,230.99	1,018.71	758.99
4	3,078.08	987.36	554.15
5	4,625.42	978.25	503.87

PVI	Station	Elevation	Curve length
6	5,489.14	1,010.84	773.88
7	6,372.01	984.33	659.16
8	8,200.73	1,001.35	539.57
*9	8,805.16	988.11	0.00

6. LEGAL REMINDER

All data and data files contained in the Profile Optimization Results are created as a result of your use of Profile Optimization for InfraWorks and are subject to the Autodesk InfraWorks Software License Agreement and the Autodesk 360 Terms of Service you accepted prior to your use of Profile Optimization.

**APPENDIX G:
PROJECT BENEFITS (ROI)**

0-30% Project Benefits - Preliminary Transportation Design BIM

<u>Chapter</u>	<u>Potential Value Process</u>	<u>Qualitative</u>	<u>Quantitative</u>
1 – Role of Project Controls and BIMxp (Planning Stage)	BIMxp fosters understanding and purpose early in the project life cycle	X	
	BIMxp creates a framework for success and to obtain benefits and manage (reduce) risk	X	
	Coordination with project controls scheduling early in project creates efficient workflows including BIM process milestones (clash, design review, visualization, other)		X
	Synchronizing design model layers into groups that correlate with typical construction processes, makes 4D very affordable, more plug and play		X
2 – Reality Capture (Survey/Data Collection)	For same overall level of effort as traditional survey, a significant increase in data is collected		X
	Potential for reduced staff time required for collection of data		X
	Multiple file formats available once data is processed, allowing flexible use of data for alternative needs	X	
	Overall accuracy levels of UAV terrain data is comparable to traditional survey methods		X
	Up-to-date aerial imagery is byproduct deliverable		X
	Provides immediate context for design	X	

3 – GIS in 3D (Preliminary Design)	Model <i>Builder</i> tool provides quick and easy access to free, open-source GIS data for rapid base map development		X
	Fully coordinate system aware database	X	
	Model Explorer, Bookmarks, and Tooltips tools provide GIS like functionality and ease of use benefits provides GIS-like ability to create overlay hierarchies, stylization, visibility display options (usability)	X	
	Imports some point cloud data (if first processed by Autodesk RECAP)		X
	First BIM software able to process large-extent, high-resolution GIS terrain and imagery via database caching technology		X
	Provides 3D GIS context with sense of place to planning and design	X	
	Hypsometric shading and light spatial analysis for elevation datasets	X	X
	Impressive CAD and GIS data interoperability		X
	Watershed analysis functionality ties to engineering drainage network functions of Infracore	X	
	Ease-of-use breaks down data and workflow siloes found in traditional infrastructure project processes, providing a single source of truth (model) improving project communication, data interpretation, accelerating schedules, and reducing potential for human-caused error	X	X
4 - 3D Decision Support (Generative Route Optimization)	Repetitive work-tasks becoming automated		X
	Interface mimics design thought process of engineer	X	
	Rapid creation and comparison of multiple alternatives with quantities		X
	Automatic report generation is cost effective approach supporting informed decision-making and releasing engineers from repetitive material generation		X
	Design engineers will be released from redundant and potentially error prone processes and empowered with different types of design roles		X

	Suitability map weighting schemes provide flexibility for establishing priorities	X	X
	Adds cumulative value to Common Data Model approach	X	
	Accelerated alternatives development (accelerated schedule = reduction of cost)		X
5 - Advanced 3D Preliminary Design for Accelerated Alternatives (Generative Profile Optimization)	Time required to optimize road profiles appears to be reduced by ~8 hours or more vs traditional method		X
	Preliminary costs and quantities are semi-automatically generated along with profile optimizations, allowing rapid quantitative comparison of alternatives		X
	Semi-automation releases engineering staff from repetitive work tasks		X
	Off-loading of computationally heavy tasks to the cloud could ease IT budgets and provide design engineering opportunities using more ubiquitous hardware		X
	Available 3D profile reduces visualization costs, facilitates discussion, decision-making and consensus		X
6 - Data Interoperability (CAD/BIM/GIS)	Autodesk Connector for ArcGIS removes spatial data-access limitations imposed by the Model Builder module. Ease of access to vast amounts of GIS data into InfraWorks enriches the planning and design process while eliminating traditional disciplinary barriers	X	X
	Support for many common industry standard Geo-database formats		
	User-friendly import, data configuration and multiple option display formatting process	X	X
	Direct Import of some point cloud data from LIDAR and Photogrammetry		X
	Exports to 3D formats that can be consumed by Sketchup, 3DS Max, Maya, Rhino, or other 3D visualization modeling software		X
	Imports LandXML and good 2D/3D Microstation DGN support	X	X

	Imports other BIM formats (open source IFC, and Autodesk REVIT)	X	X
	Imports Sketchup to expand internal visualization and design	X	X
	Demonstrates the industry trend of continued convergence between GIS, CADD, and BIM	X	
	Eliminates unwieldy GIS to CADD or CADD to GIS processes		X
	Ease of use breaks down data and workflow silo's found in traditional infrastructure project processes, improving project communication, data interpretation, accelerating schedules, and reducing potential for human-caused error	X	X

**APPENDIX H:
PRELIMINARY DESIGN NEXT STEPS**

Potential Preliminary Design Next Steps

Chapter 1 Project Controls and BIMxp

1. Organize local user groups.
2. Develop educational campaign and materials to engage counties and cities in Minnesota.
3. Develop standards and processes that can work for a wide variety of agencies.
4. Tie these preliminary design study findings to final design and construction process research studies to map out a complete transportation project life cycle.
5. Generate additional pilot projects with cities and counties with different sizes and types of projects and leverage lessons learned from this initial pilot project.
6. Develop Decision Support System matrix that helps owners determine projects that are “best fit” for BIM technology adoption.
7. Learn from successes and errors by reaching out to early adopters of BIM for infrastructure in other states.
8. Develop solid Key Performance Indicators (KPIs) and quantitative measures to track value.
9. Gather and study transportation BIMxp’s made available by states, counties, and cities that adopt BIM for infrastructure.
10. Conduct additional research on Work Break-Down structure and differences between traditional projects versus BIM projects.
11. Research and document ramifications of contract mechanisms on BIM roles and responsibilities.
12. Identify Best Practices to move the civil engineering design community forward; identify weak areas in BIM for infrastructure execution plan templates.
13. Work with vendors.

