

Feasibility of Visualization and Simulation Applications to Improve Work Zone Safety and Mobility



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1. INTRODUCTION

Highway construction projects typically involve a large number of stakeholders with varying degrees of knowledge and experience regarding interpretation of design drawings. Although transportation project designs frequently do not have the spatial complexity of building construction, project complexity and stakeholder communication is often more of a challenge due to extensive public involvement. In addition, minimal delays in transportation projects can affect public interests drastically.

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, 2D drawings, drive-through or fly-through animations, 3D rendering models, virtual reality, and 4D 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. However, visualization tools are typically used for presentation only in large-scale urban projects. Visualization is not widely accepted due to a lack of demonstrated engineering benefits for typical agency projects, such as small- and medium-sized 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 only been used in academic research settings, and 4D 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 which may provide some benefit to many agency projects. In this paper, we present the results of a feasibility study examining the use of visualization and simulation applications for improving highway planning, design, construction, and safety and mobility.

2. LITERATURE REVIEW AND EXISTING RESEARCH STUDIES

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). Highway work zones have been the subject of several recent research studies. 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). Driving simulators using 3D models to replicate road signs, construction equipment, and wildlife have been used to study drivers' behavior in a laboratory setting (Stanley 2006). Accident and work zone database displays overlaid on state highway maps have proven useful in illustrating statistical data in a graphical format (Shi 2008).

4D CAD has demonstrated numerous benefits, especially in building and industrial construction (Fischer et al. 2003). 4D CAD is a technique that visualizes scheduling data through 3D 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 in Anaheim, California and Disneyland theme park in Hong Kong with significant benefits to designers, general contractors, subcontractors, and owners. 4D CAD enhanced communication between project partners and facilitated understanding of design intent while minimizing delays during the construction phase. 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 reworking. Unforeseen conditions caused by interference and conflicts on site were discovered earlier in the design phase, allowing designers and engineers to develop constructability solutions for some circumstances such as working under cranes and in confined spaces.

Few transportation projects have utilized 4D CAD. The High Five Interchange project in Dallas, Texas used 4D CAD to facilitate the coordination on multilevel bridge construction (Liapi 2003). The researchers studied different traffic control scenarios for each construction phase. A similar approach was used for a tunnel construction project by a private company in Sydney, Australia. The project team used 4D CAD visualization techniques for communication and presentation of design and construction.

In summary, few transportation projects have utilized advanced simulation techniques, and static image composites remain the most common visualization technique in spite of recent advances in design software. The slow adoption of new simulation technology in transportation projects may have many causes, including financial and human capital investment concerns, while less complex visualization tools are perceived to provide little benefit on projects of relatively low complexity.

3. METHODOLOGY

For the feasibility study using visualization and simulation in highway work zone safety and mobility, the research team investigated current technologies, collected suggestions from academic and industry focus groups, conducted an industry survey, and developed a simulation prototype. The 24th Street Bridge Renovation Project in Council Bluffs, Iowa was selected to be the sample study project.

3.1 Project Study

In this research, the 24th Street Bridge Renovation Project in Council Bluffs was used as a project study. The renovation project is located at the existing 24th Street Bridge in Council Bluffs, Pottawattamie County, Iowa. It is a part of the Council Bluffs Interstate System (CBIS) improvements project. The project scope is to replace an existing four span 215 ft 5 in. by 53 ft pretensioned, prestressed concrete beam bridge with a two span 350 ft by 105 ft 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 phases, 24th Street will provide one-lane traffic in each direction with a shared center lane for left-hand turns.

The project was designed by HDR of Omaha, Nebraska. In November 2007 it was awarded to Cramer & Associates of Grimes, Iowa for \$12.5 million. The daily traffic on I-80/I-29 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 1. The location of the new bridge during stage 1 (looking west from the existing bridge)

3.1.1 Project Site Analysis

The reasons for selection of the site 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 which potentially affect their customers. In order to communicate between engineers and non-engineers, visualization 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 traffic merging from two interstate highways, I-29 and I-80, into one highway I-29/I-80 underneath the project site. 24th Street itself also has high traffic 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 stage 1 to 6 (with three sub-stages in stage 4). The traffic has significantly changed several times during construction periods. On both 24th Street and the bridge itself there are different settings of traffic devices, traffic signs, and lane striping which change from stage to stage. To summarize, use of 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.

3.2 Technology and Software Study

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

3.3 Commercial 4D Packages

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

3.3.1 JetStream

Jetstream is a 3D design package from Autodesk formerly known as NavisWorks JetStream. The current version is JetStream V5 that was introduced in 2007. The package comes with different software providing different tasks. JetStream Roamer is the core software working as a typical 3D navigation program. JetStream TimeLiner is an add-on binding project scheduling data onto 3D models. It was used for a 4D tunnel project in Sydney, Australia in February 2004. Thiess Pty Ltd., an Australian company, used it as a communication tool and for internal presentation to groups of contractors and project managers for area coordination. JetStream Roamer supports

major CAD or 3D model files including AutoCAD 2007, MicroStation, ArchiCAD, Viz 2007, Revit, SketchUp 6, and 3ds Max. JetStream TimeLiner supports major project schedule software including Primavera P3 and Microsoft Project. The software can export into Acrobat PDF and video files in Windows AVI format. JetStream can be used during the design and preconstruction phase to identify potential conflicts in physical space (e.g., two utility pipes occupying the same space) or work space interference (e.g., lack of overhead clearance for crane booms).

3.3.2 ProjectWise

ProjectWise is a 3D package from Bentley Systems. The current version is V8 XM edition. The core software is ProjectWise Navigator (formerly Bentley Navigator) 3D 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 3D model files including DGN, DWG, PDF, AutoPlant, TriForma, PlantSpace, PDS, Google SketchUp 5 (only), GoogleEarth, 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 2D and 3D models. Besides the 4D purpose, ProjectWise can be used for 3D online collaboration by using ProjectWise Integration Server and ProjectWise StartPoint.

3.3.3 Project 4D

Project 4D is an all-in-one 4D design software from Common Point Inc. It was developed by The Walt Disney Company and Stanford University. The current version is Project 4D 1.96. It was first used for California Screamin', a steel roller coaster 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 3D model files from 3D Studio Max/VIZ, FormZ, Rhino, XSteel and schedule files from SureTrak, Expedition, MS Project, and Excel comma or tab-delimited files. Besides Project 4D, Common Point Inc. provides add-on packages such as ConstructSim and OpSim for use in construction simulation.

