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Feasibility of visualization and simulation applications to improve work zone safety and mobility

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**Feasibility of visualization and simulation applications to
improve work zone safety and mobility**

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Civil Engineering (Construction Engineering and Management)

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Iowa State University

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Abstract

Visualization is a relatively recent tool available to engineers for enhancing transportation project design through improved communication, decision making, and stakeholder feedback. Current visualization techniques include image composites, video composites, 2-D drawings, drive-through or fly-through animations, three-dimensional (3-D) rendering models, virtual reality, and four-dimensional (4-D) CAD. These methods are used mainly to communicate within the design and construction team and between the team and external stakeholders. Use of visualization improves understanding of design intent and project concepts, and facilitates effective decision making. Visualization tools, however, typically are used for presentation only in large-scale urban projects. Visualization is not accepted widely due to a lack of demonstrated engineering benefits for typical agency projects, such as small and medium size projects, rural projects, and projects where external stakeholder communication is not a major issue. Furthermore, there is a perceived high cost of investment of both financial and human capital in adopting visualization tools. The most advanced visualization technique of virtual reality has been used only in academic research settings, and 4-D CAD has been used on a very limited basis for highly complicated specialty projects. However, there are a number of less technically sophisticated visualization methods available that may provide some benefit to many agency projects. Survey results show that respondents have neutral ideas of adopting visualization techniques used in work zone construction. However, t-test analyses of survey results show that the younger generation and persons familiar with technology believe visualization techniques can be useful more so than people of older generations or those who are not familiar with technology. In this dissertation, a work zone visualization model was developed by creating 3-D models linked with scheduling data. The visualization file was saved as a .kmz format file to be used and sent over the Internet. After viewing the developed work zone visualization, a focus group and project team members of the 24th Street Bridge Project believed the visualization would be useful as a low cost technique for communicating during construction and was adopted as an alternative visualization tool on the construction project website. In this dissertation, results of a feasibility study are presented examining the use of visualization applications for improving work zone planning, design, construction, safety, and mobility.

Chapter 1:
Introduction

Visualization is a relatively recent tool available to contractors and engineers for enhancing project design and construction through improved communication, decision making, and stakeholder feedback. Visualization techniques are becoming commonplace in building design and construction, commonly referred to under the common rubric of Building Information Modeling (BIM). Transportation project designs frequently do not have the spatial complexity of building construction; however, project complexity, staging complexity, and stakeholder communication are often more of a challenge due to extensive public involvement. Highway construction projects typically involve a large number of stakeholders with varying degrees of knowledge and experience regarding interpretation of design drawings. In addition, minimal delays in transportation projects drastically can affect public interests. The large number of stakeholders, many of whom lack technical knowledge, presents a challenge to adoption of visualization techniques in the transportation sector of the construction industry. However, projects with such diversity of stakeholders and technical capabilities could probably benefit the most from visualization techniques to enhance project understanding and communication.

The objective of this research is to examine the benefits and potential barriers to adoption of visualization techniques in the transportation sector of the construction industry. Because the focus is on construction activities, the scope of this research is limited to work zones on highway transportation projects. In this dissertation, the results of a feasibility study are presented by examining the use of visualization applications for improving work zone planning, design, construction, safety, and mobility. Following the introduction, the current state of the art and a literature review of technology adoption are presented in Chapter 2. Chapter 3 outlines the research methodology employed in this dissertation. Chapter 4 described the process used to develop a low cost, highly accessible visualization program for improving safety and mobility in construction work zones. The dissertation concludes with an evaluation of the program as used in a pilot project, a summary of the study, and

recommendations for future enhancements to the program that can make the 4-D visualization model even more beneficial to the transportation planning, design and construction process.

Chapter 2:

Literature Review and Research Studies on Technology Adoption

Current State of the Art

Current visualization techniques in the design and construction industry are image composites, video composites, two-dimensional (2-D) drawings, drive-through or fly-through animations, 3-D rendering models, virtual reality, and 4-D CAD. These methods are used mainly to communicate within the design and construction team and between the team and external stakeholders. Use of visualization improves understanding of design intent and project concepts and facilitates effective decision making. For transportation projects, however, visualization tools typically are used for public presentation only in large-scale urban projects. Visualization is not accepted widely due to a lack of demonstrated engineering benefits for typical agency projects, such as small and medium size projects, rural projects, and projects where external stakeholder communication is not a major issue. Furthermore, there is a perceived high cost of investment of both financial and human capital in adopting visualization tools. The most advanced visualization technique of virtual reality has been used only in academic research settings, and 4-D CAD has been used on a very limited basis for highly complicated specialty projects. However, there are a number of less intensive visualization methods available that may provide some benefit to many agency projects.

Recent advances in open-access platforms such as Google and Adobe may represent an opportunity to enhance visualization techniques for work zones, without the large resource commitment required of other visualization programs. Currently, the open-access platforms lack the precision to form the baseline for construction documents, but they could be beneficial in planning, evaluating, and communicating construction issues for work zones in transportation projects. The issues involved in work zone design and construction, along with alternatives for visualizing work zone layout, are discussed in the following sections.

Different visualization techniques used in transportation projects have been analyzed to identify cost and benefits in public projects (Bailey et al. 2002). Image composites have been used frequently to facilitate public involvement in the planning phase (Garrick et al. 2005).

4-D CAD has demonstrated numerous benefits, especially in building and industrial construction (Fischer et al. 2003). 4-D CAD is a technique that visualizes scheduling data through 3-D animations instead of static Gantt charts or CPM schedules. It has been used successfully in several projects such as Disney's California Adventure theme park and the Disneyland theme park in Hong Kong. Use of visualization-enhanced communication between project partners and facilitated understanding of design intent while minimizing delays during the construction phrase. The owner was able to review alternate designs for the project and make timely decisions without a deep knowledge of architecture or engineering. Benefits to the general contractor and subcontractors included productivity improvements, fewer requests for information (RFI), reductions in change orders, and less rework. Unforeseen conditions caused by interference and conflicts on site were discovered earlier in the design phrase, allowing designers and engineers to develop constructability solutions for some circumstances such as working under cranes and in confined spaces.

The Minnesota Department of Transportation used digital compositing technique to create animations for the proposed St. Croix River Bridge Project. Image and video compositing techniques rendered 3-D proposed models displayed on top of existing conditions. The animations displayed the aesthetic look of proposed construction for communication purposes to other project teams and the public (MnDOT, 2007). A limitation of the animations is that they do not provide real-time navigation, so people cannot interact and look at different perspective views.

4-D CAD has been used in site layout designs to illustrate procurement simulation in different construction projects (Ma et al. 2004). It also has been used to teach interactive schedule and planning processes in a classroom (Messner et al. 2003). Several researchers have used different combinations of software for 4-D CAD development. ArchiCAD with 3-D building models (Jongeling et al. 2007) and Autodesk Civil 3-D with Navisworks

Navigator (Strongitharm, 2008) have been used to simulate 4-D systems for visualization, communication, and clash detection. Currently, development costs of 4-D systems are high. Three-dimensional models frequently need to be developed separately from projects because they are not currently used in construction documents for most transportation projects.

Work Zones

To thoroughly study and understand work zone staging represented as several pages of 2-D drawings is a tedious job. Users have to read a combination of different pages, and then go back and forth between each page to gather all of the information. To work faster and more effectively, one possible cognitive way is to enhance work zone planning is through visualization.

As noted earlier, visualization techniques can be used to better communicate design intent and project concepts and are beneficial to the project team when making complex decisions in the planning and preconstruction phases of a project. Innovative practices and areas of improvement for work zones have been identified using industry surveys (Schrock et al. 2002). Intelligent Transportation Systems providing information to drivers before entering work zones showed effectiveness by reducing traffic congestion and improving safety (Fontaine, 2003). Several researchers have studied work zone safety and accidents in different aspects, such as the correlation of work zone settings and injury crash rates (Khattak et al. 2001), effects of nighttime construction to fatal accidents (Arditi et al. 2007), and statistical significance of crashes in work zones (Jina et al. 2008). Operation simulation and animation has been used to study paving operations in a work zone of two-way lane closure (Nassar et al. 2003). Driving simulators using 3-D models to replicate road signs, construction equipment, and wildlife have been used to study drivers' behavior in a laboratory setting (Stanley, 2006). Database of accidents and work zones displays overlaid on state highway maps have proven useful in illustrating statistical data regarding work zone crashes in a graphical format (Shi, 2008).

Few transportation projects have utilized 4-D CAD for work zone visualization. The High Five Interchange project in Dallas, Texas, used 4-D CAD to facilitate the coordination on multilevel bridge construction (Liapi, 2003). The research studied different traffic control scenarios for each construction phase. A private company used a similar approach for a tunnel construction project in Sydney, Australia (Autodesk, 2008). The High-Five Interchange project team used 4-D CAD visualization techniques for communication and presentation of design and construction allowing them to study different traffic control scenarios for each construction phase. Work breakdown structure (WBS) information was used as a 4-D data index along with 3-D models and scheduling data (Kang et al. 2007).

Koo and Fischer (2000) classified functions of 4-D CAD systems into three categories: 1) visualization, 2) integration, and 3) analysis. Other researchers (Collier et al. 1996, Riley 2000, Webb et al. 2004, Williams 1996) have shown that the technology significantly can improve the communication of the construction plan to other project stakeholders by simulating the construction process. McKinney et al. (1996) classified 4-D CAD technology into two distinctive generations: Visual 4-D CAD and Collaborative 4-D CAD. Visual 4-D CAD produces a 4-D animation for designers to evaluate and review the designs they propose. While visualization using 4-D CAD can effectively communicate completed construction plans, it does not address how the schedule was developed because it merely links the 3-D model with an existing schedule. Because of this, the researchers proposed "Collaborative 4-D CAD" as a tool to improve the construction design process. Collaborative 4-D CAD provides more of a simulation rather than a mere visualization of the construction process. Researchers have proposed several prototypes of simulation-based construction planning tools (Whyte et al. 2000, Waly et al. 2003, Xu et al. 2003, Clayton et al. 2002, Li et al. 2003, Chau et al. 2004), but none have been adopted widely in the transportation industry for use in work zone planning.

A number of specific construction challenges have been addressed by researchers to improve 4-D CAD as a construction planning tool. Akinci et al. (1997) conducted productivity and cost analysis using 4-D modeling. Riley (2000) studied the role of 4-D modeling in trade sequencing and production planning. O'Brien (2000) proposed 5-D CAD modeling by

expanding 4-D CAD models to include multi-project resource management functions for specialty contractors. Li et al. (2003) studied the application of virtual reality technology to experiment with innovative construction operations. Chau et al. (2004) used 4-D CAD technology to address building construction site utilization issues. Besides construction planning, 4-D CAD and virtual reality also proved to be a very effective tool for education of architectural and construction engineering majors (Jaafari et al. 2001, Clayton et al. 2002). Each of these visualization techniques, however, requires a significant resource commitment by agencies and vendors, as well as agreement on a common platform.

To address the issues of resource intensity and closed-access platform, Strong and Kaewmoracharoen (2008) examined the feasibility of combining readily available, inexpensive open-access software programs such as Google Earth and Adobe Acrobat with standard 2-D civil engineering design programs such as MicroStation to create animations of work zones. The animations reflect changes in work zone configurations as the project progresses, representing an opportunity to visually present complex information to drivers, construction workers, agency personnel, and the general public. The preliminary feasibility analysis identified functionality of open-access platforms, and subsequent development of the visualization technique (Strong and Kaewmoracharoen, 2009) has been received well by the transportation industry. With additional modeling inputs, it may be possible to enhance the animations to include visualization of conditions under different traffic volumes, weather conditions, and construction operations.