Chapter 2 Reality Capture/Survey Methods

1. Introduce software and documented methodology to local user groups
2. Research, develop, and document best practices for efficient Mapping to-BIM/CAD workflows.
3. Research metrics further for other means of survey collection (for instance, static and mobile LiDAR) to devices develop a toolkit to best select options for individual case studies.

Chapter 3 GIS Integration

1. Introduce software and documented methodology to local user groups.
2. Research using advanced data queries and scripting to expose context of key data attributes.
3. Research comparison of watershed calculation tool benefits/limitations vs traditional GIS-centric watershed analysis tools.
4. Research, develop, and document best practices for efficient GIS-to-BIM workflows.
5. Engage with Infracore Sandbox (beta) testing program and provide feedback to Autodesk.

Chapter 4 Corridor Optimization (Decision Support)

1. Develop standardized inputs to Corridor Optimization that work for a variety of jurisdictions.
2. Develop BIMxp section outlines to set expectations and assumptions for KBS tools such as Corridor Optimization.
3. This research scope of work does not account for deep dive into this tool. The lack of documentation or evidence of real-world practicality and accuracy contrasted by the inference of significant potential value to optimize the design alternatives process warrant future research projects specifically in this area of decision support systems.
4. Tie these preliminary design study findings to final design and construction process research studies to map out a complete transportation project life cycle.
5. Conduct additional pilot projects with cities and counties on projects of different sizes and types to contrast and compare Corridor Optimization results.
6. Organize local user groups.
7. Learn from successes and errors by reaching out to early adopters using this module on projects in other states or jurisdictions.
8. Develop solid Key Performance Indicators (KPIs) and quantitative measures to track value of the Corridor Optimization module vs traditional methods.
9. Identify Best Practices to move the civil engineering design community forward.
10. Work with vendors on new iterations of the module.

Chapter 5 Vertical Profile Optimization

1. Continued research testing to push module limits to gain better understanding.
2. In-depth examination and use of the Profile Optimization module on actual pilot projects to contrast and compare with traditional methods.
3. Initial tests utilized main road profile with no intersections; future tests should incrementally add more geometry such as main intersections or local resident access roads with corresponding turn-lanes.
4. Work with Autodesk to better understand background algorithm constraints and identify future abilities to customize to meet unique client specifications.
5. Develop standardized parameters and data entry for different types of road projects, and (for example) projects that include roundabouts
6. Interoperability of optimized profiles with other packages for QAQC and data re-purposing.
7. Best Practices Documentation for Cities and Counties adopting the technology and workflows.

Chapter 6 Data and Software Interoperability

1. Conduct thorough testing and review of the Autodesk ArcGIS Online Connector.
2. Study of metadata flow through project life cycles, from preliminary design (preferred alternative), through construction, and into operations and maintenance.
3. Study of interoperability requirements for middleware packages that facilitate valuable BIM uses (such as clash detection or 4D).

4. Investigate contractor needs and examine interoperability from there backwards into life cycle to better understand end goals. Examples of this should include:
 - a. In-depth documentation on Trimble Business Center (TBC), and identification of valuable attribute information that should be carried through life cycle into TBC and beyond.
 - b. In-depth documentation of TOPCON (or other common construction software package) requirements.
5. Identify Best Practices that support moving the local roads civil engineering design community forward; identify workarounds to overcome limitations.
6. More work to understand and resolve or develop automated workarounds for Civil3D to InfraWorks assemblies' translation issues.
7. Further engagement in InfraWorks Sandbox (beta) testing program; provide vendor feedback.
8. Create local user groups for advancing preliminary design BIM.
9. Research task to examine AASHTOWare project data requirements and interoperability roadmap; interface with AASHTOWare working group.

Chapter 7 Return on Investment

1. Drive deeper engagement with BIM, which correlates directly with better ROI. Identify pilot projects to measure ROI. Pilot projects need to be carefully selected to capture the benefits and costs associated with predefined categories. The first step is to define pilot project selection criteria. Then, a range of potential baseline and initiative pilot projects should be identified. The best combination of baseline and initiative pilot projects can then be studied to capture the benefits and costs. The degree to which the project team supports the ROI process is an important project selection criterion, as their cooperation will be needed to collect the data.
2. Develop Standardized Key Performance Indicators
3. Initiative a change management plan conducive to BIM principles
 - a. New process adaptation
 - b. Lean management approach
 - c. Use of common data environment
 - d. Workforce training and education
4. Examine a variety of existing ROI mechanisms to determine "best-fit" for potential modification and adoption by the transportation industry. Examples could be modification of the Stanford VDC scorecard or other methodology to make it work for transportation.
5. Other areas of potential study:
 - a. Ability to influence project costs
 - b. Presumed benefits to project life cycle
 - c. Development of potential qualitative vs. quantitative measures
 - d. Reducing data collection and storage through model and information sharing
 - e. Compilation of benefits from previous tasks
 - f. Life-cycle assessments