3.3.4 FourDscope

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

There are also several proprietary 4D CAD products not commercially available, such as PM-Vision by Construction System Associates, which is an in-house software used for consultant services only. There are also several defunct 4D 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 (Visual Engineering developed from research project from Boise State University).

3.4 Adaptation of Software with 3D Environment

To simulate a 4D-like system, working with a 3D environment application along with short programming codes is a viable alternative. This approach is able to create visualization and simulation without coding from scratch like working on 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).

3.4.1 Adobe Acrobat 3D

Adobe Acrobat 3D is an enhancement of typical Adobe Acrobat PDF which supports 3D models. The current version is Adobe Acrobat 3D 8. Acrobat 3D supports several 3D modeling systems including AutoCAD, MicroStation, 3ds Max, and SketchUp. The software includes pre-built navigation tools so the software can run as a stand-alone 3D environment. Users can view either online or offline similar to typical Adobe PDF files by 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 with Adobe Acrobat 3D. The benefit of using Acrobat 3D is that it is readily available without requiring additional software beyond Adobe Reader.

3.4.2 Second Life

Second Life is an online application gaining in popularity. It provides real-time 3D navigation similar to multiplayer online video games. Users can create 3D models in an online environment which can be imported from external applications; 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; however, builders operating in Second Life pay a fee for creating any item in the shared platform.

3.4.3 Google SketchUp and Google Earth

Google SketchUp is 3D modeling software which 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 which is used to create and render 2D graphics. Google SketchUp Pro functions on top of the free version and allows users to save animations and export 3D models working with other major 3D software such as AutoCAD, Revit, JetStream, and ProjectWise. Google SketchUp can work with the script by using Ruby programming language. Google Earth uses KML (Keyhole Markup Language) in the software working with other 3D models, such as SketchUp export files in DAE.

3.4.4 Walkinside

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

3.5 Other Approaches

Besides 4D-like visualization approaches, the research team studied these other techniques.

3.5.1 Handheld Device Animations

An example of work zone animation for handheld devices was created for analysis purposes. The pre-set animation shows drive-through simulation of the work zone. Such animations can be used with a cell phone or palmtop computer. The goal is to improve usage by people without computer access or those 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 pre-set videos from 3D simulations. The files are encoded and saved in available format for each device. The accessibility of this approach is satisfactory, but the simulation functionality is very limited.

3.5.2 2D 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. Then the photos were retouched using graphic software (Adobe Photoshop) as shown in Figure 2. The left photo is a current highway ramp condition, while the right photo shows a future work zone condition. This approach has the benefit of not needing the time to develop 3D models. However, it can be excessively time-consuming if there are several retouched images needed. The work time is about 30 minutes per image.



Figure 2. Original ramp (left) and traffic image retouched (right) on southwest ramp merging onto 24th Street

3.6 Software Comparison

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 3D models in any angle, The most constraining is the pre-set 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 4D software packages besides JetStream are grouped together since they share common values of the key issues listed above. Table 1 shows a comparison of the software.

Table 1. Comparison of Software

Issues	4D 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
3D development cost and time	High		High	High	Medium	Low	High
Real-time navigation	Yes	No	Yes	Yes	Yes	Yes	Yes
Availability to end-users	No	Yes	Yes	Yes	Yes	Yes	No
Internet connection required	No		No	No	Yes	Optional	No

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 compared to other software. The development cost and time are low.

3.6.1 Data Requirements

After reviewing the software there are two types of data required to create visualization and simulation programs. These are 3D modeling data and scheduling data. 3D models are data that represent real construction objects. Each model must be composed of at least model name and model properties (polygon or face). Scheduling data comes from traffic work zone schedule information. Each schedule data point must be composed of task name, staging number, and start and end dates. These two data types are linked together by their reference names to visualize the schedule by 3D models.

Existence of scheduling data is common in highway projects. However, the major obstacle is that in general, 3D models are never created as part of the design process for transportation projects. They are typically only created for major construction projects requiring public involvement or multijurisdictional approvals. Therefore, the cost to develop 3D models is typically not included in the original design proposal, and there are currently no methods to generate 3D models from 2D drawings. The feasibility of overcoming this data gap is the subject of this study.

To identify state departments of transportation's (DOT's) data needs and implementation constraints for work zone visualization and simulation programs, the research team conducted an industry survey and focus group discussion.

3.7 Focus Group

Prior to developing the simulations, the research team convened a nine-person focus group of knowledgeable industry leaders from academia, the Iowa DOT, U.S. Federal Highway Administration (FHWA), and traffic control contractors. Focus group participants viewed the simulations and were asked their opinions regarding what aspects of transportation planning, design, and construction could benefit from the use of such simulations. The focus group used open-ended questions facilitated by the principal investigator. Areas of 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.

After the analysis of survey results and the 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. A concern about the development cost and time was answered during the meeting. The research team also did a demonstration for the different parties at the project site in Council Bluffs. Some feedback from Iowa DOT engineers and contractors includes a possibility to merge the visualization and simulation into the current project website. 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.

3.8 Survey

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 three work zone configurations, each represented in ideal conditions and in poor visibility conditions, for a total of six simulations. The simulations were created in Google SketchUp Pro and Adobe Flash. Screen captures from the different visualizations are shown in Figure 3–5.