Technology Adoption

The slow adoption of new visualization technology in transportation construction projects may have many causes. It is possible that complex visualization programs carry high financial and human capital investment concerns, while less complex visualization tools are perceived to provide little benefit on projects of relatively low complexity. Prior to investigating the feasibility of visualization programs for construction work zones, it is important to understand potential barriers to adoption of new technology in a more general

sense. In an effort to determine what barriers may exist, literature from previous research on technology adoption was reviewed.

Prior research has indicated that willingness to adopt new technologies can be influenced by organizational culture (Kitchell, 1995). Some organizations have a risk-averse culture and are reluctant to abandon established technologies until new technologies are extremely well established across the entire industry and proven to be reliable and economical. In addition to organizational level effects, individuals within organizations can vary in technology adoption rates. Morris (2006) found that age of the employee is a factor in rate of technology adoption. Therefore, it can be inferred that organizations with a relatively young workforce are more likely to adopt new technologies than organizations with relatively older, long-tenured employees. In addition, prior usage of related technologies is related to technology adoption (Venkatesh, 2007). For instance, individuals familiar with gaming technology are more likely to adopt a new visualization or animation program for a non-gaming application, such as construction drive-throughs.

Kohn and Husig (2005) determined that failure to adopt a new technology is sometimes caused by a general lack of awareness of all the available alternatives among top management. They may view the decision to adopt as a black-and-white decision, where in reality there may be several combinations of technology add-ons, incremental scaling, or phased introduction that make the technology less disruptive to the daily function of the organization. Kohn and Husig also found that a failure to understand how innovative use of technology could benefit the core processes leads to a failure to adopt. Operations and technology managers may need to make a better "business case" for the new technology to warrant investment decisions by top managers.

At the operational level, Boake, Pretorius, and Pretorius (2003) identified a lack of technical capabilities among operational managers as a primary reason for lack of diffusion of new technology. For those operations managers with technical savvy, they frequently became frustrated when the organization provided an insufficient IT infrastructure to support adoption. In other words, for technology adoption to be successful, both the operational unit

leaders (e.g. project managers and designers) and employees of the IT support functions have to be knowledgeable of how the new technology functions and supportive of its adoption, including investments in training and maintenance of the system.

Ghobadian, Mole, and O'Regan (2003) found that small firms in particular are unlikely to adopt new technologies due to competitive pressures and lack of strategic planning emphasis. The exception comes if there is an industry-wide innovation openly available to all organizations within the industry at low cost. This is particularly important in the construction industry because many small subconsultants and specialty contractors must interface with any visualization program adopted by an owner agency or large design company.

Goulding et. al. (2007) found that to facilitate adoption, innovative technologies must be interactive and information rich. Designers are reluctant to move away from "tried and true" technologies because of the risk involved. Shared functionality is critical and adoption is as much a social phenomenon as a technology one. This is a critical insight, as many managers of engineering and construction organizations focus on the technical and economic issues involving technology adoption, forgetting that design and construction have strong sociological components that cannot be overlooked.

Flood et. al. (2003) used a case study analysis to identify barriers to the development, adoption, and implementation of new technology in the construction industry. They found that a lack of financial support and a failure by top management to recognize time requirements (e.g. not providing operations-level employees work time to learn the new technology) were the main problems in diffusing the new technology throughout the organization. They further observed that individuals in the construction industry held preconceived ideas against adoption of new technologies and had concerns about the impact of technology adoption on the quality of work produced.

Kaewmoracharoen and Strong (2008) identified a number of differences in the perceived value of work zone modeling and visualization programs, including generational differences, organizational differences, and institutional differences.

Summary

There appear to be many barriers to the adoption of new technology, including concerns over financial and human capital investments; lack of clarity over the economic value of the resource investment; absence of technology platforms that promote low-cost, easily accessible, widely distributed information sharing networks; and an overreliance on continuing technical support and specialized training to integrate the new technology into current operations. In addition to the barriers described above, any visualization program must provide high performance characteristics (speed, resolution, and dissemination) and provide real-time navigation using cost-effective methods include a focus group, survey, and pilot test project.

The weight of evidence from previous studies is clear: the benefits of visualization and simulation are significant, but current industry adoption is constrained by the need for a large commitment of resources and lack of agreement on a common platform, many of which are closed-access (e.g. licensed) products. The research program described in this dissertation is directed toward identifying a suitable program for visualization of transportation project work zones that can overcome these barriers to adoption. With this research objective in mind, the research methodology described in Chapter 3 begins with a review of current alternatives for work zone visualization systems to identify the highest potential visualization alternative from among a number of alternatives. Chapter 3 also presents a methodology for identifying barriers to adoption. After identification of the highest value alternative and an understanding of the barriers to adoption, the research proceeds to development of such a program as described in Chapter 4, along with a preliminary pilot test of the program for the I-80/I-29/24th Street Bridge reconstruction project in Council Bluffs, Iowa.

Chapter 3:
Methodology

For the feasibility study investigating visualization and simulation to improve highway work zone safety and mobility, the research team considered current technologies, collected suggestions from academic and industry focus groups, conducted an industry survey, and developed a visualization prototype for use on a pilot project.

Technology and Software Study

The research team studied the wide range of current visualization techniques emphasizing in 4-D CAD. The highway work zone is defined as a 4-D CAD type simulation because the time dimension is of interest. 4-D CAD is an approach that visualizes a project schedule by evolving 3-D construction models over time. The 4-D CAD concept has been used in the construction industry since early 2000. It is mainly used to visualize and prevent construction interference and work space conflict. Several 4-D CAD programs have been used on building and industrial construction projects. To develop a 4-D CAD approach for transportation construction, the team studied the feasibility of two possible techniques: (1) using a commercial 4-D software package and (2) adapting current 3-D environment software.

Commercial 4-D Packages

The most common 4-D software programs currently available on the market are NavisWorks (Autodesk), ProjectWise (Bentley), Project 4D (Common Point), and fourDscape (Balfour).

Autodesk NavisWorks (formerly known as NavisWorks JetStream) is a 3-D design package from Autodesk. The current version is Autodesk NavisWorks 2009. During the research period, NavisWorks JetStream V5 was chosen for review. The JetStream package includes various software for various tasks. JetStream Roamer is the core software that works as a typical 3-D navigation program. JetStream TimeLiner is an add-on binding project scheduling data onto 3-D models. It was used for a 4-D tunnel project in Sydney, Australia,

in February 2004. Thiess Pty Ltd., an Australian company, used it as a communication tool when they gave internal presentations to groups of contractors and project managers for area coordination. JetStream Roamer supports major CAD or 3-D model files, including AutoCAD 2007, MicroStation, ArchiCAD, Viz 2007, Revit, SketchUp 6, and 3ds Max. JetStream TimeLiner supports major project scheduling software including Primavara P3 and Microsoft Project. The software can export into Acrobat PDF and video files in Windows AVI format. JetStream can be used to detect collision for either object or working space interference.

ProjectWise is a package from Bentley Systems. The current version is the V8 XM edition. The core software is ProjectWise Navigator (formerly Bentley Navigator) 3-D navigation software. It requires ProjectWise Schedule Simulation to support integration of project scheduling data and ProjectWise Interference Manager for clash detection. It supports major CAD and 3-D model files including DGN, DWG, PDF, AutoPlant, TriForma, PlantSpace, PDS, Google SketchUp 5 (only), Google Earth, IGES, STEP, JPEG, TIFF, and 3DS. ProjectWise Schedule Simulation works with Microsoft Project, Primavera, Excel, and other XML formats. It provides tools for reviews and comments using both 2-D and 3-D models. Besides the 4-D purpose, ProjectWise can be use for 3-D online collaboration by using ProjectWise Integration Server and ProjectWise StartPoint.

Project 4D is an all-in-one 4-D design software from Common Point, Inc. The Walt Disney Company and Stanford University developed the software. The current version is Project 4D 1.96. It was first used for California Screamin', a steel rollercoaster at Disney's California Adventure theme park, and then subsequently used in the Disney Concert Hall in downtown Los Angeles. Project 4D supports CAD files including, AutoCAD, Architectural Desktop, ArchiCAD, MicroStation, and AllPlan. It supports 3-D model files from 3D Studio Max/VIZ, FormZ, Rhino, and XSteel, and schedule files from SureTrak, Expedition, MS Project, and Excel comma or tab-delimited files. Besides Project 4D, Common Point provides add-on packages such as ConstructSim and OpSim for use in construction simulation.

fourDscape is an all-in-one 4-D visualization design software from Balfour Technologies, which partners with the New York State Applied Science Center of Innovation and Excellence in Homeland Security. It has been used in several projects including the Huntsville Airport Intermodal Transportation Simulation, Alabama (TRB 2001), and 4-D Interactive Roadway Traffic Simulation in Long Island, New York (NYSDOT). The software supports AutoCAD, MicroStation, MultiGen, and Geo file formats. The software itself can work on both Windows and Linux.

There are also several proprietary 4-D CAD products not commercially available, such as PM-Vision by Construction System Associates, which is an owner-developed software used for consultant services only. There are also several defunct 4-D programs including 4D Builder Suite (D-studio innovative IC formerly Domos), 4D CAD System (JGC Corporation, a Japanese company providing 4D service), VirtualSTEP (VirtualSTEP), and Visual Project Scheduler (a research project from Boise State University).

Adaptation of Software with 3-D Environment

Working with a 3-D environment application along with short programming codes is a viable alternative to simulating a 4-D-like system. This approach allows designers to create visualizations and simulations without coding from scratch like they would have to do if they were working with C++ programming language with OpenGL. Some examples and brief descriptions of this type of software are Acrobat 3D (Adobe), Second Life (Linden Lab), SketchUp, and Earth (Google), and Walkinside (VRcontext).

Adobe Acrobat 3D is an enhancement of typical Adobe Acrobat PDF, which supports 3-D models. The current version is Adobe Acrobat 3D 8. Acrobat 3D supports several 3-D modeling systems including AutoCAD, MicroStation, 3ds Max, and SketchUp. The software includes pre-built navigation tools so the software can run as a standalone 3-D environment. Users can view items either online or offline, similar to typical Adobe PDF files when using Adobe Reader. The software can work with short scripts called Acrobat JavaScript, which is based on JavaScript. The script for working with scheduling information can be done by

exporting a scheduling file in XML format and synchronizing it with Adobe Acrobat 3D. The benefit of using Acrobat 3D is that it is readily available and does not require additional software beyond Adobe Reader.

Second Life is an online application gaining in popularity. It provides real-time 3-D navigation similar to multiplayer online video games. Users can create 3-D models that can be imported from external applications in an online environment; however, Second Life is currently not fully compatible with several applications. The script can use LSL (Linden Script Language), an internal script for the Second Life itself based on C++ language. The software is available free for users, but builders operating in Second Life pay a fee for creating any item in the shared platform.

