

# DEVELOPMENT OF OBJECT-ORIENTED DESIGN AND SPECIFICATIONS FOR IOWA DOT AND URBAN STANDARDS: PHASE I

Iowa DOT Project TR-487  
CTRE Project 02-124

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of Transportation**



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Department of Civil, Construction and Environmental Engineering

IOWA STATE UNIVERSITY

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Final Report • October 2004

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<b>16. Abstract</b> <p>Currently, individuals including designers, contractors, and owners learn about the project requirements by studying a combination of paper and electronic copies of the construction documents including the drawings, specifications (standard and supplemental), road and bridge standard drawings, design criteria, contracts, addenda, and change orders. This can be a tedious process since one needs to go back and forth between the various documents (paper or electronic) to obtain information about the entire project. Object-oriented computer-aided design (OO-CAD) is an innovative technology that can bring a change to this process by graphical portrayal of information. OO-CAD allows users to point and click on portions of an object-oriented drawing that are then linked to relevant databases of information (e.g., specifications, procurement status, and shop drawings).</p> <p>The vision of this study is to turn paper-based design standards and construction specifications into an object-oriented design and specification (OODAS) system or a visual electronic reference library (ERL). Individuals can use the system through a handheld wireless book-size laptop that includes all of the necessary software for operating in a 3D environment. All parties involved in transportation projects can access all of the standards and requirements simultaneously using a 3D graphical interface. By using this system, users will have all of the design elements and all of the specifications readily available without concerns of omissions.</p> <p>A prototype object-oriented model was created and demonstrated to potential users representing counties, cities, and the state. Findings suggest that a system like this could improve productivity to find information by as much as 75% and provide a greater sense of confidence that all relevant information had been identified. It was also apparent that this system would be used by more people in construction than in design. There was also concern related to the cost to develop and maintain the complete system. The future direction should focus on a project-based system that can help the contractors and DOT inspectors find information (e.g., road standards, specifications, instructional memorandums) more rapidly as it pertains to a specific project.</p>					
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# **DEVELOPMENT OF OBJECT-ORIENTED DESIGN AND SPECIFICATIONS FOR IOWA DOT AND URBAN STANDARDS: PHASE I**

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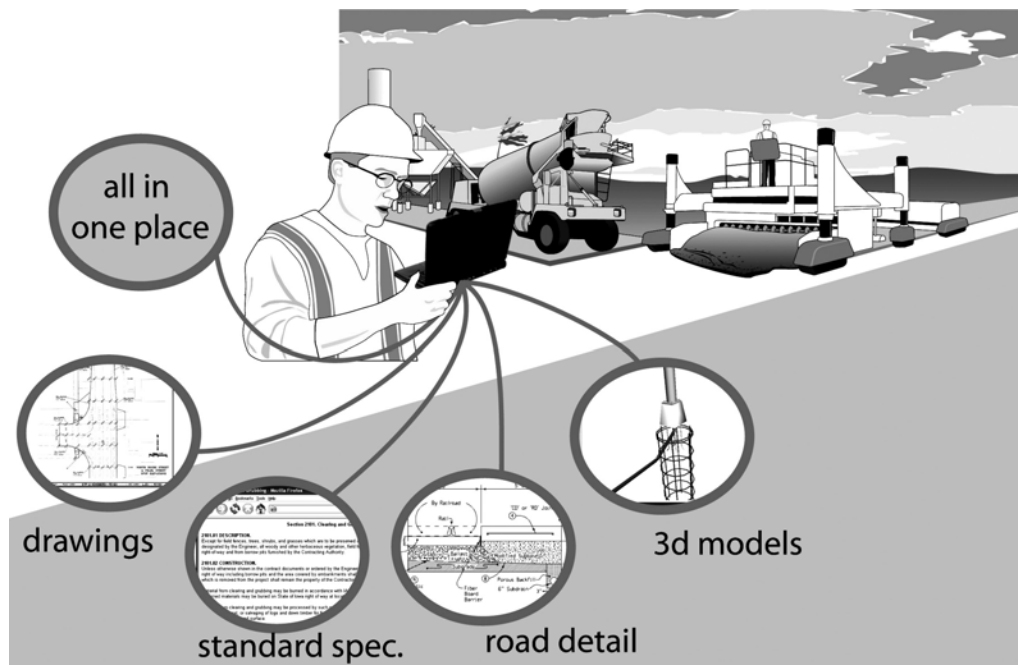
## EXECUTIVE SUMMARY

### Background

Currently, individuals including designers, contractors, and owners learn about the project requirements by studying a combination of paper and electronic copies of the construction documents, including the drawings, specifications (standard and supplemental), road and bridge standard drawings, design criteria, contracts, addenda, and change orders. This can be a tedious process since one needs to go back and forth between the various documents (paper or electronic) to obtain information about the entire project. Object-oriented computer-aided design (OO-CAD) is an innovative technology that can bring a change to this process by graphical portrayal of information. OO-CAD allows users to point and click on portions of an object-oriented drawing that are then linked to relevant databases of information (e.g., specifications, procurement status, and shop drawings).

### Vision

The vision of this study is to turn paper-based design standards and construction specifications into an object-oriented design and specification (OODAS) system or a visual electronic reference library (ERL). Individuals can use the system through a handheld wireless book-size laptop that includes all of the necessary software for operating in a 3D environment. All parties involved in transportation projects can access all of the standards and requirements simultaneously using a 3D graphical interface. By using this system, users will have all of the design elements and all of the specifications readily available without concerns of omissions. The entire concept is that a graphical system makes the process of visualizing construction projects consistent and efficient.



This report proposes a conceptual plan for the long-term development of the OODAS system, describes the development of a prototype version of the OODAS, and summarizes the time and cost study of developing and maintaining a full OODAS system. Ultimately, OODAS will provide a visual interface to design and construction standard documents that are heavily used by transportation professionals in Iowa.

## **Benefits**

Several benefits can be derived from using such a system. An object-oriented approach will make it easier for everyone, including DOT design engineers, specification writers, inspectors, and contractors, to access specification and design information without the concern that certain information is missed. OODAS would also make it easier for designers and contractors to more readily understand project requirements. Moreover, this concept allows for smoother integration of urban and state DOT specifications and design standards. Additionally, this new system will allow for a more centralized specification and design standard process, thus saving on resources and providing a visual format for accessing specifications. The entire concept is that a graphical system makes the process of visualizing construction projects consistent, and information can be released faster.

## **Methodology**

In order to develop an object-oriented system for specifications and design standards, a comprehensive methodology was developed, including the following steps:

1. Develop an understanding of the user requirements through a series of meetings and face-to-face interviews with designers and contractors.
2. Select a format for the visual interface. This interface will contain various graphical scenes with different features, such as an intersection, freeway, expressway, and two-lane highway. Each of these features will be linked with standard designs and specifications for both Iowa Department of Transportation (Iowa DOT) and Iowa Statewide Urban Design and Specifications (SUDAS).
3. Research various OO-CAD software packages and make a selection.
4. Develop a prototype model in object-oriented format and link it to certain provisions of appropriate specifications.
5. Obtain user feedback and modify the prototype.
6. Conduct a feasibility study of this concept. The feasibility study investigates the structure of a full-scale OODAS system, time and cost spent on the prototype model and estimated on a full-scale system, and maintenance and update issues.

## **Prototype Development**

The prototype model was developed using MicroStation to view and edit standard plans related to the specifications. The 3ds max and LightWave 3D were used to create the 3D models. The specifications were stored and managed by a Microsoft Access database (or XML file). Finally, Macromedia Director was used to combine the 3D model with the database to create a dynamically updated 3D interactive environment for the user.



The model went through several iterations before the final model version was completed and demonstrated to various potential users in Iowa. Numerous potential users representing counties, cities, and the state DOT provided feedback throughout the development process.

## **Economics**

Based on the prototype development, a plan to establish a full-scale OODAS system was developed consisting from an urban and rural scene, which included all of the appropriate features. Features were grouped in three levels of complexity based on the modeling effort for objects in the prototype: high complexity, moderate, and low complexity. Full-scale development costs are anticipated to be approximately \$575,000, with ongoing maintenance costs around \$87,000 per year. Maintenance costs include one full-time dedicated person to provide bi-annual updates, training, and other support of the system.

Similar to the ERL, a variety of arrangements can be developed to distribute OODAS. Iowa DOT and SUDAS could be responsible for providing OODAS to all potential users via the Internet. A CD/DVD version is still under consideration due to user preference, Internet availability, and performance of current computers. The Iowa DOT and SUDAS can sell updated OODAS on CD each time an update is issued, sell subscriptions to purchase all updated CDs issued during a certain period of time, or transfer responsibility for distribution of updated CDs to a third party. Selling subscriptions would eliminate the need to contact a list of subscribers and process payments every time an updated OODAS is issued. Transferring distribution to a third party would reduce staff requirements and administrative involvement.

## **Discussions with Potential Users**

A representative sample of potential users was compiled, including a city and county engineer, consulting engineer, construction contractor, Iowa Department of Transportation design and construction engineers, and an additional person at the federal level. Findings suggest that a system like this could improve productivity to find information by as much as 75% and provide a greater sense of confidence that all relevant information had been identified. It was also apparent that this system would be used by people more in construction than design. There were some concerns, however, related to the cost to develop and maintain the complete system and its overall value to the DOT as it is currently scoped. Key points discussed by the potential users are the following:

### *Contractor Perspective*

Mark Freier, Godbersen Smith Construction: This system will help pull together all of the information on the object with one click and would be less likely to miss anything. Mark sees that it would take only 25% of the time to obtain desired information using this approach. With the OODAS system, Mark would be able to save 1.5 to 2.25 hours each week. A current limitation with such a system is the fact that the field personnel will not use it, at least for now, since they do not have their own computers in the field. He sees this system as more office-oriented.

### *Iowa Department of Transportation Materials Perspective*

Jim Berger: OODAS should focus on getting information to the contractors that they need to know to bid the job. Three-dimensional images may be unnecessary. Perhaps a system that focuses on 2D road standards would be just as effective and more manageable. We need to help the bidders identify the incidentals on the plans. Bidders sometimes miss these incidental items and end up providing incorrect bid costs.

### *Iowa Department of Transportation Resident Engineer Perspective*

Doug McDonald: Doug felt that the OODAS system will be easier to use than the current approach. He presently uses the ERL to quickly find information and then checks the information in the specification book. Doug felt that a system like this would help newer people save time learning about the specifications; it could also save time for experienced inspectors as well. Doug believed that OODAS could cut the time by 75%, and the quality of the information could be better.

### *Iowa Department of Transportation Urban (Large) Design Perspective*

Jim Schoenrock and Don Drake: Jim and Don sensed that field would like the OODAS system a lot; they were not sure about the benefits for design since design does not use the specifications very much. They saw the primary advantage in 3D graphics related to training new technicians or engineers on the standard specifications. They also agree that there could be significant time savings in finding information using this new approach.

### *Iowa Department of Transportation Urban (Small) Design Perspective*

Dennis Smith and Yanxiao Jia: OODAS is a tool to familiarize people with standards and to help them remember certain specifications. As Dennis said, “Specs have a habit of hiding things.” He felt that beginners and seasoned designers could use this system. It would be useful to be able to obtain the latest information, and having the supplementals included would be a real plus. He also mentioned that “thoroughness is the key issue.” The OODAS system would provide greater confidence that we have not missed anything. Dennis thought OODAS would make it easier to merge SUDAS and DOT specifications.

### *Iowa Department of Transportation Rural Design Perspective*

Dave Skogerboe: Dave mentioned that the OODAS system would have great value, especially with the ability to expand and tie standard road plan, typicals, and design information. Young designers and engineers would benefit significantly from being able to visually associate with the roadway parts and their specifications. He said that our designers should be reviewing the specifications more, and using OODAS would make this process more user-friendly. Also, this approach would more efficiently identify differences between DOT and SUDAS specifications.