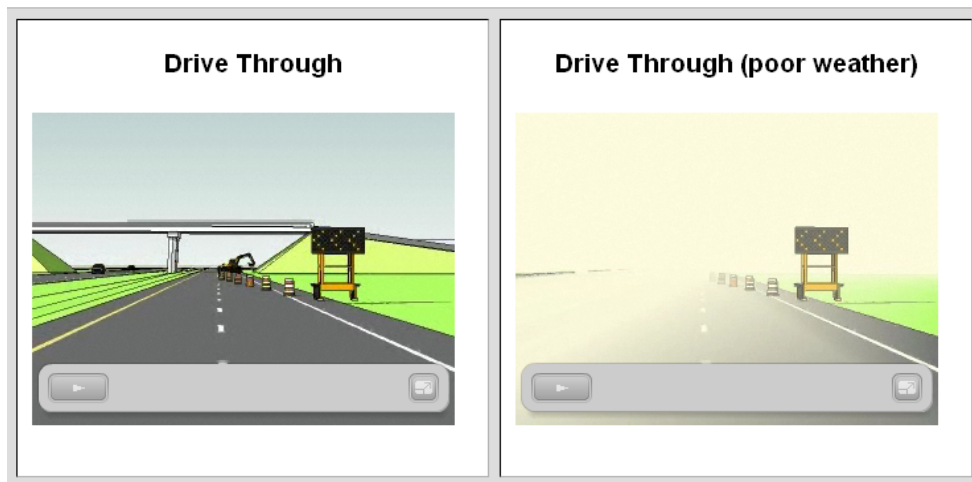


Figure 3. Traffic control for one-lane closure on divided highway

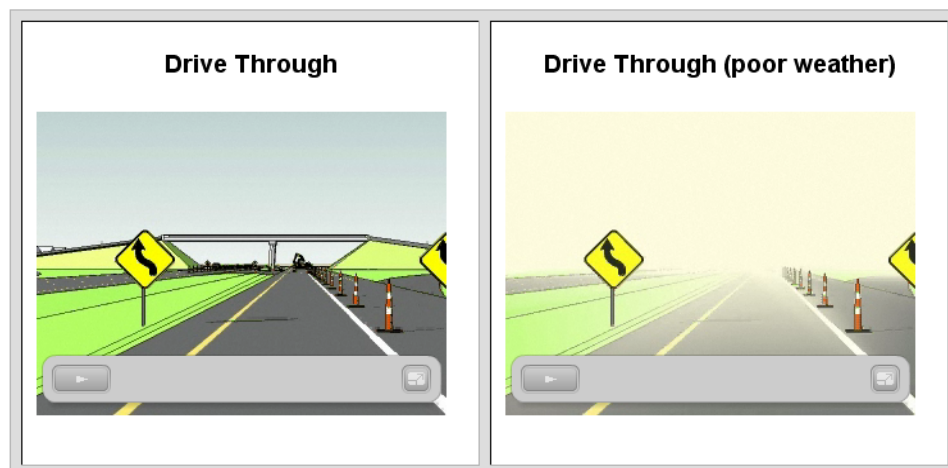


Figure 4. Traffic control for two-lane closure, head-to-head operation

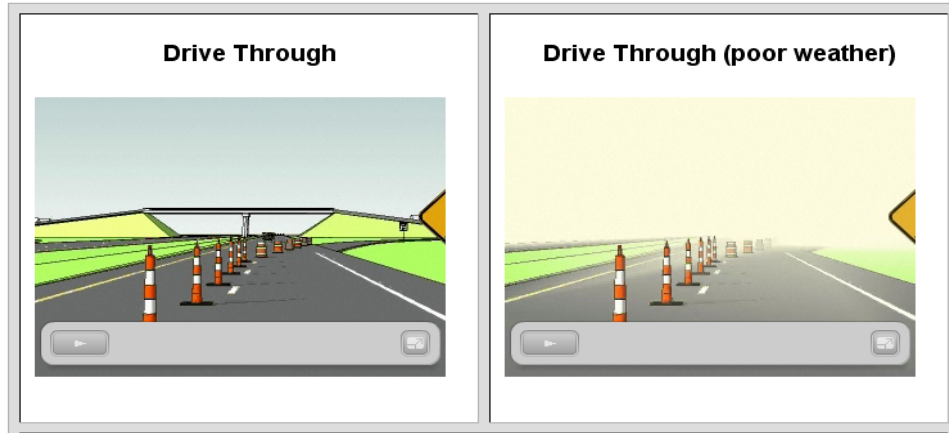


Figure 5. Traffic control for full closure with temporary detour via exit/entrance ramps

Using the issues identified in 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, while 19 items asked opinions regarding adequacy of current technologies and adoption of simulation technologies. The survey was distributed on-line 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, 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 21.

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

Several t-tests were conducted to identify differences in respondents based on attributes. Comparisons were made between six different demographics factors as described in the following sections

3.8.1 Government and Non-government Agency (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, the non-government agencies have less satisfaction than the government agencies. At the same time for the perceived benefit of work zone simulations, non-government agencies tend to disagree that the simulation can improve the current system either in planning and design, drainage design, or utility design.

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

Survey item	Non-government	Government	Significant
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%

3.8.2 Individuals with More or Less Than 20 Years' Experience

There are four answers showing significant difference in values between responders with more than 20 year experience and less than 20 years experience. People with less than 20 years experience tend to believe the usage of 3D and 4D visualization improves work zone safety more than people with more 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. T-Test data of survey results between people with more than 20 years experience and those with less than 20 years experience

Survey item	Less than 20 years	More than 20 years	Significant
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%

3.8.3 CAD Users and Non-users

One response 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 3D drawings of the work zones can improve work zone safety more than those people not familiar with the CAD system.

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

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

3.8.4 GIS Users and Non-users

There are three answers showing significant difference in values between responders who are familiar with Geographic Information Systems (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.

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

Survey item	Non-GIS user	GIS user	Significant
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%

3.8.5 2D Drawing Users and Non-users of 2D Drawings

There are nine answers showing significant difference in values between responders who are using 2D drawings as part of their jobs and those persons who are not. The persons who use 2D drawings as part of their job have higher satisfaction with the current safety technologies. Persons who do not use 2D drawings as part of their jobs have higher satisfaction with the dynamic message boards. They believe that the advanced 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.

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

Survey item	Non-2D user	2D user	Significant
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%

3.8.6 Regular Users of Scheduling Software and Non-users

There are five answers showing significant difference in values between responders who are familiar with scheduling software and those persons who are not. Persons familiar with the scheduling software have higher satisfaction with the current safety technologies but less satisfaction with the dynamic message boards. The people who are not familiar with scheduling software have higher acceptance of the usage of simulations during the design phase on drainage and utility designs including those that can prevent construction conflicts.