Google SketchUp/**Google Earth** is a 3-D modeling software that is relatively easy to use. It is available in two versions: Google SketchUp and Google SketchUp Pro. Google SketchUp is available for free as a limited version. It is used to create and render 2-D graphics. Google SketchUp Pro functions on top of the free version and allows users to save animations and export 3-D models working with other major 3-D software such as AutoCAD, Revit, JetStream, and ProjectWise. Google SketchUp can work with the script by using Ruby programming language. Google Earth uses Keyhole Markup Language (KML) in the software working with other 3-D models, such as SketchUp export files in Collada (DAE) files.

Walkinside is an application displaying 3-D real-time visualizations and simulations from VRcontext. It allows users to walk or fly around the pre-built 3-D models that are converted from either CAD files such as AutoCAD and MicroStation, or from point cloud laser scan data.

Other Approaches

Besides 4-D-like visualization and adapted 3-D approaches, the research team studied the following other techniques.

Hand-held device animations – An example of work zone animation for hand-held devices was created for analysis purposes. The preset animation shows a drive-through simulation of the work zone. Such animations can be used with a cell phone or hand-held computer. The goal is to improve usage by people without computer access or those who are currently on the road. A few limitations of this approach are the smaller screen and device availability. This approach disregards real-time navigation, using instead several preset videos from 3-D simulations. The files are encoded and saved in formats available for each device. The accessibility of this approach is satisfactory, but the simulation functionality is very limited.

2-D overlay images – This approach visualizes the work zone by overlaying traffic devices on top of current site condition photos. The research team collected highway photos of I-29/I-80 and 24th Street from a driver's perspective. The photos then were retouched using photo-editing software (Adobe Photoshop) as shown in Figure 1. The left photo is a current highway ramp condition and the right photo shows a future work zone condition. This approach has the benefit of omitting the time to develop 3-D models. However, this approach can be excessively time consuming if several retouched images are needed. The work time is about 30 minutes per image.

**Figure 1. Original ramp (left) and traffic image retouched (right)
on southwest ramp merging onto 24th Street**

<u>Software Comparison</u>

To compare the software mentioned in the previous sections, three major issues are examined:

- Costs – the costs of developing the system including software, development, and maintenance costs.

- Real-time navigation – the degree to which the software allows users to browse 3-D models in any angle; The most constraining is the preset navigation in which users can see only the restricted views such as in a drive-through animation.

- Availability – end-user benefit, hardware/software requirements, and ease of use

All 4-D CAD software packages besides JetStream are grouped together because they share common values of the key issues listed above. Table 1 shows a comparison of the software.

After the review, the research team selected a combination of Google SketchUp and Google Earth. End users can use free, downloadable software to view simulations created with these programs. In addition, end users can rotate, zoom, and pan to the specific work zone areas of interest. The development software cost is free, while other software is not. The development cost and time are low, making it the most feasible option for application in work zones.

After reviewing the software there are two types of data required to create visualization and simulation programs: 3-D modeling data and scheduling data. Three-dimensional models are data that represent real construction objects. Scheduling data comes from traffic work zone schedule information. Each schedule data point must be composed of a task name, staging number, and start and end dates. These two data types are linked together by their reference names to visualize the schedule in 3-D models.

Table 1. Comparison of software

Issues	4-D software packages	JetStream	Acrobat 3D	Second Life	SketchUp and Earth	Walkinside
Software cost	High	High	Medium	Low	Free	High
Maintenance cost	Yes	Yes	No	No	No	Yes
3-D development cost and time	High	High	High	Low	Low	High
Real-time navigation	Yes	Yes	Yes	Yes	Yes	Yes
Availability to end users	No	Yes	Yes	Yes	Yes	No
Internet connection required	No	No	No	Yes	Optional	No

*Software cost defined from high (more than $1,000), medium (between $100 and $1,000), low (less than $100), and free.
*3-D development cost and time defined from high (more than five hours on a model) and low (less than five hours on a model).

The existence of scheduling data is common in highway projects; however, the major obstacle is that in general, 3-D models are seldom created as part of the design process for transportation projects. They typically are created only for major construction projects requiring public involvement or multijurisdictional approvals. Therefore, the cost to develop 3-D models is typically not included in the original design proposal, and there are currently no cost-effective methods to generate 3-D models from 2-D drawings.

Focus Group

To identify state DOT's data needs, implementation constraints, and possible uses for work zone visualization and simulation programs, the research team conducted an industry survey and focus group discussion as described in the following sections.

The research team convened a nine-person focus group of knowledgeable industry leaders from academia, the Iowa Department of Transportation (IADOT), U.S. Federal Highway Administration (FHWA), and traffic control contractors. Focus group participants viewed simple work zone simulations and were asked their opinions regarding which aspects of transportation planning, design, and construction could benefit from the use of such simulations. The focus group used open-ended questions and was facilitated by a member of Iowa State University's Civil, Construction, and Environmental Engineering faculty. Areas of potential benefit receiving general consensus among the focus group participants included communication with the public during planning, internal traffic control during construction, drainage and utility coordination, driver education, driver preparedness, and safety training for construction workers. Potential barriers included lack of common software among project partners, variations in familiarity and computer usage within the project team, and limited resource availability for implementation. The research team used the results of the focus group dialogue to create a survey as described in the following section.

<u>Survey</u>

As part of the feasibility study, the researchers developed a set of simple work zone simulations for a large, urban interstate expansion project in order to create a common context for survey respondents. The simulations were intended to help establish a common baseline for the definition of "visualization," and represented a program in the middle of the sophistication continuum. The research team created six simulations and three work zone configurations, each represented in ideal conditions and in poor visibility conditions. The simulations were created in Google SketchUp Pro and Adobe Flash. Screen captures from the different visualizations are shown in Figure 2, Figure 3, and Figure 4. The full survey is shown in Appendix D.
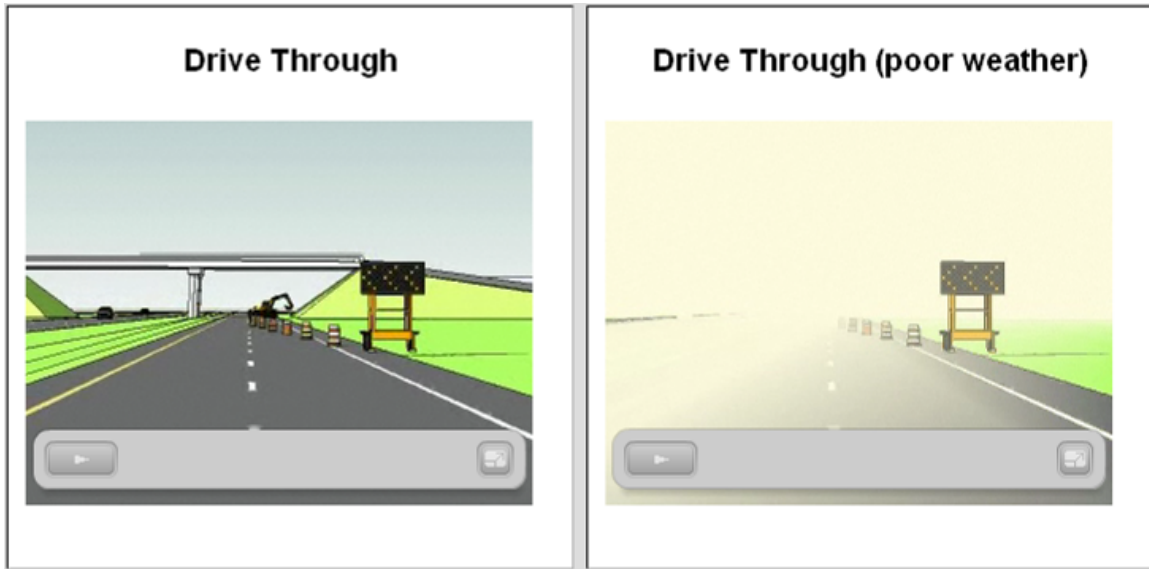
Figure 2. Traffic control for one-lane closure on divided highway
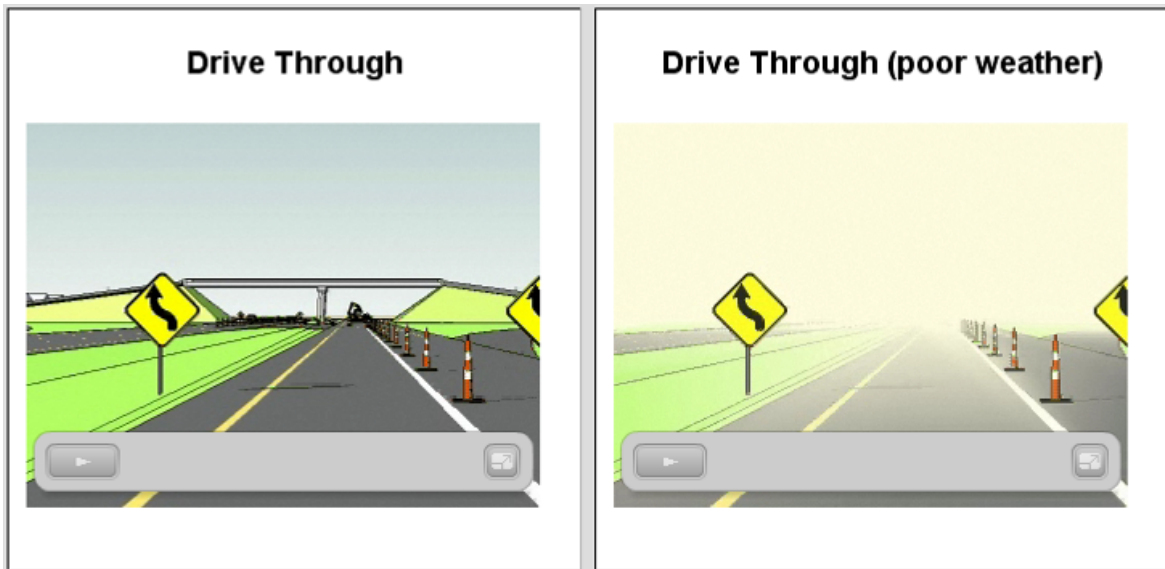
Figure 3. Traffic control for two-lane closure, head-to-head operation
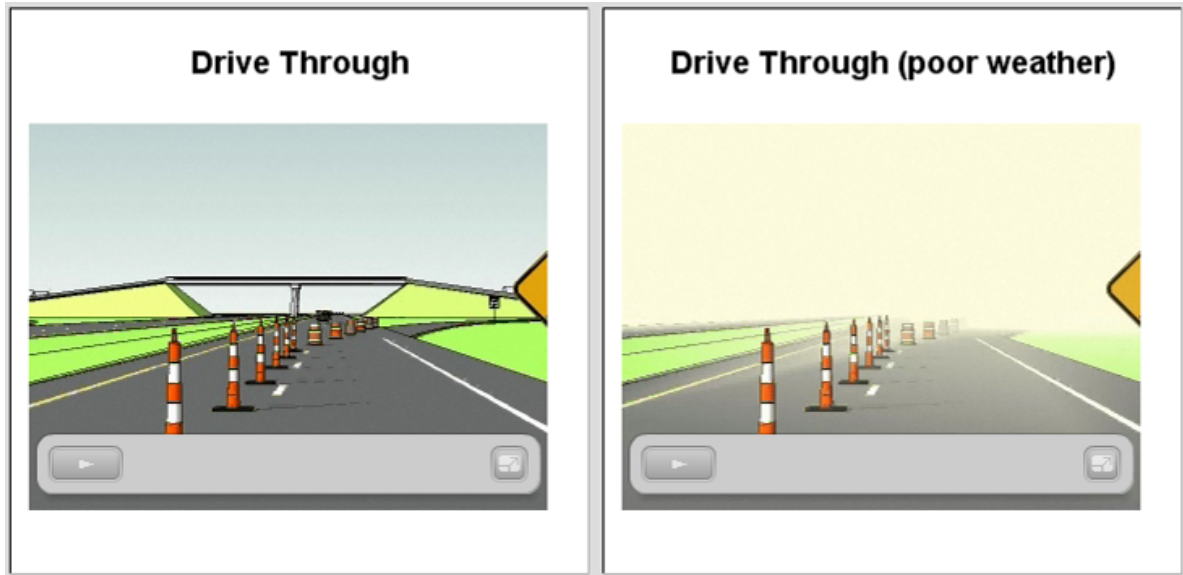
Figure 4. Traffic control for full closure with temporary detour via exit/entrance ramps

Using the issues identified by the focus group, a 40-item survey was created to gather opinions from a broad range of transportation organizations. Four questions asked for demographic information, 17 items related to job duties and computer usage, and 19 items asked opinions regarding adequacy of current technologies and adoption of simulation technologies. The survey was distributed online to municipal, county, state, and federal transportation agency personnel, engineering and design firms, and general and specialty contractors with knowledge of highway construction. A total of 51 valid surveys were returned. The average years of industry experience of the respondents was 20 years, and surveys were received from individuals representing a cross section of project roles, including supervision, design review, field operations, safety, and project management. Results of the opinion questions were measured using a Likert scale response from 1 (strongly disagree) to 7 (strongly agree) for the statement presented. Results for the 19 opinion questions are shown in Table 2.