### *Iowa Department of Transportation Bridge Perspective*

Gary Novey: Gary expressed some concerns with this system. He felt that the ERL would be sufficient to quickly and efficiently obtain specification information and that the added visual front end is not really necessary. He was also concerned about the maintenance costs and the “black box” where you really do not know what is going on inside to know that you have everything pertaining to the object. The graphic system could give a false sense of confidence. Users may not make the effort to be thorough in a review of the specifications if they only view the visual system. After five years, people know the components of bridges and do not need the aid of the visual specification system. A visual system is good for the users who do not have the knowledge of all components. Knowledgeable users do not need the visual front end since they already know what is important.

### *Iowa Department of Transportation Construction Perspective*

John Smythe: John believed that it would be very difficult to make OODAS useful for everyone. The 2D road standards are the level of visual detail required. The 3D animations are not necessary to make the system useful. Redirecting the focus to include a more project-specific approach and begin with a training focus should be the future direction of this project.

### *City Perspective*

Jeff May, City of Knoxville, IA: The upfront costs are quite high. As a comparison, the costs of developing a new car are very high, but are not bad when spread out over several thousand cars. The graphical system will be a very efficient way for the field person to find data. It is the way of the future. This will be a simple way for the field person who does not know the terminology (i.e., the technical name for an object) or is unsure exactly which book to look in. Field workers refer to the specification book daily. Designers do not refer to the specifications so often.

### *County Perspective*

Jim George, Dallas County: The visual system is the natural progression of the SUDAS/DOT combined specification. This system will make it easier for inspectors thus shortening their learning curve. You can read the specifications book to learn about the specs, but if you do not use the knowledge, you will not retain it. The graphic system will give inspectors the ability to efficiently get to all the information; inspectors may also be able to better retain the information since they will also be using it.

### *Consultant Perspective*

Steve Klocke, Snyder & Associates: The upkeep of the system would be challenging. There was concern over who would be responsible for the upkeep. The OODAS system may be good for younger engineers. Once you know the specifications, you can find information more efficiently on your own. Supplemental specifications (project specific) are fairly common. Experienced people refer to the specifications to refresh their memory as to the specific material requirements or payment terms.

### *Federal Perspective*

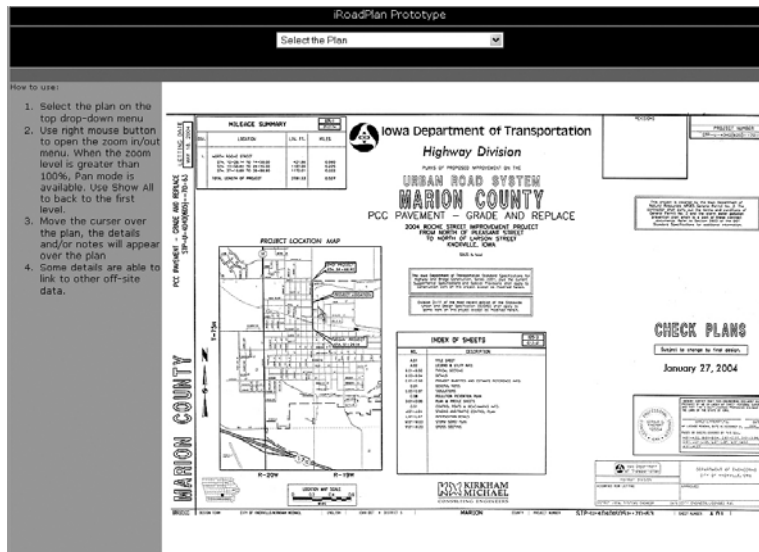
Andy Wilson, Federal Highway Administration: It looks like a great project. He is concerned about cost and time required to develop the system. Andy believes there may be a middle ground for the next phase of the project. His experience shows that the current Iowa inspectors are fairly young. "We have lost a lot of experience, and this tool could be useful to help young inspectors get started."

Based on the comments from these potential users, it was felt that a fully developed OODAS system would be too expensive to develop and maintain. There was also concern that the information would not be project-specific enough and that some information would be missed. Related to the path forward, it is apparent that there is a strong interest in helping the contractors and DOT inspectors to obtain the information they need to properly bid, construct, and inspect projects. Moreover, many people liked the visual nature of acquiring information. Thus, the future vision should focus on enhancing the current set of plans to include hot links to specifications, good and bad installations, and links to details in the drawings. This concept is explained further in the next section.

## **Recommendation for Phase II**

Most of the potential users that were surveyed for this study agree that the current paper based system is fairly cumbersome to use to the extent that many users do not refer to the specifications as often as they should. The surveyed users generally agree that the OODAS system would provide a definite improvement over the current book and drawing based system. The estimated cost of developing the OODAS system is \$575,000, and the estimated annual cost of maintenance is \$87,000. According to the 1997 economic census of construction by the US Census Bureau, the total value of heavy construction (highways, streets, bridges, and utilities) in Iowa was \$1.6 billion dollars, and even a marginal increase in performance will easily surpass the initial design cost of OODAS. However, in times of tight state budgets, investing \$575,000 into a development project is somewhat risky. Because of this issue, the recommendation for





phase II is to take the lessons learned in developing the prototype and use this knowledge to develop a project specific demonstration. This demonstration, called iRoadPlan, will be based on an actual project that is to be selected by the Office of Construction. An electronic version of the drawings will be produced to include certain object-oriented features. Below is a list of some possible items to be included in iRoadPlan. For more detail, please refer to the Recommendations section of this report.

- Electronic Road Standards – Create a link from the table of road standards that apply to the project. These road standards will be further linked to allow the user to quickly access all information related to the project. The electronic road standards will be in 2D format.
- Installation Examples – Show photographs of good and bad installations for the referenced road standards.
- Bid Items – Link from the BIAS number directly to the standard specifications.
- Detail Pop-up – Use pop-up windows to show items such as detail notes and cross-section profiles.
- Develop recommendations for required changes in the design process that would facilitate object-oriented drawings.

Future effort should look at features available in Microstation, particularly in version 8, that would help automate the process of creating electronic plans. Some features of version 8 that may help are the following:

- There is no limit to the number of references that can be attached to a DGN file.
- Each element has a unique 64-bit identifier that does not change through the life-cycle of the element. This tag number could be used to link drawing elements to specifications.
- Each element has a time stamp that indicates the time of the most recent change, which would identify changes that occurred during a particular time period.

Phase II will show that the benefits of OODAS can be incrementally implemented and still provide benefits to the end user by working with a specific project. Implementing these tasks would take approximately 12-15 months and cost approximately \$125,000.

## INTRODUCTION

Currently, individuals including designers, contractors, and owners learn about the project requirements by studying a combination of paper and electronic copies of the construction documents including the drawings, specifications (standard and supplemental), road and bridge standard drawings, design criteria, contracts, addenda, and change orders. This can be a tedious process since one needs to go back and forth between the various documents (paper or electronic) to obtain information about the entire project. There are also special provisions as well as standard specifications referenced in the contract documents that need to be understood. As transportation projects become more complex to design and build with fewer available resources, specification developers must take advantage of innovative technologies that make construction documents easier for designers and construction personnel to grasp. Such a change could ultimately reduce the chance of error, improve quality, decrease rework, and shorten the project duration. Object-oriented computer-aided design (OO-CAD) is an innovative technology that can bring such a change to specifications by graphical portrayal of information. OO-CAD allows users to point and click on portions of an object-oriented drawing that are then linked to relevant databases of information (e.g., specifications, procurement status, and shop drawings).

As illustrated in Figure 1, the vision of this study is to turn paper-based design standards and construction specifications into an object-oriented design and specifications (OODAS) system or a visual electronic reference library (ERL). Individuals can use the system through a handheld wireless book-size laptop that includes all of the necessary software for operating in a three-dimensional (3D) environment. All parties involved in transportation projects can access all of the standards and requirements simultaneously using a 3D graphical interface. By using this system, users will have all of the design elements and all of the specifications readily available without concerns of omissions. A graphical system makes the process of visualizing construction projects consistent and efficient.



**Figure 1. Vision of a full-scale object-oriented design and specifications system**

This project presents the research method and effort of developing an OODAS system using OO-CAD and other techniques. The study involves integrating both the Iowa Department of Transportation (Iowa DOT) and Iowa Statewide Urban Design and Specifications (SUDAS) into one graphical information system for use by designers and construction personnel involved with road projects in Iowa.

This report proposes a conceptual plan for the long-term development of the OODAS system, describes the development of a prototype version of the OODAS, summarizes the time and expense of developing and maintaining a full OODAS system, and proposes a future vision for this project. Ultimately, this graphical concept will provide a visual interface to design and construction standard documents that are heavily used by transportation professionals in Iowa.

### **System Benefits**

Several benefits are derived from using such a concept. An object-oriented approach will make it easier for everyone, including DOT design engineers, specification writers, inspectors and contractors, to access specification and design information without the concern that certain

information is missed. OODAS would also make it easier for designers and contractors to more readily understand project requirements. Moreover, this concept allows for smoother integration of urban and state DOT specifications and design standards. Additionally, this new system will allow for a more centralized specification and design standard process, thus saving on resources and providing a visual format for accessing specifications. The entire concept is that a graphical system makes the process of visualizing construction projects consistent, and information can be obtained faster.

### **Current Efforts to Enhance the Design and Specification Process**

An effort is currently underway to make it easier to find required specifications and provide unification of the many different city and county specifications that are used in Iowa. In order to make it easier for design and field personnel to locate Iowa DOT specifications (Iowa DOT 2001), an Electronic Reference Library (ERL) (CTRE 1999) has been created. The ERL is a fully cross-referenced and searchable version of the Standard Specifications, Supplemental Specifications, Material Instructional Memorandums, Standard Road Plans, Standard Culvert Plans, Flaggers Manual, Construction Manual, and the Statewide Urban Standard Specifications that is distributed on CD-ROM format for statewide distribution. State agencies, local agencies, and construction contractors using the Iowa DOT specifications can quickly and efficiently identify relevant specifications using key word search capability. New CDs are released on a six-month basis reflecting updates to the specifications so that the users (i.e., designers, contractors, inspectors, field engineers, suppliers, Federal Highway Administration, counties, cities, and other state DOTs) have access to the most current information. Thus far, users have found electronic specifications to be useful for quickly locating information.

Furthermore, a SUDAS committee has been formed to investigate how to best develop and integrate the urban and rural standards. An object-oriented system like the one proposed in this report can help streamline this integration effort by making the system less dependent on a specific numbering system. Information about features (e.g., light pole, signal control box, or culvert) can be accessed by the simple click of a mouse on a desired feature; information about the urban or rural specification will be available at that point.

### **Study Objectives**

The purpose of this study is to develop a conceptual plan with a case study prototype model of an OODAS system. This model will be used to test the feasibility of the concept and assess its impact on the design and construction process. Both Iowa DOT and urban specifications will be included in the object-oriented format to demonstrate the concept. Full-scale development and maintenance issues will also be addressed as part of this project. This study will also serve as the basis of a specifications management system for a specific project, which is envisioned to be a future standard.

## OBJECT-ORIENTED MODELING BACKGROUND

In the past, attempts to improve the usability of design and construction specifications have been based on various methods that provided hypertext linkages to the numerous construction documents (CTRE 1999 and Walters 2003). These hypertext-based data management systems were based on the format of original paper-based specifications, which could be somewhat different than the natural work flow. This difference is that current systems are procedural and separate information into several distinct books that need to be properly linked. A more natural process is to have all pertinent data attached and available within the objects that are impacted. Such a system is known as an object-oriented system.