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

Survey item	Non-scheduling familiarity	Scheduling familiarity	Significant
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%

4. VISUALIZATION AND SIMULATION DEVELOPMENT

From the software feasibility review, the focus group input, and survey responses from the industry, the research team developed a traffic highway visualization and simulation by using a combination of Google SketchUp and Google Earth software. The simulation was created from scratch starting from digitized 2D drawings from the 24th Street Bridge Project. Then 3D models were constructed based on the 2D layout. After that, the models were coded in Keyhole Markup Language (KML) to work with schedule data in Google Earth. Additionally, the photo-realistic image was created as a by-product result from 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 freeware, so there is no cost for the software.

For the users' side, the simulation and visualization is designed to use 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 in Windows, Macintosh, and Linux operating systems. The minimum requirements are explained in the Appendix.

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

- Operating System: Windows XP SP2
- CPU: 2.8 GHz, Pentium 4
- System Memory (RAM): 1024 MB
- Hard Disk: 70GB
- Graphics Card: NVIDIA Quadro4 900XGL 128MB of VRAM

Three freeware computer applications were used which are:

- Google SketchUp—A 3D modeling application creating whole construction items, traffic signs, and traffic devices in 3D models.
- Notepad++ (Notepad plus plus)—A text editor coding the programming language to use 3D models with scheduling data working in Google Earth.
- Google Earth—3D navigation tool with aerial and satellite photographs supported.

4.1 3D SketchUp Models

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

4.1.1 Project-Specific Models

Project-specific models are those models which are tailored 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 of 24th Street
- Interstate 80—Five-lane divided highway
- Existing ramps
- Proposed ramps
- Surrounding buildings

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

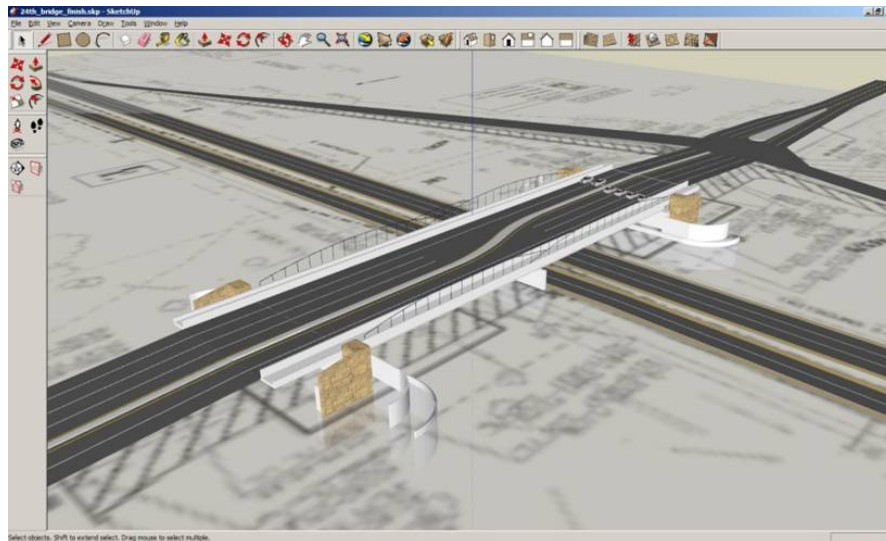


Figure 6. SketchUp proposed bridge model—Created on top of PDF/JPG drawing

The simulation was created from scratch starting from digitized 2D PDF/JPG drawings; however, 2D CAD can be used instead if available. After the 2D outlines were created, then the 3D models were created by specifying heights to each region as shown in Figure 7.

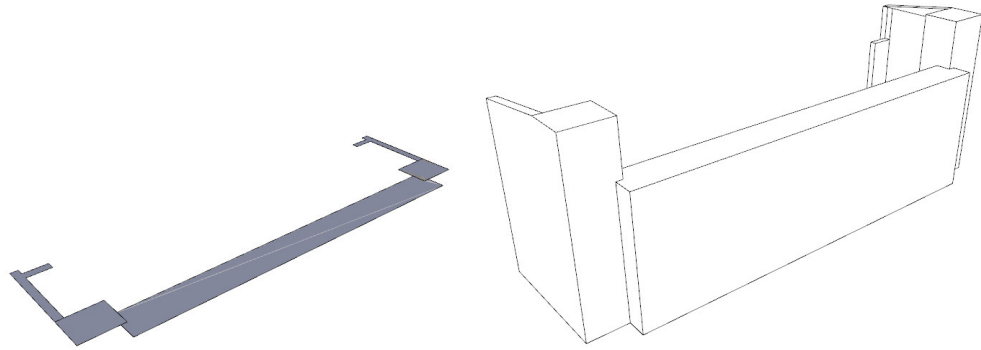


Figure 7. SketchUp wing wall model—converting from 2D outline into 3D model

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 PNG image.

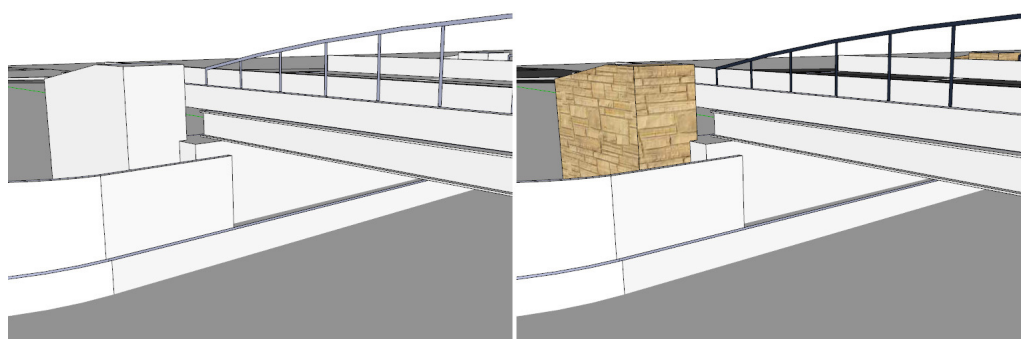


Figure 8. SketchUp wing wall model—without material (left) and with material (right)