Table 2. The average score of the survey results

Survey Item	Average Score
Drivers in highway work zones are adequately informed using existing technologies	5
Drivers in highway work zones are adequately prepared using existing technologies	4.3
Current technologies provide adequate safety for construction workers in work zones	4.7
Current technologies provide adequate safety training for construction workers in work zones	4.5
Dynamic message boards on the road increase safety in work zones	5.5
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.1
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.8
Three-dimensional drawings of work zones and road closures can improve work zone safety	4.7
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.7
Simulation of work zones in the planning and design phase would help my organization better prepare for the safe and efficient accommodation of traffic during construction	4.9
My organization would use work zone simulations in our training program	4.7
My organization would use work zone simulations in job safety analysis and evaluation	4.6
My organization would use work zone simulations in internal traffic control	4.5
My organization would use work zone simulations in communicating with the public	4.6
My organization would use work zone simulations to define access points for deliveries	4.3
In the design phase, work zone simulations would improve drainage design	3.7
In the design phase, work zone simulations would improve utility design	3.7
In the design phase, work zone simulations would prevent many construction conflicts	4.3
Simulation of work zones would be useful in driver education programs	5.8

*The scores are based on Likert Scale of 1 (strongly disagree) to 7 (strongly agree).

Several t-tests were conducted to identify differences in respondents based on attributes. Comparisons were made between six different demographic factors as described in the following sections. The statistical significance of 0.10 level (lower than 10%) was used in this study.

The research team was interested in examining whether organizational type, experience levels, or technology familiarity were factors in respondents' perceptions of the potential value of visualization software programs. Prior research has indicated that willingness to adopt new technologies can be influenced by organizational culture (Kitchell, 1995), age (Morris, 2006), and prior usage (Venkatesh, 2007). To test for the impact of these factors, student t-tests were performed comparing responses of:

- Government agency personnel to non-government agency personnel

- Individuals with more than 20 years of experience to those with less than 20 years of experience

- CAD users vs. non-users of CAD

- GIS users vs. non-users of geographic information system (GIS)

- Those who use 2-D drawings compared to those who do not use them as part of their jobs

- Individuals who regularly use scheduling software compared to those who do not

Government Agency and Non-government Contractors/Consultants

There are five answers showing significant difference in values between responders of government and non-government agencies. For the perception of the current technologies, individual from non-government agencies have less satisfaction than those from government agencies. At the same time, for the perceived benefit of work zone simulations individuals from non-government agencies tend to disagree that simulations can improve the current system either in planning and design, drainage design, or utility design. The survey results and significant values are shown in Table 3.

Table 3. T-Test data of survey result between government and non-government

Survey Item	Non-government	Government	Significance
Drivers in highway work zones are adequately prepared using existing technologies	3.875	4.857	2.1%
Current technologies provide adequate safety for construction workers in work zones	4.375	5.286	2.9%
Simulation of work zones in the planning and design phase would help my organization better prepare for the safe and efficient accommodation of traffic during construction	4.375	5.500	2.8%
In the design phase, work zone simulations would improve drainage design	3.250	4.214	5.5%
In the design phase, work zone simulations would improve utility design	3.250	4.071	8.1%

Experience Level

There are four answers showing significant difference in values between people with more than 20 years of experience and those with less than 20 years of experience. People with less than 20 years experience tend to believe more strongly that the usage of 3-D and 4-D visualization improves work zone safety than people with more than 20 years experience. People with less experience consider the use of simulations to communicate with the public more valuable than those with more experience. In contrast, people with more experience believe that the simulation can be used to prevent possible construction conflicts more than the people with less experience. Table 4 shows the survey results and significance values.

Table 4. T-Test data of survey result between people with more than 20 years of experience and those with less than 20 years of experience

Survey Item	Less than 20 years	More than 20 years	Significance
Three-dimensional drawings of work zones and road closures can improve work zone safety	5.000	4.368	7.3%
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.889	4.368	9.7%
My organization would use work zone simulations in communicating with the public	4.889	4.158	6.0%
In the design phase, work zone simulations would prevent many construction conflicts	4.000	4.737	8.7%

CAD Users and Non-users

One item showed significant differences in values between responders who are familiar with CAD and those who are not. People familiar with CAD tend to believe that 3-D drawings of the work zones can improve work zone safety more than those people not familiar with CAD systems. The survey results and significant values are shown in Table 5.

Table 5. T-Test data of survey result between CAD users and non-CAD users

Survey Item	Non-CAD user	CAD user	Significance
Three-dimensional drawings of work zones and road closures can improve work zone safety	4.353	5.000	6.8%

GIS Users and Non-users

Three survey answers show significant differences in values between responders who are familiar with GIS and those who are not. For the perception of the current technologies, people who are familiar with GIS have more satisfaction than people who are not familiar. People familiar with GIS systems believe that the simulation will be useful for driver education programs more than those who are not familiar. The survey results and significant values are shown in Table 6.

Table 6. T-Test data of survey results between GIS users and non-GIS users

Survey Item	Non-GIS user	GIS user	Significance
Drivers in highway work zones are adequately prepared using existing technologies	4.095	4.706	5.2%
Current technologies provide adequate safety for construction workers in work zones	4.429	5.000	8.7%
Simulation of work zones would be useful in driver education programs	5.350	6.118	3.5%

2-D Drawing Users and Non-users

Nine survey answers show significant differences in values between responders who use 2-D drawings as part of their jobs and persons who do not. The persons who use 2-D drawings as part of their job have higher satisfaction with the current technologies. Persons who do not use 2-D drawings as part of their jobs have higher satisfaction with dynamic message boards. They also believe more strongly that advance notice of a work zone location will improve traffic safety and mobility. They also are more likely to perceive benefit in using simulations for internal traffic control and delivery access points. Moreover, they think the simulation can be used to prevent construction conflicts and improve drainage design during the design phase. The survey results and significant values are shown in Table 7.

Table 7. T-Test data of survey result between 2-D drawings users

Survey Item	Non-2-D user	2-D user	Significance
Current technologies provide adequate safety for construction workers in work zones	3.833	4.844	3.7%
Dynamic message boards on the road increase safety in work zones	6.000	5.281	8.2%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	6.000	4.935	4.3%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	5.500	4.688	8.7%
Simulation of work zones in the planning and design phase would help my organization better prepare for the safe and efficient accommodation of traffic during construction	5.667	4.813	9.2%
My organization would use work zone simulations in internal traffic control	5.333	4.419	7.7%
My organization would use work zone simulations to define access points for deliveries	5.667	4.125	0.1%
In the design phase, work zone simulations would improve drainage design	4.500	3.563	9.0%
In the design phase, work zone simulations would prevent many construction conflicts	5.800	4.156	1.5%

Regular Users and Non-users of Scheduling Software

Five survey answers show significant differences in values between responders who are familiar with scheduling software and those persons who are not. Persons familiar with scheduling software have higher satisfaction with the current safety technologies but less satisfaction with dynamic message boards. The people who are not familiar scheduling software have higher acceptance of using simulations during the design phase on drainage and utility designs, including visualization can prevent construction conflicts. The survey results and significant values are shown in Table 8.

Table 8. T-Test data of survey result between scheduling software users

Survey Item	Non-sched. familiarity	Sched. familiarity	Significance
Current technologies provide adequate safety for construction workers in work zones	4.385	5.400	1.6%
Dynamic message boards on the road increase safety in work zones	5.577	4.700	1.9%
In the design phase, work zone simulations would improve drainage design	3.808	3.000	7.5%
In the design phase, work zone simulations would improve utility design	3.885	3.000	5.7%
In the design phase, work zone simulations would prevent many construction conflicts	4.538	3.700	7.4%

In general, the survey results indicated that responders' opinions are neutral toward the work zone visualization initiative. As a group, survey respondents did not perceive that noticeable benefits would be obtained by moving from the current system of planning and communicating work zone configurations toward 3-D visualization systems. However, analyzed t-test survey results shows that people from government agencies favor visualization benefits more than people from non-governmental organizations. At the same time, people with less than 20 years experience in highway construction favor simulation benefits more than those who have more experience in construction. In general, respondents who had less experience and more knowledge of CAD and GIS held different perceptions of the benefits of visualization than those with more experience and less familiarity with CAD and GIS technologies. In short, there may be a generational effect in perception of the value of visualizations. As generational effects fade over time and more individuals become familiar with technologies such as 4-D CAD, 3-D CAD, GIS, and project scheduling applications, the feasibility of visualization should increase and perceptions of value will move from neutral to positive.

After the analysis of survey results and simulation prototype, the research team met the focus group again to retrieve feedback. The general consensus was that the work zone simulation developed with Google Earth and Google Sketch-Up represented a very feasible and beneficial program. The research team also did a demonstration for the different parties at the project site in Council Bluffs, Iowa, as discussed in the following section.

Some feedback from Iowa DOT engineers and contractors includes a possibility to merge the visualization and simulation into the current construction project websites. The major concern is that the simulation should have been created in two different target groups, one for public viewing and a separate simulation for project team members. Some information such as detailed task schedules should not be exposed to the public.

The 24th Street Bridge Renovation Project in Council Bluffs, Iowa, was selected to be the sample study project.

Pilot Project Study

In this research, the 24th Street Bridge Renovation Project in Council Bluffs was used as a project test study. The renovation project is located at the existing 24th Street Bridge in Council Bluffs, Pottawattamie County, Iowa. It is part of the Council Bluffs Interstate System (CBIS) improvements project. The project scope is to replace an existing four-span 215'-5" × 53' pretensioned, prestressed concrete beam bridge with a two-span 350'×105' steel welded girder bridge. 24th Street itself is to be widened and the highway ramps are to be reconstructed. The interstate I-29/I-80 is to be diverted. During the construction period, 24th Street will provide one-lane traffic in each direction with the middle third lane for left-hand turns.