An object-oriented approach to software design is significantly different from a procedural approach. It combines data and behavior to organize the interacting objects (Blaha and Premerlani 1998). Object-oriented modeling can naturally map real world features into the computer world. An object-oriented system possesses objects (physical or conceptual) that contain the required information. The object-oriented approach began in the 1970s (although occasionally mentioned in 1960s) and its common meaning covers at least two features: (1) encapsulation of data and procedures inside objects and (2) interaction among objects. The suitability of an object-oriented approach to solve problems in software design is discussed more thoroughly in the literature (refer to Mullin 1989; Booch 1990; Fenves 1990; and Wasserman 1990). Object-oriented technology has also been investigated to meet the data management requirements of concurrent engineering (Spooner and Hardwick 1993).

Fances began investigating object-oriented design in the construction industry in the 1980s (1988) and widely studied object-oriented design in the 1990s. Object-oriented models were investigated for managing the large amount of data for design and construction (Johnson 1989). Many researchers remain active on issues related to database and data distribution. Luiten and Tolman (1997) investigated a method of integration of sharing of data, knowledge, and information among all project participants. Zaneldin et al. (2001) described the research efforts on representing design information, documenting design rationale, and managing design changes.

Relational databases, invented by E. F. Codd at IBM in 1970, are a collection of data organized as a set of tables from which data can be accessed in many different ways. Kim and Ibbs (1992) compared a data model based on an object-oriented design to one based on the relational model for managing data associated with construction projects and identified the strengths and weaknesses of the approaches. They pointed out that the object-oriented methodology shows significantly more promise from a semantic expressiveness perspective and provides clearer mapping. Peltonen et al. (1993) addressed several of the issues of object-oriented modeling and CAD-to-database integration, as well as developed an Engineering Document Management System (EDMS). Zaneldin et al. (2001) investigated ways to store information, record design rationale, and manage design changes using an object-oriented model.

OO-CAD systems have long been touted as the way forward for more intelligent CAD systems. In OO-CAD, the design objects contain all of the data necessary to fully describe each object. For instance, a drawing object representing a traffic signal would contain all of the standard specifications and drawings necessary to describe the material and installation specifications for a traffic signal. The idea behind this concept is that the design involves several objects that have information associated with them. When the user clicks on an object, information pertaining to that object appears. This information can be fixed or dynamic in a sense that the information about that object changes with time. In the past, only a few OO-CAD systems had been developed, and most of those were on high-end UNIX machines that were not affordable by the majority of practitioners in the construction industry. This appears to be changing with the introduction of object-oriented components in many of the popular systems (e.g., AutoCAD with objects defined in C++) (California Software Laboratories 2003).

A critical factor for data management is the way to share and convert the different data and standards in one common place. Marir et al. (2001) proposed an interactive system for integrating CAD and construction related applications. In their research, the Industrial Foundation Classes (IFC) standard was mentioned. This is one of two solutions to solve the data format issues (Harrod 2003). The other is eXtensible Markup Languages (XML). The XML data itself contains data used to exchange information between different applications or platforms. It is small in file size and flexible because it is coded in a simple text format designed to be used on any platform. XML has been used in many applications in fields from computer programming to engineering. XML data is used to define the general data structure of applications. Several developed XML schemas are open to the public, so data can be exchanged between different organizations free of charge. The XML tool will be useful in developing an OODAS system to manage the different types of data from graphical objects.

## **STUDY METHODOLOGY**

In order to develop an object-oriented system for specifications and design standards, a comprehensive methodology was developed which included the following steps:

1. Develop an understanding of the user requirements through a series of meetings and face-to-face interviews with designers and contractors.
2. Select a format for the visual interface. This interface will contain various graphical scenes with different features such as an intersection, freeway, expressway, and two-lane highway. Each of these features will be linked with standard designs and specifications for both Iowa DOT and SUDAS.
3. Research various OO-CAD software packages and make a selection.
4. Develop a prototype model in object-oriented format and link it to certain provisions of appropriate specifications.
5. Conduct a feasibility study of this concept. The feasibility study investigates the structure of a full-scale OODAS system, time and cost spent on prototype model and estimated on a full-scale system, and maintenance and update issues.
6. Obtain user feedback and provide vision for the next phase.

Each of these activities is described in greater detail below.

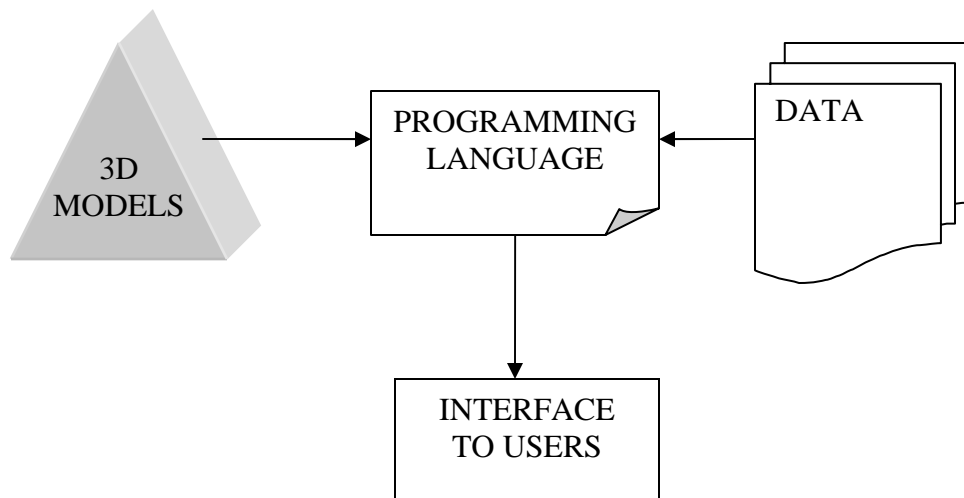
## **ESTABLISHING USER REQUIREMENTS**

The research team used a modified focus group method to obtain initial user requirements and determine the initial objects. Focus groups involve an informal technique that can help researchers assess user needs and feelings about a product or idea (Nielsen 1997). The team used the Unified System Implementation Subcommittee (USIS) as the focus group because these engineers and contractors have broad design and construction experience. In addition to guiding the OODAS project, the USIS committee is charged with finding a common specifications and design manuals for the Iowa DOT and SUDAS. The OODAS prototype has been presented to the USIS steering and district committees to gather some end-user requirements. The preliminary end-user requirements through this channel are implemented in the prototype model and summarized as follows:

- Standard pictures/scenes should be designed to allow the user to get specification information by clicking on the various objects.
- System should provide a tool to deal with the issues related to periodic updates to the standard drawings and specifications.
- Standard drawing features should be used first and then adapted into project specific drawings.
- Graphics must cover all pertinent specifications.
- System should facilitate quick decision-making and help new engineers learn specifications quicker.
- System should be useful to anybody in the civil and construction fields.
- Final product should integrate the various codes and plans.
- Search function should be provided within system.

## **FORMAT SELECTION FOR OODAS SYSTEM**

The best approach to designing this system is to separate the programming structure and the data from the model. With object-oriented programming, each unit, including programming, 3D models, and data, is developed independently. Developing each unit independently makes the system easier to organize and maintain. Figure 2 shows this concept.



**Figure 2. Illustration of combination concept**

In Iowa, different specifications are used depending on the project type and location. Iowa DOT specifications are used on state, federal, and county highway projects. SUDAS specifications are used primarily on city projects and may vary by city. The following are the lists of design standards being applied to an OODAS system.

### **Design Standards**

- Iowa DOT Design Manual
- Iowa DOT Standard Road Plans
- Iowa DOT Road Design Details
- SUDAS Standards for Public Improvements

### **Specifications**

- Iowa DOT Standard Specifications for Highway and Bridge Construction
- Iowa DOT Supplemental Specifications
- Iowa DOT Construction Manual
- Iowa DOT Instructional Memorandums
- SUDAS Urban Standard Specifications for Public Specifications



## SOFTWARE SELECTION

The chosen software should have an ability to communicate with other software by reading the properties of a specific object. It should also have the capability for user interaction and database communication. Although some general purpose programming packages such as object-oriented C++, Visual Basic (VB), and OpenGL work well with 3D models and databases, the programming is very complex, time consuming, and difficult to maintain. Since various modeling and multimedia packages are available that minimize the need for programming, a combination of several of these software packages can be used to fulfill the project purpose without the complexities of using a general purpose programming package. The software chosen for this project are categorized as (1) CAD packages for standard plans, (2) Model Streaming Software, (3) multimedia and 3D modeling software, (4) format conversion software, and (5) data management and database software.

Although the details of the software reviewed can be found in the Appendix A, some of major considerations, as illustrated in Figure 3, are listed as follows:

1. **Multimedia and 3D modeling software.** Various popular 3D modeling and multimedia tools were considered and evaluated for the study. These included 3ds max by Discreet (Discreet 2003), LightWave by NewTek (NewTek 2003), Maya by Alias Wavefront (Alias/Wavefront 2003), Softimage by Softimage Co. (Softimage 2003), and Director MX by Macromedia, Inc. (Macromedia 2003). Among these packages, 3ds max and/or LightWave 3D became the choice for the modeling software for this study because of their flexibility with object-oriented format and integration with many CAD packages. Director MX was chosen to be the multimedia authoring software because it can incorporate photo-quality images, full-screen or long-form digital video, sounds, animation, 3D models, text, hypertext, bitmaps, and Macromedia Flash content into an interactive 3D environment.
2. **Data management and database software.** For the OODAS system, a database that contains all of the written specifications must be developed. One choice in the database design is whether or not to have a centralized database on a server. The advantage of a centralized solution is that all users rely on a common database that ensures that all users are viewing accurate and up-to-date data. However, such a solution requires all users to have ready access to a high-bandwidth network connection. Since few construction sites have this access, standalone databases must be considered along with a network server. One approach of a standalone database is to connect directly to data management software such as HTML Help, which is a tool from Microsoft for creating a help file. HTML Help was selected because of its features. It is also known as HELP in the Windows operating system. Another approach is to use a database as a tool to connect to the data. Some of the major databases were reviewed such as Microsoft Access (Clearform 2003), Microsoft SQL Server (Microsoft 2003), MySQL AB (MySQL 2003), and Oracle (Oracle 2003). Among those databases that met the requirements, Microsoft Access was selected due to its standalone capability and wide availability. Furthermore, it also has an ability to connect to other network databases such as Oracle and Microsoft SQL server. During the later stages of prototype development, an XML database file was tested. Because of the features mentioned

about XML in the background section, XML might be considered better than Microsoft Access for a full-scale system.

In summary, as illustrated in Figure 4, MicroStation was used to view and edit standard plans related to the specifications. 3ds max and/or LightWave 3D was used to create the 3D models. The specifications were stored and managed by a Microsoft Access database (or XML file). Finally, Macromedia Director was used to combine the 3D model with the database to create a dynamically updated, 3D interactive environment to the user.

