TECHBRIEF

U.S. Department of Transportation
Federal Highway Administration

3D Engineered Models for Construction

UNDERSTANDING THE BENEFITS OF 3D MODELING IN CONSTRUCTION: THE WISCONSIN CASE STUDY

ABSTRACT

To evaluate the benefits of three-dimensional (3D) design data, the Wisconsin Department of Transportation (WisDOT) calculated the return on investment (ROI) for several components of a reconstruction project. The metric showed an improved efficiency in dirt-moving operations and a greater cost savings during construction of other components such as general structures, drainage, and bridges with general use of models for 3D roadway projects.

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Introduction

Transportation agencies have used three-dimensional (3D) modeling in building construction (also known as "Building Information Modeling" [BIM]) effectively for many years. In BIM applications, designers are able to identify early in the process potential construction issues, such as clashes in future piping, wiring, and HVAC ductwork.

In recent years, transportation agencies have started to plan and design roads in 3D because they understand the possible benefits that 3D models offer in construction. The benefits include improved productivity of operations and worker safety. Using 3D models also enhance the bidding process and allow contractors to use Automated Machine Guidance (AMG) to yield higher quality and less expensive construction. Agencies may provide 3D design data to potential bidders, or contractors may develop their own models for use with AMG during construction.

The Wisconsin Department of Transportation (WisDOT) is at the forefront of the movement toward using 3D modeling in roadway construction. While many States recognize the benefits that 3D models provide in earthwork operations in road construction, WisDOT's Return on Investment (ROI) calculation, using actual project data, shows that 3D modeling can result in even more significant gains during construction of roadway structures and features. WisDOT is currently verifying early ROI projections on the Zoo Interchange Project, a freeway interchange on the west side of Milwaukee.

Engineered Models for Construction (3D modeling) can reduce construction costs during all stages of construction from excavation, earth moving, and compacting and finishing to drainage, bridges, and other features. The modeling offers savings through greater accuracy, efficiency, and reduced resource cost. 3D data not only enhances design through clash detection and better visual representation of the completed project prior to breaking ground, but it also can be used for such downstream applications as AMG.

The benefits of implementing 3D modeling include:

- Integrating several design processes together, resulting in better and faster designs at a lower cost.
- Improving engineers' inspection capabilities and enhancing quality assurance, thereby increasing efficiency and optimizing resources.

Costs

- Training Costs – WisDOT design staff must complete a 100-hour web-based training program.
- Development Costs - Staff must complete separate web-based training programs in Plans Production, Survey, R/W Plats, and Construction Administration.
- Software Costs – Purchase of software and licenses for staff is required.
- Design Office Transition Costs – Transitioning from 2D to 3D design shops may take a few years to fully complete.

CASE STUDY - ZOO INTERCHANGE, MILWAUKEE, WISCONSIN

The Zoo Interchange, located west of Milwaukee, forms the junction of I-94, I-894, and US 45. The Zoo Interchange is the busiest corridor in Wisconsin, with traffic volumes averaging 350,000 vehicles per day. The $1.7 billion project, which began in 2007 and is scheduled for completion in 2018, will implement operational, safety, and capacity improvements and reduce congestion throughout the corridor.

DESIGN MODELING: The Zoo Interchange Project makes significant use of 3D models as well as components that allow users to view schedule and cost information along with the 3D design. Time planning components for staging and scheduling are called "4D modeling." Cost information linked to the modeled structures is 5D modeling. Incorporating project life-cycle data is 6D modeling. The Zoo Interchange Project primarily uses 3D and 4D modeling. The scope and complexity of this effort makes for a variety of challenges, many of which are addressed or reduced via modeling.

DESIGN-BID-BUILD: WisDOT awarded the Zoo Interchange Project as Design-Bid-Build (DBB) contract. DBB is a relatively traditional project delivery method versus design-build or other newer methodologies. The DBB process makes the use of design documents for "Bid and Build" vital in order to accurately reflect the owner agency's priorities and be constructible and free of design clashes. Using 3D modeling can ease or even automate the process of design clash detection.

WORKFLOW AND DATA COMPATIBILITY: To achieve the potential benefits of 3D modeling, all project parties needed appropriate access to the models. This open access required a methodology and a workflow for sharing, editing, and approving the models between the owner agency, the designer(s), and the contractors. Sharing and benefitting from the models also required data interoperability between different systems.

DATA COLLECTION: Data accuracy in all three dimensions is a prerequisite for achieving all the potential benefits of 3D models. For the Zoo Interchange Project, designers used 3D LiDAR technology to survey data via an integrated survey and data fusion. Designers located and plotted underground utilities in three dimensions. After collecting 3D data, the project team integrated the staging and scheduling information for the temporary roadways and structures to create a 4D model to support maintenance of traffic.