The project was designed by HDR of Omaha, Nebraska. In November 2007, the project was awarded to Cramer & Associates of Grimes, Iowa, for $12.5 million. The daily traffic on I-29/I-80 is 81,900 vehicles per day, with 11% of the traffic being trucks (2004). The traffic on 24th Street is 15,000 vehicles per day, with 19% of the traffic being trucks (2004).

Figure 5. The location of the new bridge during stage 1
(Photo to the west of existing bridge)

Project Site Analysis

The reasons for site selection used in this research are (1) public attention, (2) location, and (3) work zone settings. The bridge renovation project has gained attention from local businesses due to periods of road closures that potentially affect their customers. In order to communicate between engineers and non-engineers, visualizations and simulations are most likely to be a major and better tool for communication than typical construction drawings. The location of the construction site is also near the Iowa-Nebraska border. There is high volume of traffic merging from two interstate highways, I-29 and I-80, into one highway I-29/I-80 underneath the project site. The 24th Street Bridge itself also has a high traffic volume, with 19% of the traffic being trucks. One of the potential uses of the visualization and simulation program is to improve mobility through the work zone. For the work zone settings, the construction planning divides the traffic work zone into six different settings in six stages, from 1 to 6 (three sub-stages in stage 4). The re-routing of traffic has changed significantly several times during construction periods. On both the 24th Street and the bridge itself traffic devices, traffic signs, and lane striping change locations from stage to stage. To summarize, using a visualization and simulation program may improve the safety, mobility, planning, and construction processes within the work zone. Moreover, it can be used to better communicate with the public about upcoming road closures.

The following chapter explains the simulation development by dividing the process into three parts: 3-D model development, scheduling data conversion, and KML programming, which is necessary for using the simulation with Google Earth.

Chapter 4:
Visualization and Simulation Development

According to the software feasibility review and the focus group input, the research team developed a work zone visualization and simulation after the survey results were analyzed. Based on the combination of high performance, low costs, ability of real-time navigation, and wide accessibility, a combination of Google SketchUp and Google Earth software was selected.

The simulation was created from scratch starting from digitized 2-D drawings from the 24th Street Bridge Project. Three-dimensional models then were constructed in Google SketchUp based on the 2-D layout provided by the designer. After that, the models were coded in Keyhole Markup Language (KML) to work with schedule data in Google Earth. Additionally, photo-realistic montages were created as a by-product of the simulation. The development time was tracked and analyzed for estimation of labor hours required for development of similar visualizations on future projects. All the software development is free software, so there is no cost for the software. The list of software and the versions used are listed in Appendix A.

On the users' side, the simulation and visualization are designed to be used without the need for installing special, costly software. The only software needed to run the simulation is Google Earth, which is a free download from the Internet. It is available for Windows, Macintosh, and Linux operating systems. The minimum requirements are explained in Appendix B.

To develop the example for this feasibility study, the research team used a desktop computer with Windows XP SP2 with the following specifications:

- CPU: 2.8 GHz, Pentium 4

- System Memory (RAM): 1024 MB/ Hard Disk: 70 GB

- Graphics Card: NVIDIA Quadro4 900XGL 128 MB of VRAM

Three freeware computer applications were used, including:

- Google SketchUp – A 3-D modeling application creating whole construction items, traffic signs, and traffic devices in 3-D models

- Notepad++ (Notepad plus plus) – A text editor coding the programming language to use 3-D models with scheduling data working in Google Earth

- Google Earth – A 3-D navigation tool that supports aerial and satellite photographs

3-D SketchUp Models

All 3-D models were created by using Google SketchUp. Two types of models were built separately in this project: (1) project-specific models, and (2) library models. Both models are saved in SketchUp native format as .skp (SketchUp) files for further editing and modification. They also are saved as an interoperable format COLLAborative Design Activity (COLLADA) file to use in Google Earth.

Project-Specific Models

Project-specific models are models that tailor to specific parts of the project, including different types of roads, bridges, intersections, ramps, and so forth. In the 24th Street Bridge Renovation Project, the following models were made according to proposed and existing construction objects:

- Existing 24th Street Bridge – Four-lane undivided roadway

- Proposed 24th Street Bridge – Six-lane undivided roadway with two-lane left turn

- Existing 24th Street

- Proposed widening 24th Street

- Interstate 80 – Five-lane divided highway

- Existing ramps

- Proposed ramps

- Surrounding buildings

The models were created based on 2-D drawings retrieved from the bridge designer. The PDF drawings were converted into 2-D JPG images to use as a base for 3-D models. Figure 6 shows the completed 3-D model of a six-lane bridge on top of the base 2-D drawings.

Figure 6. SketchUp purposed bridge model – Created on top of PDF/JPG drawing

The simulation was created from digitized 2-D PDF/JPG drawings; however, 2-D CAD can be used instead, if available. After the 2-D outlines were created, the 3-D models were then created by specifying heights to each region as shown in Figure 7.
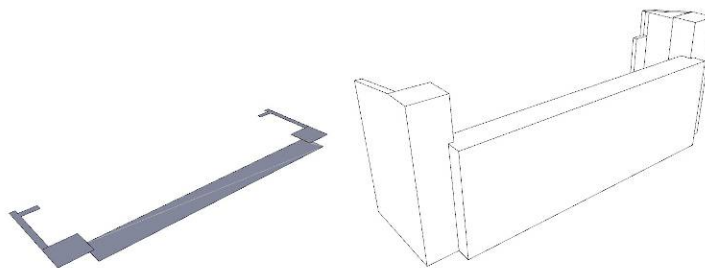
Figure 7. SketchUp wing wall model – Converting from 2-D outline into 3-D model

Colors and textures, called *materials*, were added to the models' faces. Figure 8 shows wing wall models with and without stone material applied. Figure 9 shows a material in a transparent type of safety fence using a PNG image.
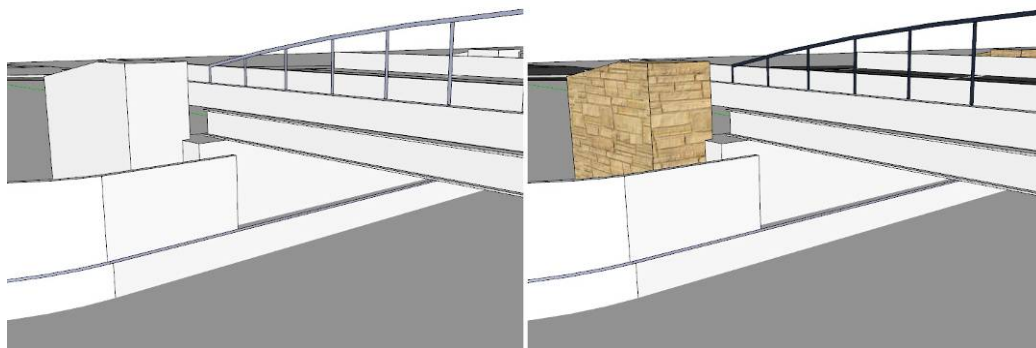
Figure 8. SketchUp wing wall model – without material (left) and with material (right)
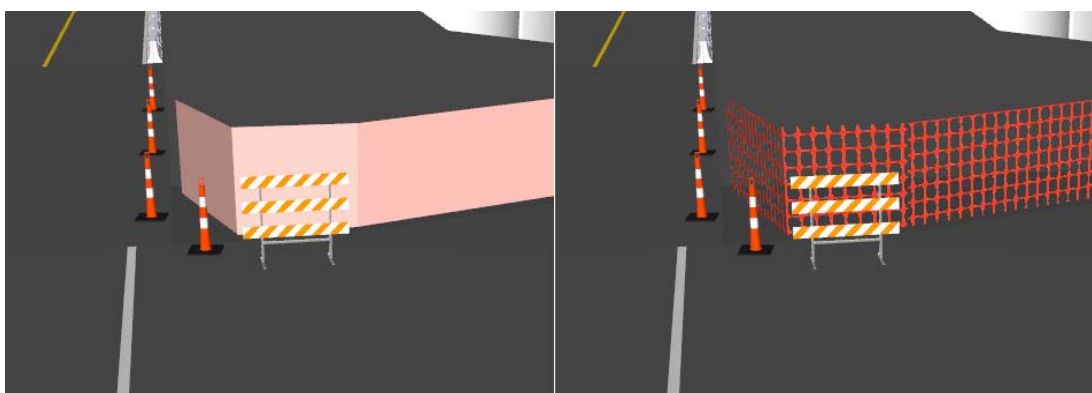
**Figure 9. SketchUp Models – Rendered image of safety fence
with plain material (left) and transparent material (right)**

The accuracy of the project-specific models can be varied depending on the purpose. Because studying the highway work zone is the main purpose in this research, some details such as crown slopes were omitted.

3-D Library Models

3-D library models were created separately from the project-based models. The library models are defined as 3-D models that are reusable in any project. Most of the objects in the

3-D library are traffic signs and temporary control devices. The library also was created and saved in SketchUp native format for reuse. In this project, all 3-D models were created following specifications from the Manual on Uniform Traffic Control Devices (MUTCD) from the Federal Highway Administration. Other than MUTCD signs and devices, some models such as a flagger were created so that they could be reused. Figure 10 shows examples of 3-D library models created and used in this research. From left to right are a tabular marker, electronic sign (chevron sign), barricade, and flagger. Note that these icons are not to scale as recreated below, but would be at-scale when incorporate into a visualization program.
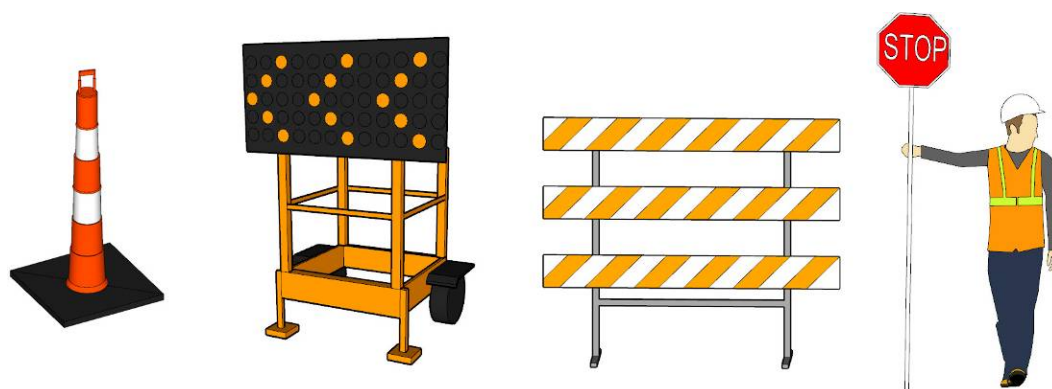
Figure 10. Three-dimensional library models – From left to right: a tabular marker, electronic sign, barricade, and flagger