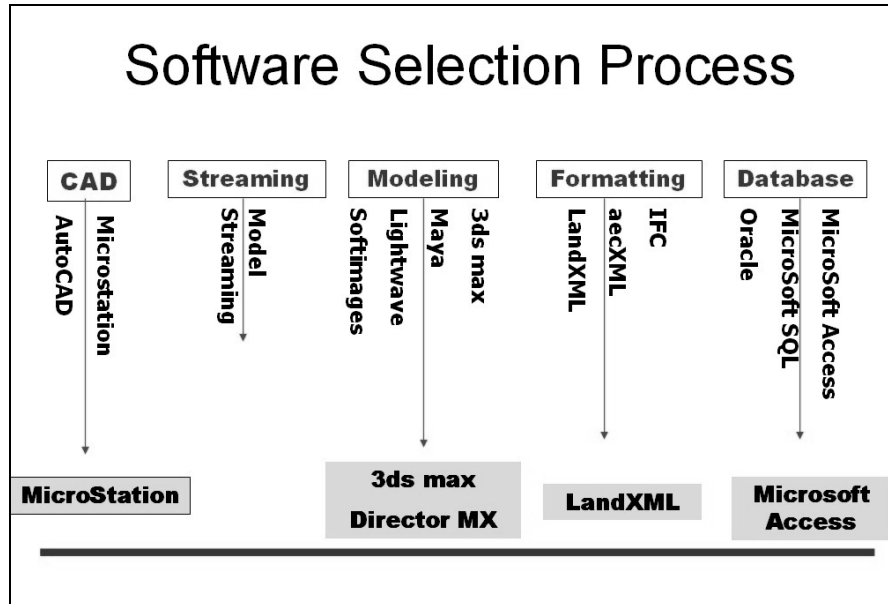
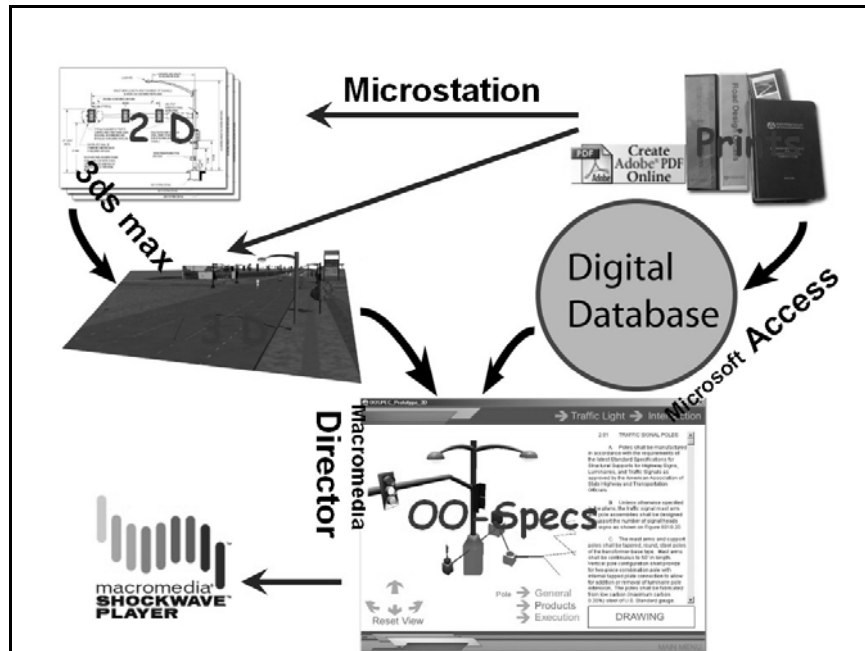


Figure 3. Software selection process



**Figure 4. Software selection decision illustration**

## PROTOTYPE MODEL DEVELOPMENT

The research team developed a prototype in phase I to substantiate the feasibility and effectiveness of an OODAS model. First, the current design standards and construction specifications were studied by choosing typical objects for the prototype. The team then created a 3D model to test the concept and workability of an OODAS system. The prototype was brought to several focus group meetings and improved based on the feedback. The prototype and its demonstration revealed that the concept is valuable and that the current ERL can be fully reused.

### Objects and Data

The developed prototype demonstrates a typical local street intersection. To help researchers quickly set up the 3D models in a meaningful way, the Lincoln Way and Grand Avenue intersection in Ames, Iowa was used as a physical reference (Figure 5). This intersection was recently rebuilt and is representative of current standard design and specifications including a double left lane, single left lane, right turn lane, median, complicated traffic control devices, and underground utilities. Therefore, a scene based on this intersection would contain sufficient objects to illustrate the research concept quite satisfactorily. However, the computer generated 3D scene was not exactly the same as the physical intersection. The objects were modeled after the standard designs, whereas the actual intersection had slight variations from the standards.



**Figure 5. Lincoln Way and Grand Avenue intersection, Ames, Iowa**

The objects created in the prototype model include, as illustrated in Table 1, a cross-section of a street, a driveway, traffic signal devices, street lights, and intakes, each of which contains several sub-objects. For example, the object of street was further divided into pavement (including joint and sealant), subbase, undisturbed soil along with sidewalk and curb, sanitary sewer, storm sewer and other underground utilities. The objects were created following the dimensions from standard drawings, and related specification data were linked to the sub-objects. All standard drawings and specifications are from both Iowa DOT and SUDAS standards. For example, the 2D views of the street pavement object can be found in Iowa DOT standard drawing RH47B.

### **Programming Involved**

Programming involved in the prototype includes Lingo, C++, HTML, and HTML HELP. Among these, the bulk of the programming was performed in Lingo. Lingo, the programming language used by Macromedia Director, can set up navigation control, define 3D object behavior, link the model to the outside database, and apply Macromedia Director Xtras. Xtras are software components that extend the functionality of Macromedia Director movies, projectors, and Shockwave movies (Macromedia 2003). A small portion of C++ programming was used for Macromedia Director Xtra and Application Programming Interface (API), which provides access to the support functions defined in the classes and additional useful functionality. HTML programming was used to modify the existing ERL data file when needed and to display Scalable Vector Graphics (SVG) files. The SVG format is a new standard for web graphics, which exceeds the capabilities of older style raster image formats, such as JPG. This new format has consistent quality at different zoom levels and on different sized screens (Software Mechanics PTY ltd 2003).

**Table 1. Case objects and related design and specification information**

Objects		Description		Materials		Methods		Drawings
Main (1)	Sub-Objects (2)	DOT (3)	SUDAS (4)	DOT (5)	SUDAS (6)	DOT (7)	SUDAS (8)	DOT (11)
Light Pole	Pole	2523.06		4185.02		2523.22		rm31
	Luminaries	2523.07		4185.03				rm31
	Conduit	2523.10		4185.10				rm34a
	Hand hole	2523.11		4185.08		2523.22		rm42
	Base	2523.05		4185.02				rm43
	Footing	2523.03		4101.01				rm39
	Cage	2523.03		4101.01				rm39
	Bolt	2523.15		4185.02				rm39
Drive Way	Sidewalk							
	Driveway							
	Curb	2301.17						
	Pavement	2301.01		4115.01				
Traffic Signals	Signal Head	2525.05		2525.01				
	Loop Detector	2525.04		2525.01				
	Pole	2525.06		2525.01				
	Push Button	2525.05		2525.01				
	Footing	2525.06		4101.01				
	Conduit	2525.02		2525.01				
	Cabinet	2525.03		2525.01				
Intake	Concrete Fillet		6030.1	4149.04	6030.2.01		6030.2.01	ra40
	Insert		6030.1	4149.04				ra40
	Access Cover		6030.1	4149.05				ra54
	Storm Sewer	2503.01	4020.1.02	4149.03	4020.2.01	2503.04	4020.2.01	ra50
	Backfill		3010		3010		3010	
	Frame		6030		6030		6030	
	Pavement							
Street	Pavement	2301.01	7010.1.02	4115.02	7010.2.02		7010.2.02	rh47b
	Curb	2512.01	7010.1.07	4101.01				
	Sidewalk	2511.01	7030.1.02	2511.02	7030.2.02		7030.2.02	
	Sanitary Sewer	2503.01	4010.1.02	4149.03	4010.2.01	2523.04	4010.2.01	
	Utilities Lines	1104.11	2010.1.06					
	Subbase	2110.01	2010.1.02	4122.02	2010.2.04		2010.2.04	
	Joint - Sealant	2542.01		4136.02	7010.2.02		7010.2.02	rh50
	Dirt	2102.01	2010.1.02	2102.04	2010.2.04		2010.2.04	
	Storm Sewer	2503.01	4020.1.02	4149.03	4020.2.01		4020.2.01	ra51

### Prototype Development Process

The prototype application operates on the concept that a user browses around a 3D scene and selects an object in order to obtain the desired specification information. A simple example is explained in the following five steps:

1. **Browsing the 3D scene.** A user can simulate moving around in the 3D scene by turning left or right or moving in or out of the scene (refer to Figure 6).
2. **Selecting the specification and the version of specification.** The prototype allows the user to select the appropriate specification (i.e., Iowa DOT or SUDAS along with the appropriate version) (refer to Figures 7 and 8).
3. **Selecting the object.** The user can select a particular object by placing the mouse on the object and clicking the left button. After selecting an object, the user is presented with a detailed view. In this example, a light pole in the scene is identified (refer to Figure 9).
4. **Selecting sub-objects for providing greater detail.** Greater detail can be provided by clicking on parts of the object within the detailed view. After selecting the object from step 3, the interface will be changed into the Object View as shown in Figure 9. Selecting a part of the object will provide more detailed information regarding the object.
5. **Selecting specification information from the context menu.** The user can select one of the context menus, which appear over the object as shown in Figure 10. Then, the specifications with the all previous criteria will appear on the screen displayed in Figure 11. At this stage, if users re-select the specification type and version, the new information will be generated by re-clicking the sub-objects.



**Figure 6. Interface for an urban intersection**



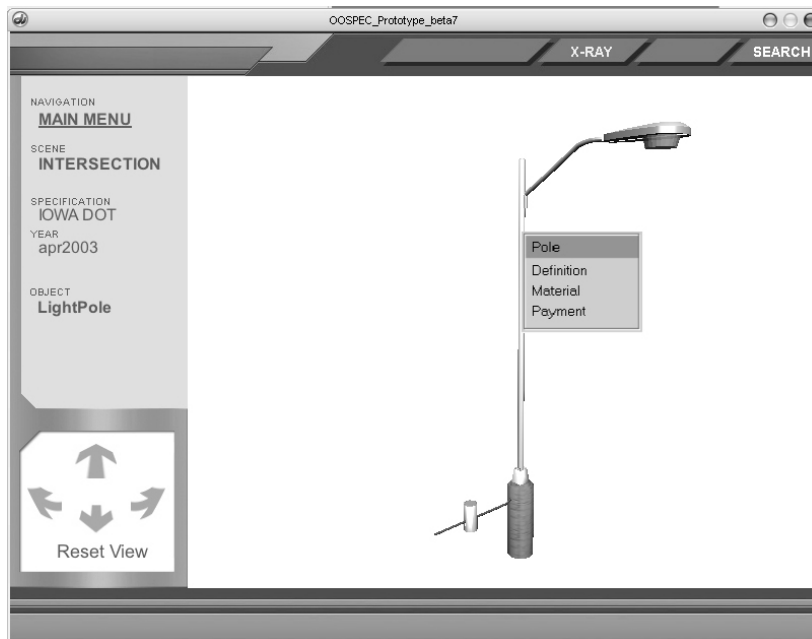
**Figure 7. Scene stage interface illustrating the two types of specifications**



**Figure 8. Scene stage interface illustrating the specification version date**

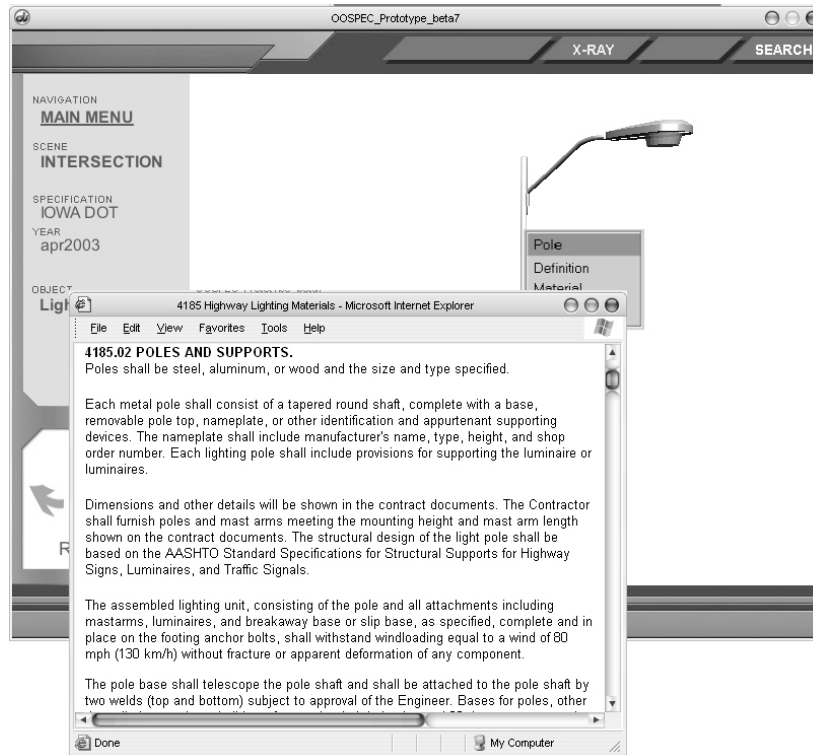


**Figure 9. Selecting an object view of a light pole**



**Figure 10. Object view illustrating light pole model with context menu**





**Figure 11. Specifications retrieved from the ERL displayed in Internet Explorer**

## Major Features of the Prototype

The prototype interface consists of four parts, including a view window along with a function toolbar, selection menu, and 3D control button panel (refer to Figure 12). The view window displays the scene view for selecting an object and the object view for selecting a sub-object. The design and specification data can be accessed from a sub-object with a context menu. The context menus actually link the data in ERL through a database control table (Microsoft Access or XML). While the detail of technical development can be found in the Appendix B, the major features of prototype are described below.