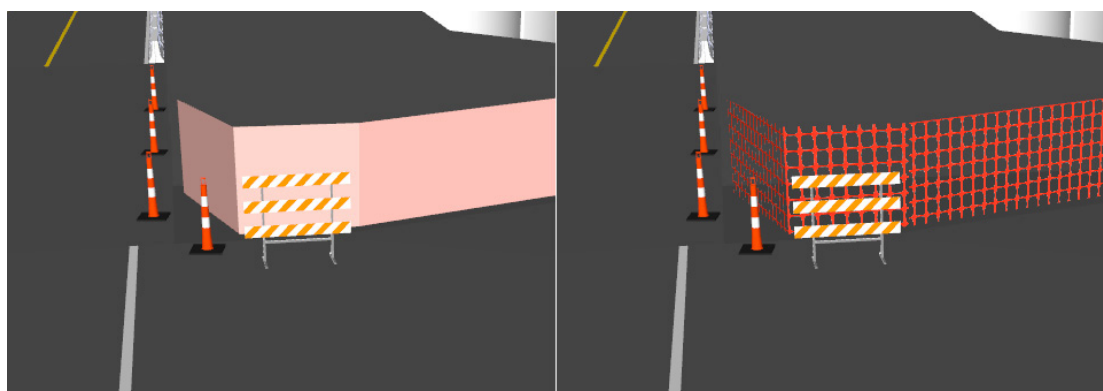


Figure 9. SketchUp Models—safety fence in plain material (left) and transparent material (right)

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

4.1.2 3D Library Models

3D library models were created separately from the project-based models. The library models are defined as 3D models which are reusable in any project. Most of the objects in the 3D library are traffic signs and temporary control devices. The library was also created and saved in SketchUp native format for reuse. In this project they were created following specifications from the Manual on Uniform Traffic Control Devices (MUTCD) from the FHWA. The accuracy of the library models are exactly the same as shown in the specifications. Other than MUTCD signs and devices, some models such as a flagger were created to be reused. Figure 10 shows examples of 3D library models created and used in this research; from left to right are tabular marker, electronic sign (chevron sign), barricade, and flagger. Note that these icons are not to scale below, but would be at-scale when incorporated into a visualization program.

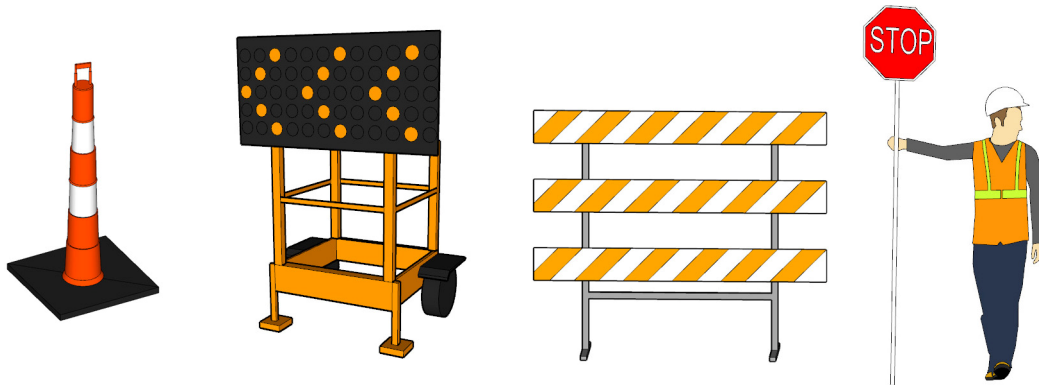


Figure 10. 3D library models—from left to right tabular marker, electronic sign, barricade, and flagger

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.

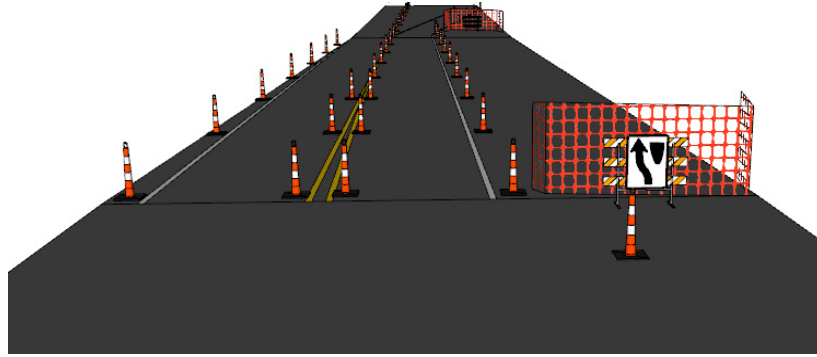


Figure 11. Library models setup illustrating work zone installation

To use 3D models with different applications, they were saved in COLLADA (COLLABorative Design Activity) interoperable format. COLLADA is a text-based format file arranged in XML style with the extension .dae; example of codes are shown in Figure 12. This type of file is able to be opened in any text editor. The .dae files can be retrieved from a temporary folder in SketchUp and transferred to models developed in Google Earth. Google SketchUp Pro (paid version) has a slight benefit which is the ability to save files in extension .dae directly.

```
<?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

4.2 Scheduling Data

The scheduling data used in this research was 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 Construction Inc. provided the research team with a preliminary schedule. For the highway construction schedule, in addition to the typical construction schedule, tasks are grouped into stages for traffic control. Work zone stages are also used as schedule milestones. In this research, instead of using start and end dates for separate tasks, start and end dates of traffic work zone stages were used. Each stage schedule is linked to a 3D model representing the work zone configuration under that stage of construction.

4.3 Models and Schedule Linkage

3D 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. At the same time, if the specified time is outside the range of the start and end date, the model specific to that stage disappears.

3D 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 date of removal of the temporary objects.

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 shows in 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 by a screen capture in Figure 13.



Figure 13. Google Earth Simulation—displaying time navigation

The visualization program is available for view at <ftp://www.ctre.iastate.edu/>, under the WorkZoneVisual directory. The site requires a Username (ctreftp) and Password (ftpctre). Once in the WorkZoneVisual directory, download the 24stbridge.kzm file. Figure 14 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 14. KML code—an example of TimeSpan tag

4.4 Google Earth KML

Keyhole Markup Language, known as KML, is a markup language used in Google Earth. Unlike a programming language, the markup language is a language type running directly in the software without additional compiling. In this research, Notepad++ was used as a text editor.

The KML file, with a native extension of .kml, is a markup code in XML format. The current standard is KML 2.1. It was first developed by Keyhole and now Google. Similar to other markup languages, text in angle brackets represents functions and identifiers, while text outside the brackets are values. An example of KML code shown in Figure 15 creates an illustration of the box-shaped polygon shown in Google Earth in Figure 16. The locations are defined in latitude and longitude in <coordinate> with the height defined in <extrude>.