These library models were imported directly into the work zone visualization and then set at locations according to traffic-phasing layout drawings as shown in Figure 11.
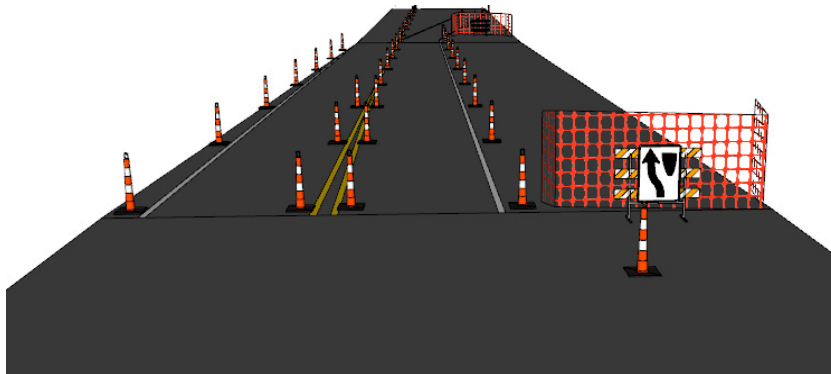
Figure 11. Library models setup illustrating work zone installation

The library models created as part of this research project include:

- 1 flagger in safety vest

- 6 traffic devices

    o Barricade

    o Drum

    o Electronic sign (chevron sign)

    o Safety cone

    o Tabular marker

    o Temporary concrete barrier

- 23 traffic signs

    o 1 guide sign

    o 4 regulatory signs

    o 14 warning signs

    o 4 other signs

To use both project-specific and library models in other applications, the files were saved in COLLADA interoperable format. A COLLADA is a text-based format file arranged in XML

style with the extension .dae. An example of codes is shown in Figure 12. This type of file can be opened in any text editor. The .dae files can be saved from temporary files in SketchUp or exported as files directly in Google SketchUp Pro. The workflow diagram is displayed in Figure 13.

```
<?xml version="1.0" encoding="utf-8"?>
<COLLADA xmlns="http://www.collada.org/2005/11/COLLADASchema"
version="1.4.1">
   <asset>
      <contributor>
         <authoring_tool>Google SketchUp 6.4.112</authoring_tool>
      </contributor>
      <created>2008-03-04T23:24:39Z</created>
      <modified>2008-03-04T23:24:39Z</modified>
      <unit name="inches" meter="0.0254"/>
      <up_axis>Z_UP</up_axis>
   </asset>
   <library_images>
      <image id="material0-image" name="material0-image">
         <init_from>../images/drawing.png</init_from>
      </image>
   </library_images>
   <library_materials>
      <material id="material0ID" name="material0">
         <instance_effect url="#material0-effect"/>
      </material>
      .
      .
      .
```

Figure 12. COLLADA file code example
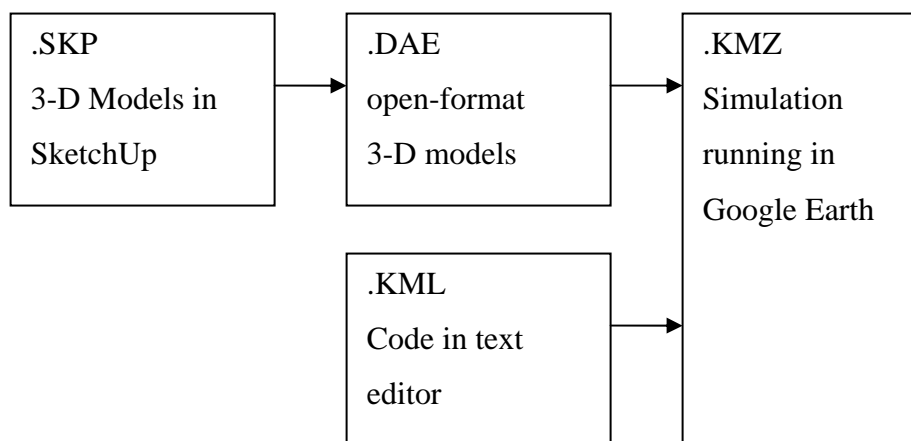
Figure 13. Software work flow diagram

Scheduling Data

Scheduling data used in this research were retrieved from the SureTrak schedule from both the contractor (Cramer) and a research team at Iowa State University performing schedule research on the 24th Street Bridge project

Cramer provided the research team with a preliminary schedule. The project schedule was divided into six phases called "stages" in the project documents. In this research, instead of using start and end dates for separate tasks, as is typically done in 4-D CAD programs, start and end dates of traffic work zone stages were used. Each stage schedule is linked to a 3-D model representing the work zone configuration under that stage of construction.

Models and Schedule Linkage

Three-dimensional models and schedule data were linked by KML code. The code controls the appearance of the models according to the defined schedule. When the specified time is in between the start and end dates, the models appear on the screen. Also, if the specified time is outside the range of start and end date, the model specific to that stage disappears.

Three-dimensional models in each type have different start and end dates listed below:

New construction to be built

- The start date is set according to the contractor's schedule.
- The end date is set from the estimated duration.

Existing structures to be demolished

- The start date is set as the project start date.
- The end date is set according to the scheduled duration for demolition.

Temporary construction objects

- The start date is set according to the scheduled installation date.

- The end date is set according to the scheduled un-installation date.

Surrounding environment objects

- The start date is set as the project start.

- The end date is set as the project finish.

To use the time function in Google Earth, a time navigation bar appears the top-right corner of the simulation screen. End-users can control the timeline by either dragging the cursor to a specific date or playing the simulation from start to finish as shown (screen capture) in Figure 14. A series of static simulation displays is shown in Appendix C.

The full visualization is available via web link at <http://itshee.com/workzone/> .

Figure 14. Google Earth Simulation – Displaying time navigation

Figure 15 shows an example of what the code looks like in KML. Time value is arranged in year-month-date format (YYYY-MM-DD, i.e. 2008-14-01), which can go into details of hours, minutes, and seconds depending on the accuracy needed.

```
<name>Stage 1</name>
<TimeSpan>
        <begin>2008-04-01</begin>
        <end>2008-04-28</end>
</TimeSpan>
.
.
.
```

Figure 15. KML code – An example of TimeSpan tag

Google Earth KML

Keyhole Markup Language, known as KML, is a markup language in XML format used by Google Earth. It has an extension of .kml. The markup code is a set of text defining how elements such as text or graphics appear. Unlike programming languages, markup language is a code defining data, not procedures, so it cannot be computed. XML is a widely used markup language because of its simplicity and flexibility allowing users to define the mark-up elements.

The current standard of KML is KML 2.1. It was first developed by Keyhole and later by Google. Keyhole is a software company in the geospatial data visualization field, founded in 2001. Google acquired it in 2004. Similar to other markup languages, text in angle brackets represents functions and identifiers, while text outside of brackets represents values. An example of KML code shown in Figure 16 creates an illustration of the box-shaped polygon shown in Google Earth in Figure 17. The locations are defined in latitude and longitude in <coordinate> fields with the height defined in <extrude> commands. All elements are based on current KML standard, which can be found in KML documentation on the Google website.

```
<Placemark>
        <name>Building</name>
        <GeometryCollection>
                <Polygon>
                        <extrude>1</extrude>
                        <altitudeMode>relativeToGround</altitudeMode>
                        <outerBoundaryIs>
                        <LinearRing>
                        <coordinates>
                            -95.87880425187282,41.23544760697231,17
                            -95.87881741416284,41.2357473556454,17
                            -95.87868505197329,41.23575066753321,17
                            -95.8786718902864,41.23545091882539,17
                            -95.87880425187282,41.23544760697231,17
                        </coordinates>
                        </LinearRing>
                        </outerBoundaryIs>
                </Polygon>
        </GeometryCollection>
</Placemark>
```

Figure 16. KML code – An example of a box-shaped polygon
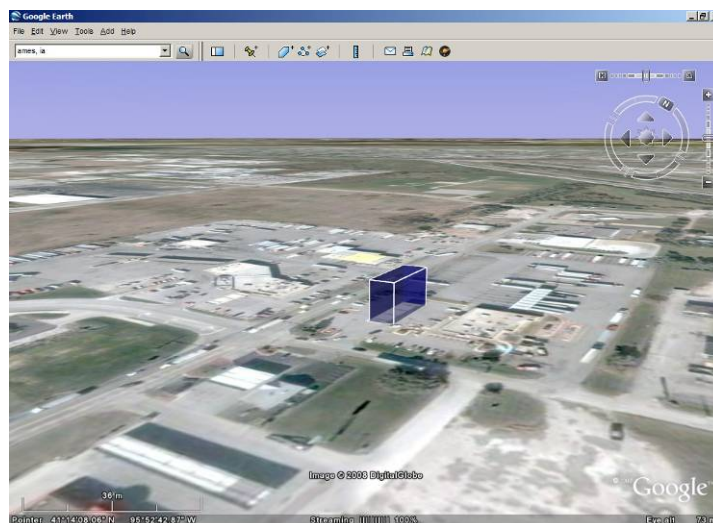
Figure 17. A box-shaped polygon created from KML displaying in Google Earth

A set of data in KML is composed of different models and their functions in separate sets, called placemarks. Each placemark consists of several functions, primarily models, location, and style. An example of a KML placemark is displayed in Figure 18. To explain the code, the 3-D file *model6.dae* displays at the location of the longitude and latitude at

-95.879033808603 and 41.232260364904 respectively. The model will appear if the date cursor is in between the periods of 29 October 2008 through 26 November 2008 as shown in Figure 19. The full KML program is shown in Appendix E.

```
<Placemark id="Stage 6">
    <name>Stage 6</name>
    <TimeSpan>
        <begin>2008-10-29</begin>
        <end>2008-11-26</end>
    </TimeSpan>
    <Model>
    <Location>
        <longitude>-95.879033808603</longitude>
        <latitude>41.232260364904</latitude>
    </Location>
    <Link>
        <href>models/model6.dae</href>
    </Link>
    </Model>
</Placemark>
```

Figure 18. KML code – An example of each model

**Figure 19. Visualization of 24th Street Bridge northbound
during stage 6 displaying in Google Earth**

KML elements used in this project are listed below:

Main elements

- <kml> – root element of a kml file

- <Document> – a container of features and styles

- <Folder> – an element to organize other features

- <name> – name of the display

- <visibility> – an element used to define whether a feature is to be visible or not

Camera elements

- <LookAt> – an element to define a virtual camera relative to the object

- <heading> – rotation about the z axis

- <tilt> – rotation about the x axis

- <roll> – rotation about the y axis

- <latitude> – latitude of the point

- <longitude> – longitude of the point

- <range> — distance from the point of latitude and longitude to the camera

Styles

- <style> – styles referred by other elements

- <linestyle> – drawing style of color and width

- <polystyle> – polygon style

- <color> – color of elements

Models

- <Placemark> – a feature with associated other geometries

- <TimeSpan> – appearance of element defined by <begin> and <end>

- \<GeometryCollection> – a container of geometry primitives with the same feature

- \<polygon> – an element of polygon model

- \<Location> – location of the model composed of \<longitude>, \<latitude>, and \<altitude>

- \<Orientation> – rotation of 3-D models composed of \<heading>, \<tilt>, and \<roll>

- \<Scale> – resizing of elements

- \<Link> – link other elements to the main model

2-D graphics

- \<screenoverlay> – an image overlay element

- \<icon> – a location of overlay image

- \<overlayXY> – a point of overlay image

- \<screenXY> – a point relative to the screen

- \<size> – the image size

Estimated Development Time

The research team kept track of the work hours required to develop the 3-D models and KML codes for visualization and simulation of the 24th Street Bridge project. A total of 44 hours were required in the following categories:

- Review project document (10 hours)

- Create 3-D project models – bridges, ramps, and roads (5 hours)

- Create 3-D library models – traffic signs and devices used in the project (10 hours – reusable)

- Set up traffic zone simulations for six stages and two sub-stages – lane striping, signs, and devices (15 hours)

- Code in KML for Google Earth (2 hours)

- Demonstrate, critique, and revise (2 hours)

As mentioned, library models are created once and reused as duplicated models for different stages in the same project as well as for future projects.