### *Real time 3D interface*

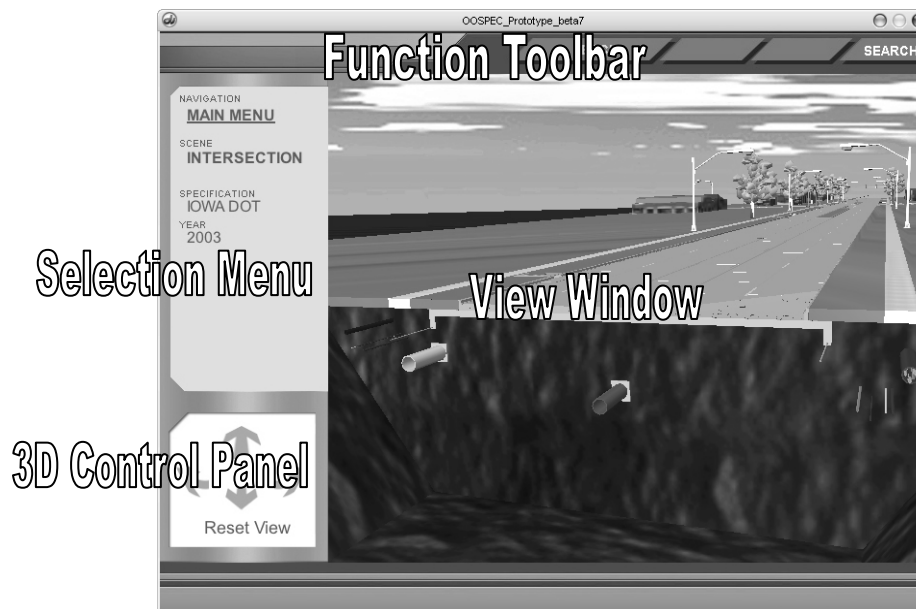
The prototype is based on the real time 3D interface which means the user controls the 3D models and retrieves data simultaneously. The 3D objects can be fully rotated, panned, and zoomed.

## *Object-Oriented Model*

The prototype was constructed by building a repository of high quality, reusable graphics and components of specifications that can be combined in various ways to produce new reusable components at higher and higher levels of abstraction. Specification objects in the database store non-graphical data in a logical structure together with the standard graphics that, in 3D, are in OO-CAD formatted files. Because of its 3D format, the main scene and objects can be rotated, panned, and zoomed. Each component (sub-object) of an object is associated with certain specification information, stored in the ERL database. By moving the object to a certain position, the user can click on any aspect of the model. Then, a context menu appears directing the user to the database containing the relevant specification information for that portion of the design. Therefore, users can easily locate information and project requirements from an object.

## *Multiple standards*

As was shown in Figure 8, the prototype accommodates multiple specifications into one graphical view. The user can access all the project requirements quickly and efficiently from one common view. The provisions from different standards for a physical object can also be tracked.



**Figure 12. Interface of the road utilities**

## *Multiple versions of specifications*

The prototype allows a user to get specific data from the correct version of the applicable specification. This can benefit those who are building projects that span over a year or with

multiple contracts. This will also help those who manage multiple projects that were let for bidding over different years. The critical changes between different specifications versions can also be shown on an object model so that the user can quickly see the difference between specifications versions (Figure 13).



**Figure 13. Object stage interface with the intake and sewer pipes**

### *External database*

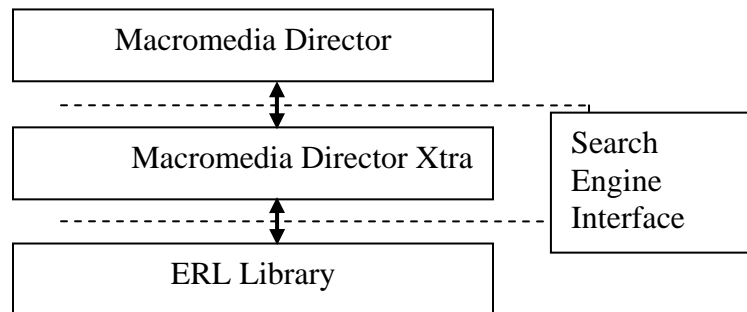
As mentioned in the conceptual plan, the prototype model fully uses the ERL database. This will bring significant savings on the system development and maintenance costs. During the prototype development, three different approaches to link the ERL database and 3D models were tested.

1. Connect to the ERL files through database table. When the user selects a sub-object, a Lingo program in Macromedia Director determines the name of the sub-object selected and looks for a match in an external database. The database returns a list of object properties. Another Lingo program uses this list to create a context driven pop-up menu. Finally, when one of the items in the pop-up menu is selected, Lingo interprets the selected item into the specific section number and opens the appropriate ERL document in a browser as was shown in Figure 11.
2. Connect to the ERL files through XML. This is similar to the approach of connecting through a database table except that an XML formatted file is used instead of a database. The XML file is smaller than the database file, and the XML file can be read by any program that supports XML. A drawback is that the tools for editing XML files are not as convenient as those for editing database files.

3. Connect to an HTML Help file through an XML file. HTML Help is an application that wraps up all the ERL html files into a searchable document. This approach is similar to the approach of connecting through a XML file but produces a different output appearance.

### *Search function*

In the ERL system, a commercial search engine searches the ERL database and puts the results together as a content file. This process is not generated dynamically. If the ERL library is changed, this process needs to run again. Such a search engine works well with the ERL system because its content changes twice a year, and the process of regenerating the index is not problematic. Also, the search function is much faster once the index is created. However, the OODAS is an object-oriented system, in which the objects are located separately with the data. The retrieval of the data for an object should be dynamic. To use the ERL database efficiently, a direct searching method was used with the OODAS prototype, by which the specifications are generated dynamically from the current ERL database. There are two processes within this method (Figure 14): one is to communicate with the ERL database and query the specified keyword, and the other is to communicate with Macromedia Director and return the search results to the software tool.



**Figure 14. Workflow of the OODAS search function**

By using this search function, users can have access to all of the related specifications by clicking a sub-object.

### *Self-Running*

OODAS was developed in two formats: one is a standalone executable application that runs from the user's computer; the other is a Shockwave file that runs through an Internet browser. In both cases, no additional software purchase is required to run the model. No additional software is needed to run an executable application. A Shockwave player, which is the only software needed to play the Shockwave file, can be downloaded free of charge from Macromedia. A CD that

contains a prototype in executable application format is available; therefore, the readers are encouraged to test the features discussed above.

## **FULL-SCALE DEVELOPMENT AND MAINTENANCE ISSUES**

Based on knowledge gained through developing the prototype, an estimate of the cost to develop and maintain the full OODAS system can be made. This section provides a description of the full OODAS system, relationship between OODAS and ERL, possible methods for distributing OODAS to the users, computer requirements for OODAS users, and update and maintenance process.

### **Description of the Full OODAS System**

As with the prototype, the full OODAS system will consist of scenes that portray typical features of highway and bridge construction. There will be two main scenes. One scene will focus on objects typical of a rural setting, and the other scene will focus on objects typical of an urban setting. As illustrated in Figure 15, the urban scene mainly contains arterial streets, collector streets, and local streets. The rural scene mainly contains various types of highways (Freeway/Expressway, Super-two/Two-lane highway), transitional facilities, and ramps and loops. Table 2 describes the scope of these elements. Each element consists of many objects. The objects are grouped in three levels of complexity based on the modeling effort for objects in the prototype: high complexity, moderate, and low complexity. A high complexity (HC) object is one with many sub-objects and complicated geometrics such as a portion of street. A HC object usually has more than 5,000 polygons in the 3D modeling process. A low complexity (LC) object is one that has few or no sub-objects and has a simple geometric (such as a STOP sign). A LC object usually has less than 100 polygons. Any objects between HC and LC are grouped into moderate complexity (MC) objects. A full OODAS system will use typical 3D objects to link the drawings and specifications instead of using all the possible objects. The details of these objects are in Appendix C. Each object also contains a sub-object that links to standard designs and specific specification information. In summary, the development of an urban scene involves a minimum of 150 objects (9 high complexity, 30 moderate complexity, and 111 low complexity objects). The development of a rural scene involves a minimum of 121 objects (9 high complexity, 18 moderate complexity, and 94 low complexity objects). Among these low complexity objects, 73 objects are identical or very similar in both the urban and rural scenes.

### **Relationship between OODAS and ERL**

ERL provides an indexed interface to many of the standard designs and specifications for both the Iowa DOT and SUDAS. OODAS is designed to use the index provided by ERL as a database. This will save the time and effort that would be required to develop a new database, and the current ERL users can easily accept the fully developed OODAS system in the future. Some modifications of ERL will be necessary. In order for users to obtain specific information, the current ERL data file (which is mostly in html format) will need additional indexing. ERL

currently has all first-level sections of the specifications indexed. OODAS will require indexed subsections to allow for more exact data extraction. These additional indexes will be performed as part of the OODAS development. In summary, OODAS will completely reuse the ERL data.