```

<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 15. KML code—an example of a box-shaped polygon

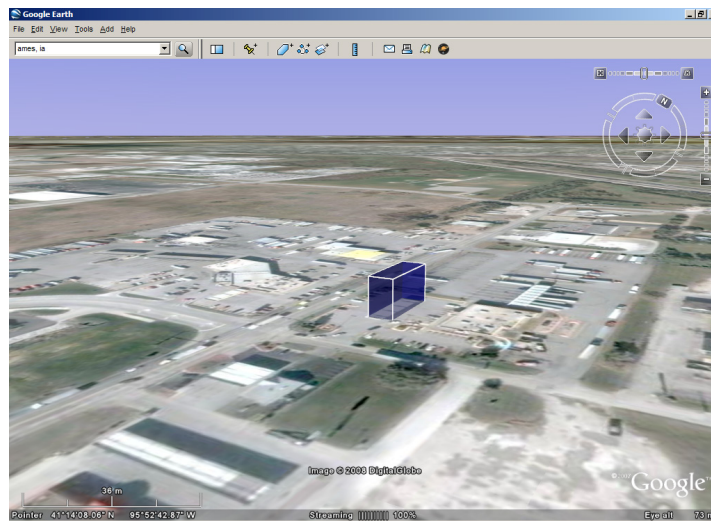


Figure 16. A box-shaped polygon created from KML displayed in Google Earth

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 17. To explain the code, the 3D 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 October 29, 2008, through November 26, 2008, as shown in Figure 18.

```

<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>
<altitude>0.000000000000</altitude>
</Location>
<Link>
  <href>models/model6.dae</href>
</Link>
</Model>
</Placemark>

```

Figure 17. KML code—an example of each model

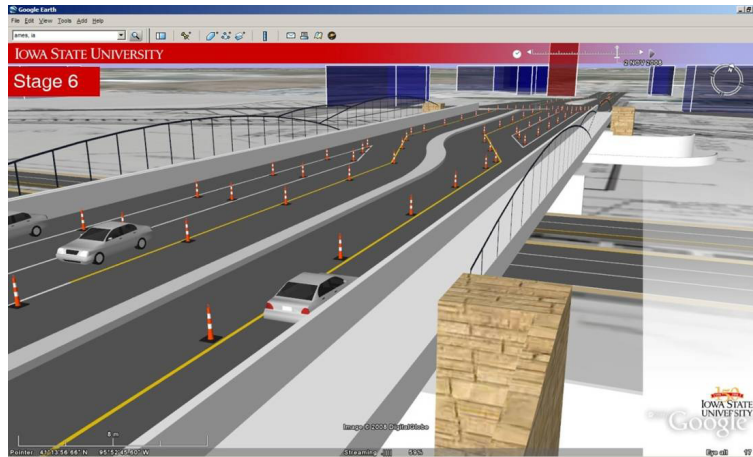


Figure 18. Visualization of 24th Street Bridge northbound during stage 6—displayed in Google Earth

4.5 Estimated Development Time

The research team kept track of the work hours required to develop the 3D 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 3D project models—bridges, ramps, and roads (5 hours)
- Create 3D library models—traffic signs and devices used in the project (10 hours—reusable)
- Setup traffic zone simulations for 6 stages and 2 substages—lane striping, signs, and devices (15 hours)
- Code in KML for Google Earth (2 hours)
- Demonstrate to retrieve feedback (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.

4.6 Deployment

The KML file can be deployed separately as several .kml files or a single-file package as .kmz, which is more convenient to send over the network. The file .kmz is a typical zipped format. It contains several .kml files.

To open either the .kml or .kmz file, end users can open the file directly in Google Earth. The simulation will appear in the middle of the screen. If the 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 temporary storage.

Besides work zone visualization and simulation, the existing 3D proposed bridge was rendered by software named Kerkythea as a by-product result. The photo realistic images of the bridge are displayed in Figure 19 and Figure 20.



Figure 19. Rendered image of proposed 24th Street Bridge looking toward the west



Figure 20. Rendered image of proposed 24th Street Bridge in bird's-eye view

5. SUMMARY AND RECOMMENDATIONS

5.1 Summary

The survey results indicated that responders' opinions are neutral toward the work zone simulation initiative. The simulation's potential benefits are not noticeable over the current work zone system. However, analyzed t-test survey results showed that people from government agencies favor simulation benefits more than non-government people. 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, those 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

The simulation also shows that it is feasible to use relatively simple programs as tools for public communication and 4D visualization of traffic work zones at different construction phases. From the meetings with focus groups and Council Bluffs engineers and contractors, people prefer 3D simulation over the typical 2D drawings for communication purposes. Some suggest using it via the project website. For the planning phase it can be useful to communicate between stakeholders showing how the current and future traffic work zone looks without causing other interference and construction conflicts. The ease of use and the availability to everyone are major keys to developing the system further.

The visualization of the 24th Street Bridge work zone is available on a CD attached to this final report.

5.2 Recommendations

Future research should examine how the simulation can be improved in the level of detail. The approach can be altered depending on the visualization and simulation purposes. Some recommendations are as follows.

- 3D model details—The visualization can be improved by increasing the accuracy or dimensional scale of the models themselves. However, development cost will likely be increased accordingly. In the future, if the highway construction design process moves from 2D to 3D design, the 3D models can be available without recreating them. For instance, in the building construction sector of the industry, several firms have migrated from CAD to building information modeling (BIM) which is a 3D model-based design. Returning to highway construction, some software such as Autodesk Civil 3D provides 3D designs which 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.
- Time details—The visualization can be improved by increasing the level of detail of the

schedule from a day to an hour or a minute. To do this can be as simple as modifying code in KML to a specific time period. An example of application for higher time details is to simulate task traffic control or quality control such as installation of the traffic devices in a specific time period.

- Traffic Management—If traffic counts are available in time intervals for the construction site, the simulation could be modified to incorporate a realistic traffic mix and flow. This 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.