Deployment

The KML file can be deployed separately as several .kml files or a single-file package as .kmz. The latter is more convenient to send over a network. Files with extensions .kmz are a typical zipped format that contains several .kml files. The animation is available for viewing on the Iowa DOT website: www.iowadot.gov/cbinterstate/construction24th.asp

To open either a .kml or a .kmz file, end-users can open the file directly in Google Earth. The simulation will appear in the middle of the screen. If an Internet connection is available, aerial and satellite images will display underneath the models. However, to use the models with aerial and satellite images without Internet connection, users can pre-load those images into the software's temporary storage.

Besides work zone visualization and simulation, 3-D models can be exported to work with other software such as Autodesk Revit or Kerkythea rendering software. The photo-realistic images from the Kerkythea are displayed in Figure 20 and Figure 21. Such compatibility can be useful in developing quick composite images for communicating with the public.

Figure 20. Rendered image of proposed 24th Street Bridge looking toward west

Figure 21. Rendered image of proposed 24th Street Bridge in bird's-eye view

Chapter 5:
Evaluation, Summary, and Recommendations

Evaluation

As discussed earlier in this dissertation, the use of visualization techniques in transportation construction projects has been very limited. The reluctance to adopt visualization for transportation construction projects could be caused by a number of technological, economic, and sociological factors. A review of the existing state of the art in visualization software programs suggests that insufficient technology is not the primary barrier to adoption of visualization technology. A number of 2-D, 3-D, and 4-D software platforms are commercially available to provide visual models of transportation construction work zones. Advanced programs using virtual reality programs are in development, but not yet commercialized.

Although real economic costs and benefits were not examined in this dissertation, the study did investigate industry perceptions, costs, and benefits. It appears that lack of perceived benefit is a contributing factor in the reluctance to adopt visualization technologies in transportation construction projects. Many of the platforms available for creating visualization models have intense data requirements and provide very high levels of detail and accuracy, making them expensive and labor intensive to adopt. There is a general perception among transportation industry leaders that the benefits in terms of reduced costs, better planning, faster construction, safer work zones, and so on do not warrant investment of scarce resources.

Perhaps the greatest barrier to adoption of visualization techniques in transportation construction projects is sociological in nature. There are generational, organizational, and individual differences in awareness and perception of value regarding visualization techniques. Many long-tenured individuals in the transportation construction industry lack the awareness of new innovations and alternative platforms available to create work zone visualizations. Organizational differences in capabilities make closed-platform (licensed)

proprietary programs difficult to implement across the entire project team. Some individuals see benefits in using visualization as a planning tool, whereas others see it as an additive task to an already overburdened industry. Based on the findings of this study, it appears that the highest barrier to adoption of visualization techniques in transportation construction results from sociological factors, not economic or technological issues.

In order to overcome these barriers, any visualization tool would have to be widely accessible to all project partners, relatively intuitive to understand and navigate, and readily convertible from existing, standard 2-D construction documents. A review of existing alternatives suggested that a visualization program combining Google platforms held promise in overcoming many of the sociological barriers. In addition, because these open platforms are widely available at little or no cost, the perceived lack of economic benefit can be diminished. The tradeoff in using a Google platform is loss of detail and accuracy, but as noted, the barrier is not primarily technological in nature. Therefore, it seems logical that work zone visualizations could provide benefit even at reduced levels of details, especially for planning, safety, and public communication purposes.

The benefits of a Google open platform system for visualization are that it provides a unique contribution of a real-time navigation and 4-D simulation at minimum costs. The system provides stakeholders a visualization program to easily understand work zone settings from start to finish. It provides 3-D models along with project scheduling. The models display in a manner similar to 4-D CAD where the models appear/disappear according to scheduling data simulating real construction. Any user with minimal computer skill can navigate and investigate 3-D models in every angle. Additionally, the system is developed by powerful free software and requires comparatively very few labor hours to develop the visualization. All files also are based on open formats, which allow any member of the project team to use and modify them without purchasing a license.

As part of this research, a pilot test of Google work zone visualizations was demonstrated to the project focus group. The industry experts serving on the focus group identified several areas of potential benefit, including prevention of work area interference, internal traffic

control, safety training, and educational purpose. Some possible technological barriers such as lack of technological familiarity or common software were overcome by using simple, downloadable, and open access platforms.

The Google visualization also was demonstrated to the 24th Street Bridge Project team members. The project partners for the 24th Street Bridge confirmed the system's usefulness and ease of use, and acknowledged its potential as a planning tool in highway construction projects. In fact, the 24th Street Bridge project team found the Google visualizations to be of such benefit that they decided to display them on the project's website as a supplement to the standard 2-D work zone configurations typically shown on public websites for transportation projects. One concern raised by the general contractor and resident engineer for the 24th Street Bridge was privacy of construction information. There was a general belief that details of scheduling data should not be exposed to the public. Such details could lead to loss of competitive advantage on low bid awards, and also could cause public perception of schedule performance to become fixed before project details were finalized. A more general work zone visualization, without specific calendar start and end dates, could provide most of the same benefits without creating the potential problems of misinformed public perceptions and loss of competitive advantage.

Summary

In general, the results of the t-tests support the notion that organizational, generational, and technological familiarity factors influence the perceived value of visualization techniques. This finding, along with the comments from the focus group and a review of available visualization technologies, contributed to the finding that the primary factors involved in the failure to adopt visualization are primarily sociological, along with a perceived lack of economic value. Actual technological capabilities were not a factor in the failure to adopt visualization, as there are a number of viable options for creating visualizations of transportation construction work zones.

To overcome the sociological and economic barriers to adoption, a pilot work zone visualization was created by drafting 2-D drawings in Google SketchUp in order to create 3-D models from scratch. The Google 3-D models were then programmed in Keyhole Markup Language to connect the models to the time periods in which the model would appear in the visualization based on staging plans and construction schedule information provided by the general contractor. Finally, every file was saved as a .kmz file ready to deploy in Google Earth.

The visualization also shows that it is feasible to use relatively simple programs as a tool for public communication and 4-D visualization of traffic work zones at different construction phases. From the meetings with focus groups and Council Bluffs project engineers and contractors, people prefer 3-D visualization over the typical 2-D drawings for communication purposes. Some suggest using it via the project website on all future projects as an improved means of communicating to the traveling public. For the planning phase, the Google visualization can be a useful tool for communicating between stakeholders, depicting how current and future traffic work zones will look without causing other interference and construction conflicts. The ease of use and the availability to everyone are major keys to developing the system further.

Limitations

One of the tradeoffs in using open-access platforms such as Google is the loss of detail and accuracy. Future research should examine how such open-access visualization programs can be improved in different levels of detail. The approach can be altered depending on the visualization and simulation purposes. Some specific recommendations are described in the following paragraphs.

A major improvement in detail and accuracy could be achieved in the 3-D model details. The visualization can be improved by increasing the accuracy or dimensional scale of the models themselves. Some model-level of detail such as road curb, road shoulder, crown slope, and cross slope can be added to make it more realistic and to use for geometric design. However,

development cost will likely be increased accordingly. In the future, if the highway construction design process moves from 2-D to 3-D design, the 3-D models can be available without recreating them. For instance, in the building construction sector of the industry, several firms have migrated from CAD to BIM, which is a 3-D model-based design. Returning to highway construction, some software such as Autodesk Civil 3D provides 3-D designs that can be used in Google Earth. An example of application for higher model details is to simulate drive-through on the real-time geometric design measuring driver reactions, truck turning radius, and drainage design, for example. In spite of this, each application will require a different level of details. To find the proper level of details, studies and surveys should be done.

Additional detail can be added to the time dimension of the visualization. The visualization can be improved by increasing the level of details of the schedule from a day to an hour or a minute. To do this, it can be as simple as modifying code in KML to a specific time period. An example of application is to simulate task traffic control or quality control such as installation of the traffic devices in a specific time period. Providing a greater level of detail in the schedule may be important in work zone transitions, lane change-over, or other short-duration, high-traffic disruption events.

The study described in this dissertation identified a primarily sociological phenomenon in failure to adopt work zone visualizations. However, the survey was intended as a complement to the literature review, focus group, and a pilot test, and was not designed as an in-depth analytical tool for identifying sociological factors. The purpose of the research was to identify barriers to adoption of visualization techniques and pilot test a visualization program intended to overcome as many of those barriers as possible. To meet this objective, the research employed a multi-method research design intended to capture a broad array of potential issues, but not to examine any specific issue in depth. This breadth-for-depth tradeoff is appropriate given the objectives of the research, but does present a limitation to a more complex understanding of the impact of interrelated technological, economic, and sociological factors on technology adoption.

For example, to fully understand how sociological factors contribute to technology adoption, survey respondents ideally should have a better understanding of the range of visualization alternatives prior to completing their surveys. In this dissertation, the visualizations that respondents viewed were very simplistic. They did not provide full values across a range of visualization alternatives. Results from respondents for those simple visualizations may be different if they were shown a full range of potential visualizations across the sophistication continuum. To improve the results, more complicated visualization programs should be used, such as the visualization included as the final product of this research. Such an approach can demonstrate different aspects of visualization and thoroughly show work zone construction and staging development.

Recommendations for Future Enhancements

The initial test of feasibility has shown great promise in creating cost effective, widely accessible visualizations of construction work zones on transportation projects. However, future visualization programs could be enhanced, even at the existing level of detail available through Google and Adobe. For instance, the addition of a traffic management function would improve the realism of the visualization, making it a more effective planning tool. Most traffic data are available in time intervals such as vehicles per day or left turns per A.M. peak hour. Therefore, traffic data share a similar construct to schedule data, namely event per unit of time. The same programming that integrates schedule data for the construction work zone visualization could be used to incorporate traffic data. Such an enhanced visualization program could incorporate a realistic traffic mix and flow, allowing engineers and safety officers to review alternative work zone configurations in the planning stage, determining the optimal configuration and transition schemes prior to awarding the construction contract. The enhanced visualization could allow for examination of queue lengths, wait times, turning movements, blind spots, and many other types of analysis prior to the start of construction.

Another enhancement readily possible is the incorporation of a web application. Further research might be developed with web applications to improve accessibility of visualizations. Web applications of models developed for the purpose of stakeholder and public

communication is becoming a trend in project coordination and communication protocols. The work zone visualization could be developed as an application to be accessed via a web browser over a network. Such an enhancement would be reliant on a common web browser to render the application executable without Google Earth installation, and future research could examine the most appropriate combinations of web browser platforms and application. The primary benefit of a web-based application is that designers and planners can deploy and receive responses in shorter periods of time than in a typical desktop application. The software and data required to create the visualization would be stored in a centralized network, so it would not be necessary to send the software and raw data back and forth between the designers/planners and the intended audiences. A web-based application also provides benefit when communicating with mobile devices such as smartphones or netbooks. With the growing popularity of mobile phones and improvement of mobile phone technologies, development of web-based application would represent an effective alternative for communicating with project partners and the traveling public.