CLASH DETECTION: Clash detection is the process for identifying physical conflicts or collisions between two elements in the model occupying the same space. This process takes place prior to construction in the field, and is also known as spatial coordination. Clash detection tools typically produce two types of results or "products" from these 3D design models: clash jobs resulting from automatically comparing the various models and visualizations of those models. A June 2012 Clash Detection Review Meeting allowed utilities on Zoo Intersection Project to identify clashes in signals, freeway traffic management systems, lighting, signing, and drainage components at 108 locations. Project designers dealt with these clashes early in the process, eliminating a significant number of contract change orders and subsequent design issue notices (DINs) during construction. Figure 1 shows screen captures from the clash detection process that compare various design standards during model development.

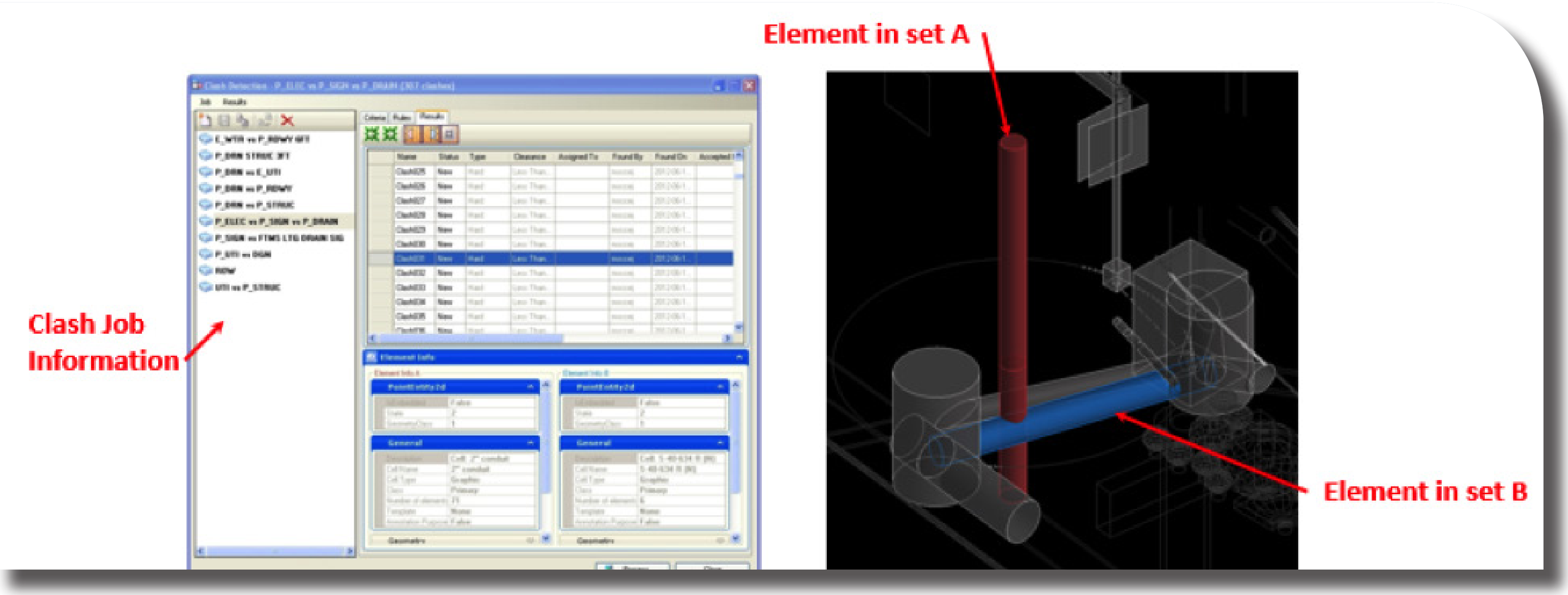

Figure 1: Screen captures from clash detection software.

BUILD FASTER AND MORE AFFORDABLY: In addition to clash detection, 3D modeling is helping WisDOT accelerate and improve the Zoo Interchange Project. It also provided better information to the public via renders and drive-through animations, as shown in Figure 2. Plans, specifications, and estimates production used 3D models, incorporating roads, structures, utilities, surfaces and sub-surfaces, signs, signals, lighting, traffic, and landscaping. The 3D AMG model informed both the bidding and construction process.

The Zoo Interchange Project Team also integrated timing components into the 3D models to create 4D models that address project schedules and plans.

OTHER OPPORTUNITI

The Zoo Interchange Project is ongoing. As the project moves forward, 3D models provide the foundation for additional benefits through the use of 4D modeling (incorporating time elements for staging and scheduling), 5D modeling (linking cost components to the modeled structures), and as the project nears completion, 6D modeling (including the as-built specs, operations and maintenance (O&M) information, and other project life cycle data).

Figure 2: Example animation from 3D model.