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APPENDIX A: LIST OF SOFTWARE AND VERSIONS USED IN THE RESEARCH PROJECT

Animation for survey

- Adobe Flash CS3 (9.0.2)–multimedia authoring software for the Internet
- Google SketchUp Pro 6 (6.4.112)–3D modeling and animation software

4D-like visualization and simulation

- Google Earth 4.2 (4.2.0205.5730)–virtual globe software
- Google SketchUp 6 (6.4.112)–3D modeling software
- Notepad++ 4.82–text editor

Rendering

- Adobe Photoshop CS3 (10.0)–graphics editor
- Kerkythea 2008 echo–rendering software

APPENDIX B: END-USERS SYSTEM MINIMUM REQUIREMENT

Windows

- Operating System: Windows 2000, Windows XP, Windows Vista
- CPU: 500Mhz, Pentium 3
- System Memory (RAM): 256MB minimum, 512MB recommended
- Hard Disk: 400MB free space
- Network Speed: 128 Kbits/sec
- Graphics Card: 3D-capable with 16MB 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, 1GHz or faster
- System Memory (RAM): 256MB minimum, 512MB recommended
- Hard Disk: 400MB free space
- Network Speed: 128 Kbits/sec
- Graphics Card: 3D-capable with 32MB of VRAM
- Screen: 1024x768, "Thousands of Colors"

Linux

- CPU: 500Mhz, Pentium 3
- System Memory (RAM): 256MB RAM
- Hard Disk: 500MB free space
- Network Speed: 128 Kbits/sec
- Graphics Card: 3D-capable with 16MB 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



Figure C.1. Bird's-eye view over the bridge—looking north from project start to finish



Figure C.2. Driver's view at the south of the bridge—looking north from project start to finish



Figure C.3. Bird's-eye view over Interstate 29/80—looking west from project start to finish



Figure C.4. Bird's-eye view over the bridge—different perspectives during stage 5

APPENDIX D: SURVEYS 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

Survey item	Government		
	Non-gov.	Gov.	Significant
Drivers in highway work zones are adequately informed using existing technologies	4.875	5.357	12.0%
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%
Current technologies provide adequate safety training for construction workers in work zones	4.750	4.500	30.2%
Dynamic message boards on the road increase safety in work zones	5.500	5.357	40.3%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.500	5.154	29.5%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.875	5.143	32.5%

Three-dimensional drawings of work zones and road closures can improve work zone safety	4.875	4.786	44.2%
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.625	5.214	10.1%
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%
My organization would use work zone simulations in our training program	4.625	5.357	10.7%
My organization would use work zone simulations in job safety analysis and evaluation	4.750	5.071	28.2%
My organization would use work zone simulations in internal traffic control	4.375	5.071	14.8%
My organization would use work zone simulations in communicating with the public	4.500	4.929	23.0%
My organization would use work zone simulations to define access points for deliveries	4.500	4.643	38.9%
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%
In the design phase, work zone simulations would prevent many construction conflicts	4.500	4.714	36.9%
Simulation of work zones would be useful in driver education programs	6.250	5.786	20.8%

Survey item	20 years experience		
	less	more	Significant
Drivers in highway work zones are adequately informed using existing technologies	4.889	5.105	25.9%
Drivers in highway work zones are adequately prepared using existing technologies	4.333	4.316	48.2%
Current technologies provide adequate safety for construction workers in work zones	4.667	4.684	48.4%
Current technologies provide adequate safety training for construction workers in work zones	4.500	4.421	41.5%
Dynamic message boards on the road increase safety in work zones	5.222	5.526	21.2%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.111	5.111	50.0%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.944	4.632	23.5%
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%
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	5.000	4.842	36.9%
My organization would use work zone simulations in our training program	4.500	4.667	35.9%
My organization would use work zone simulations in job safety analysis and evaluation	4.556	4.389	35.3%
My organization would use work zone simulations in internal traffic control	4.444	4.444	50.0%
My organization would use work zone simulations in communicating with the public	4.889	4.158	6.0%
My organization would use work zone simulations to define access points for deliveries	4.278	4.474	30.8%
In the design phase, work zone simulations would improve drainage design	3.667	3.789	40.9%
In the design phase, work zone simulations would improve utility design	3.722	3.737	48.9%
In the design phase, work zone simulations would prevent many construction conflicts	4.000	4.737	8.7%

Simulation of work zones would be useful in driver education programs	5.824	5.579	29.1%
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Survey item	CAD users		
	No	Yes	Significant
Drivers in highway work zones are adequately informed using existing technologies	5.000	5.045	44.4%
Drivers in highway work zones are adequately prepared using existing technologies	4.118	4.545	12.4%
Current technologies provide adequate safety for construction workers in work zones	4.471	4.864	17.0%
Current technologies provide adequate safety training for construction workers in work zones	4.529	4.455	41.6%
Dynamic message boards on the road increase safety in work zones	5.471	5.364	38.8%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.059	5.143	42.7%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.529	5.045	11.5%
Three-dimensional drawings of work zones and road closures can improve work zone safety	4.353	5.000	6.8%
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.412	4.864	13.3%
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	4.706	5.136	17.6%
My organization would use work zone simulations in our training program	4.824	4.476	22.5%
My organization would use work zone simulations in job safety analysis and evaluation	4.471	4.619	36.9%
My organization would use work zone simulations in internal traffic control	4.235	4.762	13.2%
My organization would use work zone simulations in communicating with the public	4.353	4.727	21.5%
My organization would use work zone simulations to define access points for deliveries	4.529	4.227	20.9%
In the design phase, work zone simulations would improve drainage design	3.824	3.682	39.1%
In the design phase, work zone simulations would improve utility design	3.706	3.818	41.2%
In the design phase, work zone simulations would prevent many construction conflicts	4.563	4.273	29.1%
Simulation of work zones would be useful in driver education programs	5.750	5.727	47.9%

Survey item	GIS users		
	No	Yes	Significant
Drivers in highway work zones are adequately informed using existing technologies	4.905	5.235	15.5%
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%
Current technologies provide adequate safety training for construction workers in work zones	4.429	4.529	39.0%
Dynamic message boards on the road increase safety in work zones	5.429	5.353	42.2%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.095	5.125	47.5%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.667	5.000	22.5%