Conclusion

The development of visualization programs for construction work zones on transportation projects has been hindered by technology adoption barriers that are primarily sociological and secondarily economic. This dissertation has presented an alternative approach to visualization using low-cost, open-access software platforms that can overcome many of these barriers. The visualizations provide full navigation, incorporate real-time construction schedule information, and are easily used by individuals with only basic computer skills. The visualizations developed in this dissertation have proven to be very useful tools for planning and communicating with the traveling public. However, the visualizations lack the level of detail and accuracy required to be used as construction documents.

Future research can be directed at improving the level of detail and accuracy within open-access platforms such as Google. Enhancements can be made to the existing visualization program by incorporating traffic data and moving the visualization to a web-based application.

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Appendix A: List of Software and Versions Used in the Research Project

Animation for survey - proprietary software licensed by Iowa State University

- Adobe Flash CS3 (9.0.2) – multimedia authoring software for the Internet

- Adobe Photoshop CS3 (10.0) – graphics editor

- Google SketchUp Pro 6 (6.4.112) – 3-D modeling and animation software

4-D-like visualization and simulation – free software

- Google Earth 4.2 (4.2.0205.5730) – virtual globe software
  (http://earth.google.com/)

- Google SketchUp 6 (6.4.112) – 3-D modeling software
  (http://sketchup.google.com/)

- Notepad++ 4.82 – text editor
  (http://notepad-plus.sourceforge.net/)

- Kerkythea 2008 echo – rendering software
  (http://www.kerkythea.net/)

Appendix B: End-Users System Minimum Requirement

Windows

- Operating System: Windows 2000, Windows XP, Windows Vista

- CPU: 500 Mhz, Pentium 3

- System Memory (RAM): 256 MB minimum, 512 MB recommended

- Hard Disk: 400 MB free space

- Network Speed: 128 Kbits/sec

- Graphics Card: 3-D capable with 16 MB of VRAM

- Screen: 1024x768, "16-bit High Color" screen

- DirectX 9 (to run in Direct X mode)

Macintosh

- Operating System: Mac OS X 10.4 or later

- CPU: G4 CPU, 1 GHz or faster

- System Memory (RAM): 256 MB minimum, 512 MB recommended

- Hard Disk: 400 MB free space

- Network Speed: 128 Kbits/sec

- Graphics Card: 3-D capable with 32 MB of VRAM

- Screen: 1024x768, "Thousands of Colors"

Linux

- CPU: 500 Mhz, Pentium 3

- System Memory (RAM): 256 MB RAM

- Hard Disk: 500 MB free space

- Network Speed: 128 Kbits/sec

- Graphics Card: 3-D capable with 16 MB of VRAM

- Screen: 1024x768, "16-bit High Color" screen

- Tested on Ubuntu version 6.06, but also works on other distributions

Appendix C: Simulation Examples of the 24th Street
Bridge Renovation Project

Bird's-eye view over the bridge – looking north from project start to finish

Driver's view at the south of the bridge – looking north from project start to finish
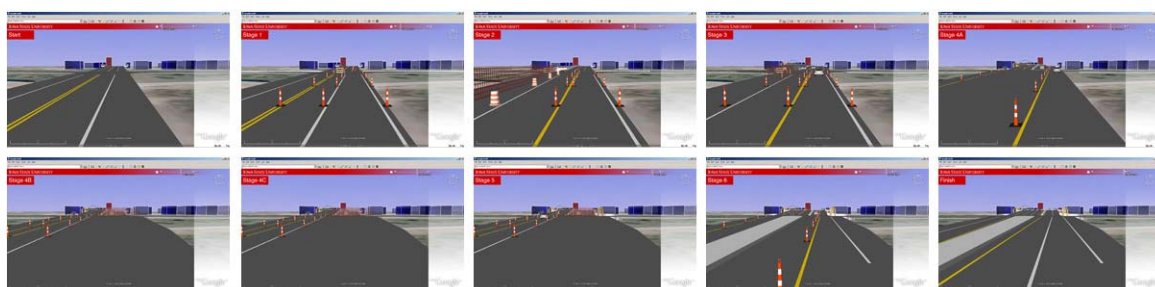
Bird's-eye view over Interstate 29/80 – looking west from project start to finish

Bird's-eye view over the bridge – different perspectives during stage 5

Appendix D: Survey Questions

Work Zone Visualization Project Survey

A research team from the Center for Transportation Research and Education at Iowa State University is interested in your opinions regarding the use of simulation and visualization software to improve work zone safety and mobility for highway reconstruction projects. The following survey will take 10-15 minutes to complete, including the time required to watch the short simulations described below. We know that time is your most valuable asset, and we appreciate your assistance in helping us understand the feasibility of using simulation and visualization software in transportation planning, design, and construction.

Prior to completing the survey, please follow the link below to view three work zone simulations, each of which is configured for three hypothetical construction stages. In each stage, roads are closed in different locations due to construction activity. In the Drive Through boxes (top left and right), you can start the simulation simply by clicking the PLAY button. The top left Drive Through represents good weather conditions; the top right shows same work zone in poor weather conditions. The box at the bottom of the page shows a Map View which the user can pan and zoom for different 2-D visualizations.

When you have viewed the simulations and visualizations for each of the three stages, close the simulations window and complete the survey below.

Thank you very much for your time and assistance with this project.
Link to simulations: http://manop.public.iastate.edu/vis/

Part 1: Background information
1) Which of the following most closely matches your title:
   - o   Project Manager
   - o   Resident Engineer
   - o   Design Engineer
   - o   Safety Officer
   - o   Field Engineer
   - o   Field Superintendent

- o Operations Manager
- o Other_____

2) What are your primary job responsibilities (check all that apply):
- o Overall coordination of project tasks
- o Supervise design activities
- o Prepare design documents
- o Administer design documents
- o Supervise construction activities
- o Prepare final construction documents
- o Administer final construction documents
- o Supervise contract compliance
- o Prepare contracts/Procurement
- o Award contracts/Procurement
- o Field supervision
- o Safety/Risk control
- o Quality control
- o Quality assurance

3) How long have you worked in the highway construction industry?
- o _____ years

4) What is the classification of your organization:
- o General Contractor
- o Construction Manager
- o Design Builder
- o Specialty Contractor
- o Designer
- o Consultant
- o Government agency
- o Other_____

Part 2: Computer and Software Usage

5) How often do you use a computer as part of your primary job responsibilities?

   o   Almost never

   o   2-3 times per week

   o   4-5 times per week

   o   Every day

6) How often do you use Internet?

   o   Almost never

   o   2-3 times per week

   o   4-5 times per week

   o   Every day

7) What is your current computer operating system?

   o   Windows 2000

   o   Windows XP

   o   Windows VISTA

   o   Macintosh

   o   Other_____

8) Do you use Computer Aided Design software as part of your job responsibilities?

   o   yes (please answer Question 9 below)

   o   no (please go to Question 13)

9) What kind(s) of Computer Aided Design (CAD) software do you use (check all that apply)?

   o   Microstation

   o   AutoCAD

   o   ArchiCAD

   o   Revit

   o   Other_____

   o   Other_____

   o   Other_____

10) If you primarily use Microstation, are you familiar with AutoCAD?

- o Yes
- o No
- o Not applicable

11) If you primarily use AutoCAD, are you familiar with Microstation?

- o Yes
- o No
- o Not applicable

12) How often have you encountered file conversion problems with your CAD program?

- o Never
- o A few times
- o Somewhat often
- o Frequently

13) Do you use GIS (geographic information system) data in your work?

- o Yes
- o No

14) Do you use 2-D drawings in your day-to-day work?

- o Yes
- o No (go to Question 16)

15) If yes, approximately what percentage of drawings are produced and distributed in hard copy versus electronic format? (if some documents are produced in both formats, total will exceed 100%)

- o _____% Hard copy
- o _____% Electronic format

16) What percentage of your design and construction documents are produced using 3-D drawings or 3-D models in your work?

- o _____% 3-D

17) Do you use project scheduling software as part of your job responsibilities?

- o   yes (please answer Question 18 below)
- o   no (please go to Question 21)

18) Which of the following scheduling software packages are you familiar with for highway projects

(Check all that apply)?

- o   Primavera
- o   SureTrak
- o   Microsoft Project
- o   Microsoft Excel
- o   Other_____

19) How often does your organization update the schedule on a typical project?

- o   Daily
- o   Weekly
- o   Bi-weekly
- o   Monthly
- o   Never

20) Approximately what percentage of schedule information is distributed in hard copy versus

electronic format? (if some information is produced in both formats, total will exceed 100%)

- o   _____% Hard copy
- o   _____% Electronic format

21) What is your preferred method for contacting project partners if there is a schedule conflict?

(Check all that apply)

- o   Phone
- o   Email
- o   Regular Mail
- o   Overnight Mail
- o   Other_____

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Part 3: Work Zone Issues

Please rate your agreement with the following statements on a scale of

1 (strongly disagree) to 7 (strongly agree)

22) Drivers in highway work zones are adequately **informed** using existing methods and
technologies.

1	2	3	4	5	6	7
strongly			neither agree			strongly

23) Drivers in highway work zones are adequately **prepared** using existing methods and
technologies.

1	2	3	4	5	6	7
strongly			neither agree			strongly

24) Current methods and technologies provide adequate safety for construction workers in highway
work zones.

1	2	3	4	5	6	7
strongly			neither agree			strongly

25) Current methods and technologies provide adequate safety training for construction workers in
highway work zones.

1	2	3	4	5	6	7
strongly			neither agree			strongly

26) Dynamic message boards on the road increase safety in highway work zone.

1	2	3	4	5	6	7
strongly			neither agree			strongly

27) If drivers know the exact location and configuration of the work zones along the highway, it will
significantly improve **safety** in the work zone.

1	2	3	4	5	6	7
strongly			neither agree			strongly

28) If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve **mobility** in the work zone.

1	2	3	4	5	6	7
strongly			neither agree			strongly

29) Three-dimensional drawings of the work zone and road closures can improve highway work zone safety.

1	2	3	4	5	6	7
strongly			neither agree			strongly

30) Four-dimensional simulations of the work zone and road closures can improve highway work zone safety.

1	2	3	4	5	6	7
strongly			neither agree			strongly

31) Simulation of work zones used in the planning and design phase would help my organization better prepare for the safe and efficient accommodation of traffic during construction.

1	2	3	4	5	6	7
strongly			neither agree			strongly

32) My organization would use work zone simulations in our training program.

1	2	3	4	5	6	7
strongly			neither agree			strongly

33) My organization would use work zone simulations in job safety analysis and evaluation.

1	2	3	4	5	6	7
strongly			neither agree			strongly

34) My organization would use work zone simulations in internal traffic control.

1	2	3	4	5	6	7
strongly			neither agree			strongly

35) My organization would use work zone simulations in communicating with the public.

1	2	3	4	5	6	7
strongly			neither agree			strongly

36) My organization would use work zone simulations to define access points for deliveries.

1	2	3	4	5	6	7
strongly			neither agree			strongly

37) In the design phase, work zone simulations would improve drainage design.

1	2	3	4	5	6	7
strongly			neither agree			strongly

38) In the design phase, work zone simulations would improve utility design.

1	2	3	4	5	6	7
strongly			neither agree			strongly

39) In the design phase, work zone simulations would prevent many construction conflicts.

1	2	3	4	5	6	7
strongly			neither agree			strongly

40) Simulation of work zones would be useful in driver education programs.

1	2	3	4	5	6	7
strongly			neither agree			strongly

Appendix E: KML Code for the Main File (doc.kml)

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```
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