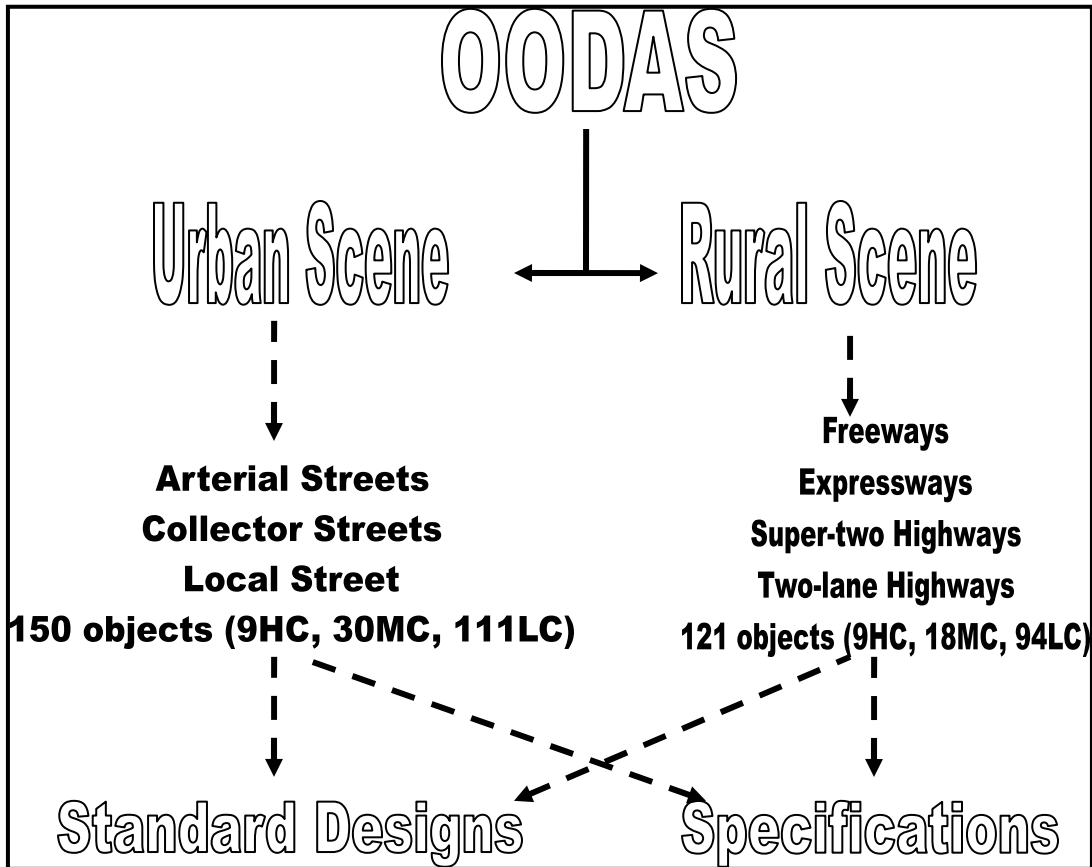


Figure 15. Overall structure of a full-scale OODAS system

### OODAS Distribution

Similar to the ERL, a variety of arrangements can be developed to distribute OODAS. Iowa DOT and SUDAS could be responsible for providing OODAS to all potential users via the Internet. Although OODAS was initially proposed to be a Web-based product, a CD/DVD version is still under consideration due to user preference, Internet availability, and performance of current computers. The Iowa DOT and SUDAS can provide new versions of OODAS on CD each time an update to the specifications is issued, sell subscriptions to all updates issued during a certain period of time, or transfer responsibility for distribution of updates to a third party. Selling subscriptions would eliminate the need to contact a list of subscribers and process payments every time an updated OODAS version is issued. Transferring distribution to a third party would reduce staff requirements and administrative involvement.

**Table 2. Definitions of elements in the urban and rural scenes**

<b>Elements</b>	<b>Scopes</b>
<b>Urban Scene</b>	
Arterial Streets	Highways extensions in the urban areas
Collector Streets	Streets that connect major arterials routes, minor arterials routes, and local streets
Local Streets	Streets that provide direct access to residential and commercial property and carry low traffic volumes
<b>Rural Scene</b>	
Freeways	Multi-lane divided highways with full access control—access allowed only at interchanges
Expressways	Multi-lane divided highways with at-grade intersections, often in combination with interchanges at high-volume intersections and primary routes
Super-two Highways	Rural two-lane undivided highways with enhanced geometrics to improve operational and safety features. Intersections are at-grade
Rural Two-lane Highways	Rural undivided highways with at-grade intersections
Transitional Facilities	Roadways that transition between a high-speed rural driving environment and a reduced speed urban environment
Ramps and Loops	Facilities that allow access at interchanges

### **System Requirements**

OODAS currently supports several versions of the Microsoft Windows operating system with the following specifications:

- Windows 98, Pentium II, 64MB RAM
- Windows 2000, Pentium III, 128MB RAM
- Windows XP, Pentium III, 128MB RAM
- Microsoft Internet Explorer 6 or Netscape 7.1

However, in order to run OODAS at a normal speed, the minimum requirements for users of Microsoft Windows system should be Window 2000 or later, Internet Explorer 5.0 or later, OpenGL driver, and Direct 9.0b. The hardware requirements should be Intel III 800Mhz CPU, 640 MB memory, 1GB hard drive, and a 16 bit color monitor with a 1024x768 resolution.

OODAS also supports the Macintosh operation system with the following specifications:

- Mac OS 9.2, Power Macintosh G3, 64 MB RAM with Microsoft Internet Explorer 5.1
- Mac OS 10.1.5, Power Macintosh G3 with Microsoft Internet Explorer 5.2, Netscape 7.1, or Safari

## **Maintenance and Update Issues**

From the beginning of this project, minimizing the cost for maintaining this system has been an overriding design criterion. Because of the importance of these costs, OODAS was designed to reduce or eliminate maintenance costs whenever possible. This can be accomplished with, as previously discussed, dynamically linking the objects and data, reusing the ERL database, and minimizing the software requirements to run the system.

### *Maintenance Considerations*

In addition to the cost of development, the cost to maintain and update OODAS must be determined. Issues that must be considered include:

1. Release of new components for the 3D library of design standards as the design standards are updated
2. Update of the OODAS database to coincide with the twice a year update cycle of the standard specifications
3. Administrative procedures and overheads of maintaining the OODAS system
4. Maintenance of facilities and inclusion of new facilities such as new server and new distribution media
5. Quality of customer service and user expectations
6. User instruction and training issues

### *Update Effort within Iowa DOT and SUDAS Cycle*

Currently, the Iowa DOT releases the design and specification updates twice a year. Because OODAS uses ERL as its database, changes to the standard specifications will require limited changes to OODAS. OODAS will only be impacted if sections are added, deleted, or renumbered. As an example, in the October 2003 update of the Iowa DOT standard



specifications, the only OODAS changes would have been the addition of eight new subsections. Most of the OODAS update effort will center on changes to the standard drawings because these changes may require the 3D library. To measure the effort of updating, the changes to the design standards and drawings must be evaluated. Table 3 shows the changes of the standard design for the October 2003 update cycle. 171 of 996 standard designs were modified during this cycle, including all changes among Iowa DOT road standards, bridge standards, culvert standards, and SUDAS urban design standards. The changes represent 17.2% of all of the standard drawings. The level of the changes varies among the different files. Some changes are very minor and have very low impact on OODAS. For example, many of these changes simply change a few notes. Other updates have low impact on OODAS, such as a change of concrete thickness. In a few cases, the update is moderate, such as a change to a new type of intersection. The details of changes mentioned in Table 3 are listed in the appendix G.

**Table 3. Drawing files changed for the April 2004 letting**

Standard Design (1)	Total Files (2)	Files Changed (3)	Percent Changed (4)
Standard Road Plans	422	46	10.9%
Standard Bridge Plans	230	91	39.6%
Standard Culvert Plans	112	8	7.1%
SUDAS Design Standards	232	26	11.2%
<b>Total</b>	<b>996</b>	<b>171</b>	<b>17.2%</b>

### **Time and Cost Analysis**

Based on the time needed to develop this prototype model and on its cost, the time and cost of developing a full scale OODAS system can be estimated. The following section gives a summary of the analysis.

#### *Analysis Method*

Due to the uncertainty and variance of objects in the full OODAS system, compared to those in the prototype, there is no way to use single point estimates to specify the time for future development. Therefore, a range estimate method is employed with assumptions of the researchers' best judgments based on this pilot study. The procedure for this method includes the following considerations:

- Tracking the time and cost for the pilot study and categorizing them
- Identifying the portion of the time that is applicable to the full OODAS development
- Defining a set of time units for different levels of object complexity
- Estimating the total number and complexity of objects for the full scale system
- Simulating the time ranges and cost for developing the full OODAS system

Based on experience gained through the development of this pilot study, the authors were able to estimate the minimum, maximum, and a most likely time required to develop an object based on the complexity of the object. This type of system can be analyzed using a statistical triangular distribution because the tracked data meet the three necessary conditions for a triangular assumption:

- The optimistic (minimum) effort needed to develop an object is known.
- The pessimistic (maximum) effort needed to develop an object is known.
- The most likely effort-hour falls between the optimistic and pessimistic values, forming a triangular shaped distribution, which shows that values near the optimistic and pessimistic values are less likely to occur than those near the most likely value.

The decision-making software—Crystal Ball (Decisioneering 2001)—was used to perform the simulation.

### *Time Spent on Prototype*

The time spent on developing this prototype model can be categorized into project planning, system development, and wrap-up time (a definition of these terms is given in the footnotes of table 4). The system development time is the most significant factor used to forecast the full system development cost and is further categorized to include project preparation, 3D modeling, data indexing, model and data matching, and programming time. Preparation time includes time for reading and analyzing the design standards and specifications, determining the objects with related drawings and specifications, and studying the required software. 3D modeling time includes time for creating geometrics, assigning textures, and creating W3D files. Data indexing time includes time for clarifying or reorganizing (if necessary) the data files in the existing ERL, creating an index, and establishing the database. Model and data matching time includes time for establishing relationships between 3D objects and data objects. Programming time includes writing required Lingo, C++, and HTML codes and creating a search function.

The pilot study duration was 17 months or 3500 effort-hours; however, the research team spent many hours on preplanning, developing a comprehensive plan, and testing different software and features of modeling. These activities will not occur again in the next phase. Therefore, only system development time is meaningful to estimate the cost of the full system development. Table 4 provides hours for each activity. 1,248 hours were spent on developing the prototype, which included preparing, 3D modeling, data indexing, model and data matching, and programming. Among these activities, the 3D modeling and programming activities occupy a large portion, approximately 72% or 900 hours of time (Figure 16 and Figure 17). Of these hours, the 3D modeling took 200 hours or 16% of development time. Table 4 also gives the 3D modeling time of each object for the prototype. As seen in Table 4, the street object has seven sub-objects (curb, lane marking, pedestrian ramp, sub-base, subgrade, pavement, and median) and took 80 effort-hours to develop.

**Table 4. Overall time spent on the prototype**

(1)	(2)	(3)	(4)	(5)
Project Stage			Weeks	Effort-hours
Stage 1 Project Planning January - April 2003			17	816
Stage 2 Development Trials May - August 2003			17	816
Stage 3 Final System Development September - February 2004			26	1248
Preparation				158
3D Modeling	Sub-object	Polygons		200
Street	7	6,390		80
Curb and Gutter				
Pedestrian Ramp				
Pavement Marking				
Subbase				
Subgrade				
Pavement				
Median				
Traffic Signal Pole	9	1,530		24
Light Pole	5	1,536		18
Intake	9	461		30
Traffic Signs	3	36		6
Stop Sign				
Speed Limit Sign				
Keep Right Sign				
Utilities	5	3,252		18
Data Indexing				100
Model and Data Matching				90
Programming				700
Stage 4 Project Wrap-up March - May 2004			13	624
Total (17 months)			73	3504

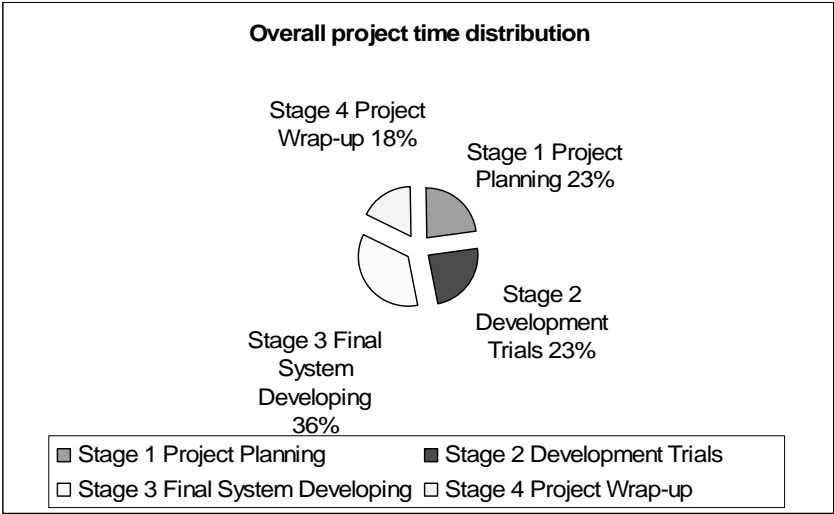
Notes:

<sup>1</sup>Based on an assumption of 48 effort-hours per week (2 students at 20 hours/week and 2 faculty at 4 hours/week).