RETURN ON INVESTMENT

WisDOT recently completed an effort to develop an ROI estimating method for 3D modeling projects using data from the Mitchell Interchange Project as it neared completion. The Mitchell Interchange was part of the larger 94 North-South Freeway Project, which was intended to improve the outdated design of the interchanges and roads through the addition of medians, shoulders, and consistent exits as well as to increase capacity by adding more lanes. A total of 17 interchanges were updated for ease of use and safety along a 35-mile stretch that includes 3 counties in Wisconsin and crosses into the State of Illinois. The Mitchell Interchange was one of the most complex interchanges being redesigned primarily due to its high traffic volume but also because it included a redesign of 14 bridges, 3 tunnels, 29 retaining walls, several entrance and exit ramps, 7 noise barrier walls, 54 sign structures, multiple utilities, and many other complex factors.

WisDOT originally developed the Mitchell Interchange using traditional two-dimensional plans. However, WisDOT generated 3D models at the completion of the project to investigate the potential impacts of design modeling on cost savings. Because clash detection was not performed during development of the Mitchell Interchange plans, the project provided a good opportunity to more 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 DINs.

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. Design issue notices (DINs) are changes to the design that become necessary due to conflicts or issues identified during construction. 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. Table 1 below shows the estimated percentage of impact that the use of 3D modeling could have had on each DIN category on the Mitchell Interchange Project. Figure 3 below shows the estimated percent of impact for each DIN category graphically. As shown, 3D modeling results in the majority of gains in categories other than earthwork, such as general structures, drainage, and other features.

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

Table 1. Estimated Cost Impact from the Use of 3D Modeling on the Mitchell Interchange Project

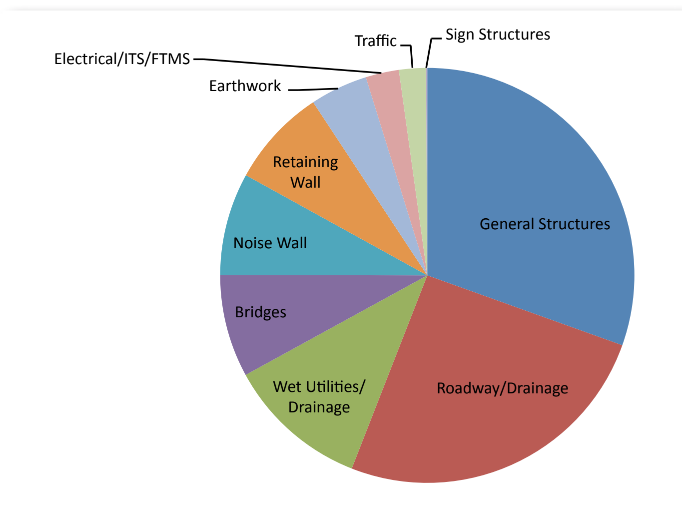

Figure 3: Estimated return using 3D modeling using DIN Categories on Zoo Interchange ROI Analysis

WisDOT found through this examination of ROI for 3D modeling on the Mitchell Interchange Project that the majority of the gains are possible in general structure and roadway/ drainage components. And while earthwork is often thought of initially for significant gains in return on investment using 3D, it makes up only a small percent of the return that can be realized through the use of 3D modeling. WisDOT is looking to realize these potential ROI gains using 3D modeling on the Zoo Interchange Project. WisDOT staff is also leading development of a Transportation Research Board paper to further detail the results of their ROI effort related to the Mitchell Interchange and the Zoo Interchange projects, which will be available in fall 2013.

LESSONS LEARNED

- 3D modeling is increasingly being used by transportation agencies across the country to reduce costs and time needed to complete roadway projects.
- 3D data can enhance not only design through clash detection and better visual representation of the completed project prior to breaking ground but it can also support downstream applications such as AMG.
- A methodology and work flow for sharing, editing, and approving 3D model files is critical to success.
- Cost gains achieved through the use of 3D modeling can be more significant during general, drainage, structural, and feature design categories than during earthwork and excavation alone.

GLOSSARY / TERMS

- 3D model – graphical representation incorporating the depth, breadth, and height
- 4D model – linking 3D model components to incorporate time/ schedule information
- 5D model – linking 4D model components to incorporate cost-related information
- 6D model – upgrading an as-built model to incorporate facilities management or project lifecycle information, such as O&M manuals, specifications, and warranty information
- Automated Machine Guidance (AMG) – 3D modeling data combined with global positioning system (GPS) technology to provide horizontal and vertical guidance in real time to construction equipment operators.
- Contract Change Orders – changes required by the project owner to roadway construction plans during project execution.
- Design Bid Build (DBB) – project delivery method in which a transportation agency contracts for development of the design, and construction of a roadway
- Design Issue Notice (DIN) – notification issued by transportation agency to recognize and alter the design of a roadway element, based on an issue or problem identified during construction
- LiDAR (Light Detection and Ranging) – a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light
- MOT – maintenance of traffic
- O&M – operations and maintenance
- ROI - return on investment

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