Three-dimensional drawings of work zones and road closures can improve work zone safety	4.571	4.882	24.5%
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.476	4.882	16.5%
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	4.810	5.118	25.9%
My organization would use work zone simulations in our training program	4.450	4.882	17.8%
My organization would use work zone simulations in job safety analysis and evaluation	4.350	4.824	14.6%
My organization would use work zone simulations in internal traffic control	4.400	4.765	22.3%
My organization would use work zone simulations in communicating with the public	4.381	4.882	14.7%
My organization would use work zone simulations to define access points for deliveries	4.429	4.294	36.3%
In the design phase, work zone simulations would improve drainage design	3.524	3.941	21.0%
In the design phase, work zone simulations would improve utility design	3.571	4.000	20.2%
In the design phase, work zone simulations would prevent many construction conflicts	4.300	4.471	37.5%
Simulation of work zones would be useful in driver education programs	5.350	6.118	3.5%

Survey item	2D drawing users		
	No	Yes	Significant
Drivers in highway work zones are adequately informed using existing technologies	4.833	5.094	28.0%
Drivers in highway work zones are adequately prepared using existing technologies	4.500	4.344	38.2%
Current technologies provide adequate safety for construction workers in work zones	3.833	4.844	3.7%
Current technologies provide adequate safety training for construction workers in work zones	4.667	4.438	32.1%
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%
Three-dimensional drawings of work zones and road closures can improve work zone safety	5.333	4.594	11.2%
Four-dimensional simulations of work zones and road closures can improve work zone safety	5.000	4.594	23.8%
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 our training program	5.167	4.548	16.4%
My organization would use work zone simulations in job safety analysis and evaluation	5.167	4.452	11.9%
My organization would use work zone simulations in internal traffic control	5.333	4.419	7.7%
My organization would use work zone simulations in communicating with the public	5.167	4.500	15.3%
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 improve utility design	4.500	3.625	10.4%
In the design phase, work zone simulations would prevent many construction conflicts	5.800	4.156	1.5%
Simulation of work zones would be useful in driver education programs	6.200	5.625	18.0%

Survey Item	Scheduling software users		
	No	Yes	Significant
Drivers in highway work zones are adequately informed using existing technologies	4.923	5.400	10.5%
Drivers in highway work zones are adequately prepared using existing technologies	4.269	4.400	38.2%
Current technologies provide adequate safety for construction workers in work zones	4.385	5.400	1.6%
Current technologies provide adequate safety training for construction workers in work zones	4.385	4.600	30.0%
Dynamic message boards on the road increase safety in work zones	5.577	4.700	1.9%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve safety in the work zone	5.115	4.889	34.2%
If drivers know the exact location and configuration of the work zones along the highway, it will significantly improve mobility in the work zone	4.731	4.900	37.1%
Three-dimensional drawings of work zones and road closures can improve work zone safety	4.577	4.900	26.8%
Four-dimensional simulations of work zones and road closures can improve work zone safety	4.577	4.800	32.5%
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	4.808	5.000	36.1%
My organization would use work zone simulations in our training program	4.538	4.778	33.5%
My organization would use work zone simulations in job safety analysis and evaluation	4.385	4.889	17.2%
My organization would use work zone simulations in internal traffic control	4.385	4.889	18.7%
My organization would use work zone simulations in communicating with the public	4.615	4.300	28.2%
My organization would use work zone simulations to define access points for deliveries	4.385	4.100	25.5%
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%
Simulation of work zones would be useful in driver education programs	5.654	5.800	38.4%

APPENDIX E: 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 2D 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:
 - Project Manager
 - Resident Engineer
 - Design Engineer
 - Safety Officer
 - Field Engineer
 - Field Superintendent
 - Operations Manager

- Other _____
- 2) What are your primary job responsibilities (check all that apply):
- Overall coordination of project tasks
 - Supervise design activities
 - Prepare design documents
 - Administer design documents
 - Supervise construction activities
 - Prepare final construction documents
 - Administer final construction documents
 - Supervise contract compliance
 - Prepare contracts/procurement
 - Award contracts/procurement
 - Field supervision
 - Safety/risk control
 - Quality control
 - Quality assurance
- 3) How long have you worked in the highway construction industry?
- _____ years
- 4) What is the classification of your organization:
- General Contractor
 - Construction Manager
 - Design Builder
 - Specialty Contractor
 - Designer
 - Consultant
 - Government agency
 - Other _____

Part 2: Computer and Software Usage

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

- Almost never
- 2–3 times per week
- 4–5 times per week
- Every day

6) How often do you use the Internet?

- Almost never
- 2–3 times per week
- 4–5 times per week
- Every day

7) What is your current computer operating system?

- Windows 2000
- Windows XP
- Windows VISTA
- Macintosh
- Other _____

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

- yes (please answer Question 9 below)
- no (please go to Question 13)

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

- Microstation
- AutoCAD
- ArchiCAD
- Revit
- Other _____
- Other _____
- Other _____

- 10) If you primarily use Microstation, are you familiar with AutoCAD?
- Yes
 - No
 - Not applicable
- 11) If you primarily use AutoCAD, are you familiar with Microstation?
- Yes
 - No
 - Not applicable
- 12) How often have you encountered file conversion problems with your CAD program?
- Never
 - A few times
 - Somewhat often
 - Frequently
- 13) Do you use GIS (geographic information system) data in your work?
- Yes
 - No
- 14) Do you use 2D drawings in your day-to-day work?
- Yes
 - 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%)
- _____% Hard copy
 - _____%Electronic format
- 16) What percentage of your design and construction documents are produced using 3D drawings or 3D models in your work?
- _____% 3D

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

- yes (please answer Question 18 below)
- 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)

- Primavera
- SureTrak
- Microsoft Project
- Microsoft Excel
- Other _____

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

- Daily
- Weekly
- Bi-weekly
- Monthly
- 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%)

- _____% Hard copy
- _____%Electronic format

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

(Check all that apply)

- Phone
- Email
- Regular Mail
- Overnight Mail
- Other _____

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 disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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 disagree			neither agree nor disagree			strongly agree

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 disagree			neither agree nor disagree			strongly agree

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 disagree			neither agree nor disagree			strongly agree

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 disagree			neither agree nor disagree			strongly agree

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 disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

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

1	2	3	4	5	6	7
strongly disagree			neither agree nor disagree			strongly agree

APPENDIX F: KML CODE FOR THE MAIN FILE (DOC.KML)

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  </Placemark>
</Folder>
</Document>
</kml>
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