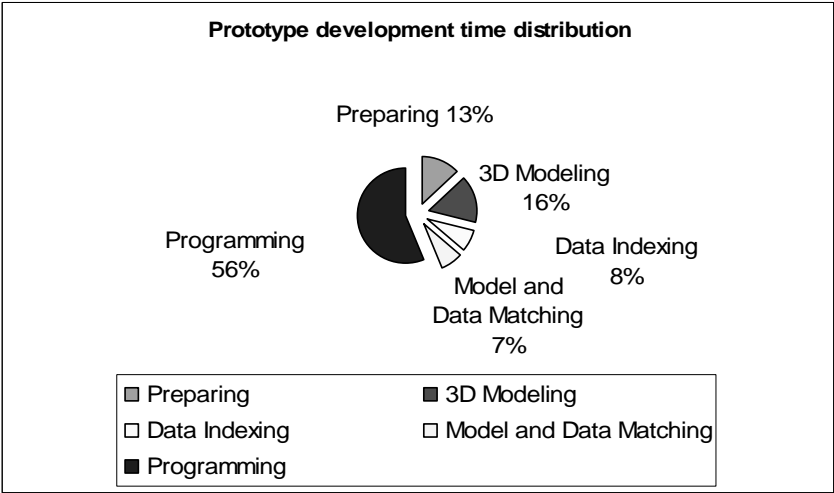
<sup>2</sup>Project planning time defines the time spent on getting ready for technical development to start, which includes the time for searching for related literature, determining methodology, selecting hardware and software, and defining system feature requirements.

<sup>3</sup>Wrap-up time defines the time spent on writing reports, developing the implementation plan, and evaluating the research direction.

<sup>4</sup>System development time defines the time spent on developing the system, which includes the time of preparing, 3D modeling, data indexing time, model and data matching, and programming.



**Figure 16. Overall project time distribution**



**Figure 17. Prototype development time distribution**

*Time Estimated for Developing Full-scale System*

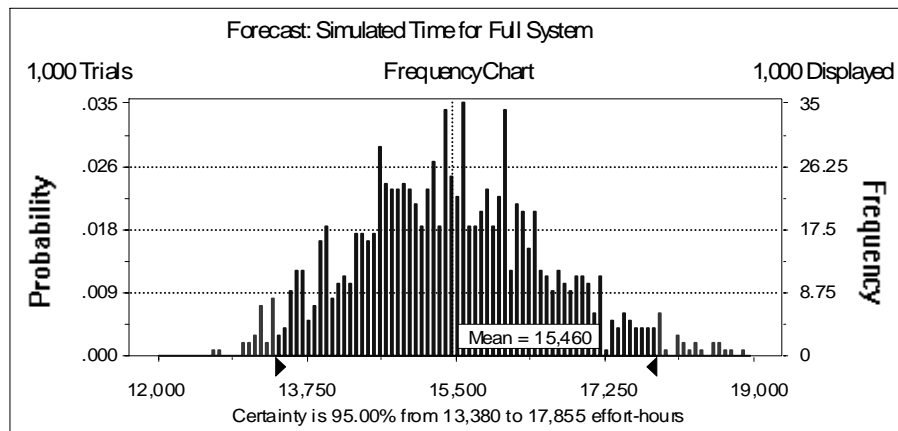
Based on this pilot study and an assumption of continuing the development with a knowledgeable research team, a set of time units was determined in terms of time per object. As mentioned in the method section, the objects are grouped into three complexity levels based on the modeling effort for objects: high complexity, moderate complexity, and low complexity. Table 5 gives the optimistic (minimum), most likely, and pessimistic (maximum) number of hours for developing an object for each different complexity level (high, moderate, and low) as

well as for each development activity. Crystal Ball uses Monte Carlo simulation to determine the likely range of development effort. While these point-estimated values are listed in the table as a comparison, the simulation was run to obtain the range of effort-hours as shown in the Table 5. In general, with 95% certainty, the time to develop an object ranges from 223 to 335 with a mean of 273 effort-hours for high complexity objects, from 93 to 137 with a mean of 112 effort-hours for objects with moderate complexity, and from 29 to 52 with a mean of 40 effort-hours for low complexity objects.

As mentioned above, a workable full system should contain, as shown in Table 4, a total of at least 198 objects (18 high, 48 moderate, and 132 low complexity objects). By combining the number of objects and the estimated number of development hours for each object, the Monte Carlo simulation resulted in a range of 12,186 to 19,332 effort-hours with a mean of 15,460 hours to develop the full system (Figure 18). Assuming 14 hours of research time a day (3 half-time students with 2 supervising researchers), the mean time of development is 49 months with a range from 42 to 57 months. However, these numbers could be significantly reduced by using an additional staff. Also, the prototype model can be modified and reused in the full-scale system.

*Cost for Developing Full-scale System*

The cost anticipated for developing the entire system is also illustrated in Table 5. These costs include the purchase of the hardware and software, researcher’s time, and report preparation costs. The total cost of developing a full OODAS system, just for specifications and related standard design based on a set of typical objects above, was estimated about \$575,000.



**Figure 18. Monte Carlo simulated time to develop a full OODAS system**

**Table 5. Time and cost assumption for full system development based on prototype**

System Developing Activities		Developing Time (hours)			Suggested Simulation
		O	M	P	
(1)	(2)	(3)	(4)	(5)	(6)
Preparing		14.9	22.2	35.0	
	High Complexity	30.2	38.5	56.1	Triangle
	Moderate Complexity	9.1	17.6	28.0	
	Low Complexity	5.6	10.5	21.1	
3D modeling		67.7	90.3	137.8	
	High Complexity	140.1	186.8	280.3	Triangle
	Moderate Complexity	56.1	70.1	105.1	
	Low Complexity	7.0	14.0	28.0	
Data Indexing		4.4	7.7	13.8	
	High Complexity	5.6	10.5	17.6	Triangle
	Moderate Complexity	4.2	7.0	14.0	
	Low Complexity	3.5	5.6	9.8	
Model and Data Matching		4.0	9.4	16.4	
	High Complexity	7.0	17.6	28.0	Triangle
	Moderate Complexity	3.5	7.0	14.0	
	Low Complexity	1.4	3.5	7.0	
	Point Estimated	91.1	129.6	203.0	
	Time Per High Complexity Object	182.9	253.4	381.9	
	Time Per Moderate Complexity Object	72.9	101.7	161.2	
	Time Per Low Complexity Object	17.6	33.7	65.9	
	Crystal Simulation	Min	Mean	Max	
	Time Per High Complexity Object	222.6	273.1	334.3	
	Time Per Moderate Complexity Object	92.3	112.0	136.7	
	Time Per Low Complexity Object	28.4	39.1	51.2	
Estimate Scenes in Full System		Typical Objects			Time (10)
(7)	(8)	(9)			
		Numbers	Min	Mean	Max
	High Complexity	18	4007	4916	6018
	Moderate Complexity	48	4429	5378	6561
	Low Complexity	132	3750	5166	6753
	Subtotal	198	12186	15460	19332
Development Time (hours)		12186	15460	19332	15460
Crew Rate, including benefits (\$)					27.00
Total Labor Cost (\$)					417,420
Software Purchases (\$)					5,000
Hardware Purchases (\$)					5,000
Other (travel, printing, etc.) (\$)					30,000
Subtotal (\$)					452,420
Indirect 26%					117,629
Total Project Estimate (\$)					575,049

### *Time and Cost of Update Cycle*

The time and cost anticipated for performing a 6-month update is illustrated in Table 6. Assuming the update in the latest cycle is typical of past updates, the time to modify the OODAS system is about 145 effort-hours. These costs include researcher's time and report preparation costs. The individual selected to maintain the OODAS system would also be responsible for training people and answering questions. It appears that it would be best to hire someone on a full-time basis to provide maintenance and support for this system. The total semi-annual cost of each update including support is estimated to be about \$ 43,470.

**Table 6. Time and cost estimated for a 6-month cycle update**

Estimate Update in Full System		Typical Time Unit (minutes)			Time	
(1)	(2)	Numbers	Min	Mean	Max	(4)
	High Complexity	0				
	Moderate Complexity	2		480		960
	Low Complexity	49		120		5880
	Very Low Complexity	61		30		1830
	Total	112				8670
Total Labor Cost (\$) ½ year salary						32,500
Other (software maintenance, etc.) (\$)						2,000
Subtotal (\$)						34,500
Indirect 26%						8,970
Total Project Estimate (\$)						43,470

In general, the development of a full system with minimum typical objects will take an average of 4 to 4.5 years and cost about \$575,000 for Iowa DOT and SUDAS specifications and related standard drawings. From the beginning of this project, minimizing the cost of maintaining this system has been an overriding design criterion. Because of the importance of these costs, OODAS was designed to reduce or eliminate maintenance costs whenever possible. The estimated annual cost to maintain the OODAS system is expected to be around \$87,000. This figure includes the cost to hire one dedicated person to maintain the OODAS system and pay for software license fees.

### **Changes in Operating Procedures**

There are four steps in maintaining OODAS, some of which may require operating changes with the Iowa DOT and SUDAS. These steps include maintaining the 3D library, updating the database, modifying ERL, and programming modifications. Each of these steps is described below along with the skills necessary to accomplish the required tasks.

### *Maintaining the 3D Library*

Changes to the road and bridge standards may require changes to the 3D library. Creating and modifying 3D models requires a skill that is a blend between the engineering skills necessary for working with CAD drawings and the artistic skills required to choose an appropriate level of detail that accurately and aesthetically portrays the road and bridge objects. This task also requires knowledge of a 3D modeling software package. This prototype was developed using a 3D modeling software package called 3D Studio Max, a product owned by AutoDesk.

### *Updating the Database*

The function of the database is to link the drawing objects to the appropriate specification number. Changes to the specification content that do not impact the numbering system of the specifications will not impact the OODAS database. However, whenever a section, subsection, sub-subsection, and so forth is created, deleted, or renumbered, the database will need to be changed to reflect this change. In the October 2003 update, there were eight new subsections added to the Iowa DOT Standard Specifications. The skills required for modifying the database are the same as those for editing a Microsoft Excel spreadsheet. In the worst case, if the numbering system for a specification book is completely changed, the databases will have to be recreated from scratch.

### *Modifying the ERL*

To make OODAS more useful, some changes to ERL are required. Currently, the ERL files are bookmarked at all first-level subsections. This allows the user to quickly access any first-level subsection. In some instances, the entire subsection contains much more information than is required for a particular 3D object. In these instances, access to a second- or third-level subsection is desirable. These bookmarks will be created as part of the OODAS development. However, during the maintenance phase, the OODAS team will need to coordinate with the ERL team to ensure that additional bookmarks are maintained. Basic HTML editing skills are required for this task.

### *Programming*

Since low maintenance is a design criterion for OODAS, the Macromedia program was designed to be dynamic. The actual linking of the objects to the specifications is handled by the database. The Macromedia program only matches the name of the drawing object to the corresponding database entry. Once the full OODAS system is developed, no additional changes to the Macromedia program will be required. The only exception would be changes to the look of the OODAS interface. The skills required are knowledge of Macromedia Director and its Lingo programming language. Also, Adobe Photoshop is convenient for creating and adjusting images that are used within Macromedia Director.



## **Discussions with Potential Users**

As part of the project research scope, it was necessary to obtain feedback from potential users regarding their views of a fully developed OODAS program. A representative sample of potential users was compiled, including a city and county engineer, consulting engineer, construction contractor, Iowa Department of Transportation design and construction engineers, and an additional person at the federal level. Findings suggest that a system like this could improve productivity to find information by as much as 75% and provide a greater sense of confidence that all relevant information had been identified. It was also apparent that this system would be used more by people in construction than in design. There were some concerns, however, related to the cost of developing and maintaining the complete system and its overall value to the DOT as it is currently scoped. Individual comments follow.

### *Contractor Perspective*

Mark Freier, Godbersen Smith Construction: Specification information is found in many different places of the specifications. This system will help pull together all of the information with one click on the object. Therefore, you are less likely to miss information. For example, for an intake, it would be possible to pull up casting numbers, which would be very helpful when ordering. Mark sees that it would take only 25% of the time to obtain desired information using this approach. He also mentioned that he currently needs to photocopy portions of the specifications and give them to field personnel or others. With the new system, he would be able to email portions of the specifications—it would be faster and more convenient. Mark said that he uses the specifications 2-3 hours per week. With the OODAS system, Mark would be able to save 1.5 to 2.25 hours each week. A current limitation with this system is the fact that field personnel will not use it, at least for now, since they do not have their own computers in the field. He sees this system as more office-oriented.

### *Iowa Department of Transportation Materials Perspective*

Jim Berger: The DOT knows the plans and specifications; the contractor needs to know them. The system should focus on getting the information to the contractors that they need to know to bid the job. Three-dimensional pictures may be unnecessary. He did offer some suggestions regarding the future direction related to focusing more at the project level. Perhaps, a system that focuses on two-dimensional road standards would be just as effective and more manageable. We need to help the bidders identify the incidentals on the plans. Bidders sometimes miss these incidental items and end up providing incorrect bid costs. One thought was for the system to identify incidentals in the specification bid items using the same “red flash” technique found in the OODAS system.

### *Iowa Department of Transportation Resident Engineer Perspective*

Doug McDonald: Doug felt that the OODAS system will be easier to use than the current approach. He presently uses the ERL to quickly find information and then checks the information in the specification book. Doug felt that a system like this would help newer people save time learning about the specifications. It could also save time for experienced inspectors as well. He mentioned that inspectors typically refer to the specifications 2-3 times per day to obtain information on one item each time and generally spend 5-20 minutes on each item. Doug

believed that OODAS could cut the time by 75%, and the quality of the information could be better.

#### *Iowa Department of Transportation Urban (Large) Design Perspective*

Jim Schoenrock and Don Drake: Jim and Don sensed that field would find the OODAS system useful. They were not sure about the benefits for design since design does not use the specifications very much. They saw the primary advantage in 3D graphics related to training new technicians or engineers on the standard specifications. They also agree that there could be a significant timesaving in finding information using this new approach.

There was some concern over the use of modified road standards. For example, the standards for the storm sewers on I-235 are non-standard. The visual system would be good for a small area like the Lincoln Way/Grand Ave intersection. Experienced users know the specification book. New engineers would benefit from using this new system. However, even after several years at the DOT, some designers still do not know all of the specification books.

#### *Iowa Department of Transportation Urban (Small) Design Perspective*

Dennis Smith and Yanxiao Jia: OODAS is a tool to get people familiar with standards and would help people remember certain specifications. As Dennis said, “Specs have a habit of hiding things.” He felt that beginners and seasoned designers could use this system. It would be useful to be able to obtain the latest information, and having the supplementals included would be a real plus. He mentioned that “thoroughness is the key issue.” He also liked the idea of highlighting changed items to quickly identify objects that are linked to updated specifications.

The OODAS system could help provide greater confidence that we did not miss anything. Designers do not refer to the specifications enough because the specifications are not convenient. Dennis said that OODAS would be more beneficial to the field. Furthermore, Dennis thought OODAS would make it easier to merge SUDAS and DOT specifications. “Get it up and running.”

#### *Iowa Department of Transportation Rural Design Perspective*

Dave Skogerboe: Dave mentioned that the OODAS system would have great value, especially with the ability to expand and tie standard road plan, typicals, and design information. Young designers and engineers would benefit significantly from being able to visually associate with the roadway parts and their specifications. He said that our designers should be reviewing the specifications more, and using OODAS would make this process more user-friendly. Also, this approach would more efficiently identify differences between DOT and SUDAS specifications.

#### *Iowa Department of Transportation Bridge Perspective*

Gary Novey: Gary expressed some concerns with this system. He felt that the ERL would be sufficient to quickly and efficiently obtain specification information and that the added visual front end is not really necessary. He was also concerned about the maintenance costs and the “black box” where you really do not know what is going on inside to know that you have everything pertaining to the object.

The graphic system could give a false sense of confidence. Users may not make the effort to be thorough in a review of the specifications if they only view the visual system. After five years, people know the components of bridges and do not need the aid of the visual specification system. A visual system is good for the users who do not have the knowledge of all components. Knowledgeable users do not need the visual front end since they know what is important. He would like to see a graphical representation of a bridge.

#### *Iowa Department of Transportation Construction Perspective*

John Smythe: John believed that it would be very difficult to make OODAS useful for everyone. The 2D road standards are the level of visual detail required. The 3D animations are not necessary to make the system useful. Redirecting the focus to include a more project-specific approach and begin with a training focus would be a good future direction for this project. More specific comments from this interview are summarized below.

- The ERL is a good way to find out information for a general search of an incidental item. It is faster, however, to go directly to the book for specific items that you know about instead of going to the ERL. John mentioned that inspectors primarily use the specification book.
- John sees the OODAS system as good for training purposes.
- It is the unusual features (e.g., bridge handrails) that would make people go to OODAS.
- At a recent AGC meeting, John heard a contractor say that it is difficult to keep up with changes to the specifications—this is surprising since it is their responsibility to build projects according to the plans and specifications. The critical change feature in OODAS may help out.
- Scenes could be tied to road standards. For example, with guardrail, there are several issues that require referring to several different specs/standards: road standards (R.S.) type, grading standards, lapping, bolting, posts, acceptable material supplier instructional memorandums (IM), and how contractor will be paid. Currently, the links between road standards and bid items are not clear. John mentioned that it would be good to take a PCC job to look at all of the specifications and road standards that apply.
- Being project specific is really the key:
  - Use actual project plan and include all of the appropriate links.
  - Link pictures of good and bad installations (e.g., guardrail).

#### *City Perspective*

Jeff May, City of Knoxville, IA: The upfront costs are quite high. As a comparison, the costs of developing a new car are very high, but are not bad when spread out over several thousand cars. The graphical system will be a very efficient way for the field person to find data. It is the way of the future. This will be a simple way for the field person who does not know the terminology (i.e., the technical name for an object) or is unsure exactly which book to look in. Field workers refer to the specification book daily. Designers do not refer to the specifications so often.

#### *County Perspective*

Jim George, Dallas County: The visual system is the natural progression of the SUDAS/DOT combined specification. This system will make it easier for inspectors thus shortening their learning curve. You can read the specification book to learn the specs, but if you do not use the knowledge, you will not retain it. The graphic system will allow inspectors to efficiently acquire all of the pertinent information when needed and may help them better retain this information. Jim is ready to see the system implemented.

#### *Consultant Perspective*

Steve Klocke, Snyder & Associates: The upkeep of the system would be challenging. There was concern over who would be responsible for the upkeep. The OODAS system may be good for younger engineers. Once you know the specifications, you can find information more efficiently on your own. Supplemental specifications (project specific) are fairly common. Experienced people refer to the specifications to refresh their memory as to the specific material requirements or payment terms.

#### *Federal Perspective*

Andy Wilson, Federal Highway Administration: It looks like a great project. He is concerned about cost and time required to develop system. Andy believes there may be a middle ground for the next phase of the project. His experience shows that the current Iowa inspectors are fairly young. "We have lost a lot of experience, and this tool could be useful to help young inspectors get started."

## **RECOMMENDATIONS**

There are several recommendations related to the continuation of this project dealing with technical, implementation, and next phase issues.

### **Technical Issues**

From a technical standpoint, the existing prototype model can be further streamlined. For instance, from the Lingo programming perspective, there is some redundant programming code that can be eliminated as well as shortened as a result of learning this new language. Additionally, the models can be improved by making them more realistic while keeping the size of each object (number of polygons) to a minimum. Moreover, deeper layers of indexes can be developed for the ERL which would allow users to obtain the desired information more quickly. In many instances, the precise specification information for the desired object is included somewhere under a main heading or subheading. Users might need to scroll through the information provided to find the specific information. Finally, because of the XML features discussed earlier in this report, XML might be considered better than Microsoft Access for the full-scale system.

## **Implementation Issues**

Since the object-oriented design and specification concept will be new for users from the Iowa DOT, designers, and construction contractors, there will need to be an appropriate indoctrination and training. Many people are accustomed to using standard paper documents and are not familiar with obtaining information electronically, as is the case with OODAS. It is anticipated that a training workshop will be necessary to explain how to use this system and address any questions and issues that arise. Moreover, as is with the ERL, maintenance of the OODAS system will be required. Someone with knowledge in the 3D modeling applications discussed in this report will be needed to make the necessary bi-yearly updates to the OODAS application. An internet accessible approach to interacting with the design and specification system will ensure that users have the most current version. Cost savings are anticipated because CDs/DVDs will not be required for the online version.

## **Future Direction**

Several benefits of using a visual system to access specifications were discussed as a result of this project. These benefits are faster access to information and ease of comprehension for inexperienced personnel. However, there is some concern regarding the cost of full system implementation and maintenance in relation to the potential impact. Based on comments from several potential users, the focus of OODAS must be more project-specific. That is, instead of improving the access to the standard specifications and related documents, OODAS should focus on making information on specific projects easier for bidders and inspectors to obtain. This could be accomplished by enhancing the existing project plans to create an electronic version of the 2D drawings. Not only would such a system have hot links to the appropriate specifications (DOT or SUDAS), road and bridge standards, and IMs, but the electronic version could also contain links within the document to aid contractors in finding the critical incidental notes and assist inspectors in referenced road and bridge standards in the project. This type of system would be very useful for bidders, contractors building the project, and DOT inspectors as it would save them time in looking up information, and this may actually encourage them to look up information rather than rely on memory. To satisfy the potential user requirements, an iRoadPlan (Intelligent Road Plan) prototype was created. The iRoadPlan prototype presents an example of how such a system would look and what type of information could be included.

The iRoadPlan was developed using the Macromedia Flash software program to link a drawing to external databases. Macromedia Flash can import vector drawings exported from either Microstation or AutoCAD as well as scanned raster drawings. The vector format is important as this allows a user to zoom in or out of a drawing without losing clarity. The storage size of vector files is also typically smaller than raster based files, which improves the usability of the final system. The drawings are imported into Flash, where the links are created. The links are able to link to any part, including other drawings, pop-up notes, cross-sections, Web pages, etc.

There are several benefits associated with using the iRoadPlan system:

1. Easy to retrieve other related information, including standard road plans and general specifications.

2. Easy to view details of other related notes or drawings by popping them up over the drawings.
3. Easy to see cross-sections in the same screen without flipping over to see different cross-sections on different pages as is necessary in the paper-style format.
4. Able to view any detail of the drawing by using Vector-type graphic. The quality of the high-level zoom is as good as the normal-level zoom.
5. Flexible in any system. The iRoadPlan can be used in both Windows and Macintosh systems by using the Flash environment. Flash can be downloaded for free from Macromedia and is already build-in for Windows XP.

The same databases in OODAS can be used in the iRoadPlan project without creating an additional database. 3D drawings could be incorporated into this project to show further details, such as cross-sections at different stations and so forth. This approach will require the use of a portable computer on the site (laptop or PDA). It is important to note that the advantages of using a vector graphic format include small file size and high quality at the high-level zoom, which is different from raster graphic formatted files.

Figure 19 shows the initial screen for iRoadPlan using a road construction project in Marion County, Iowa. Note that this view shows the familiar look and feel of traditional paper plans.

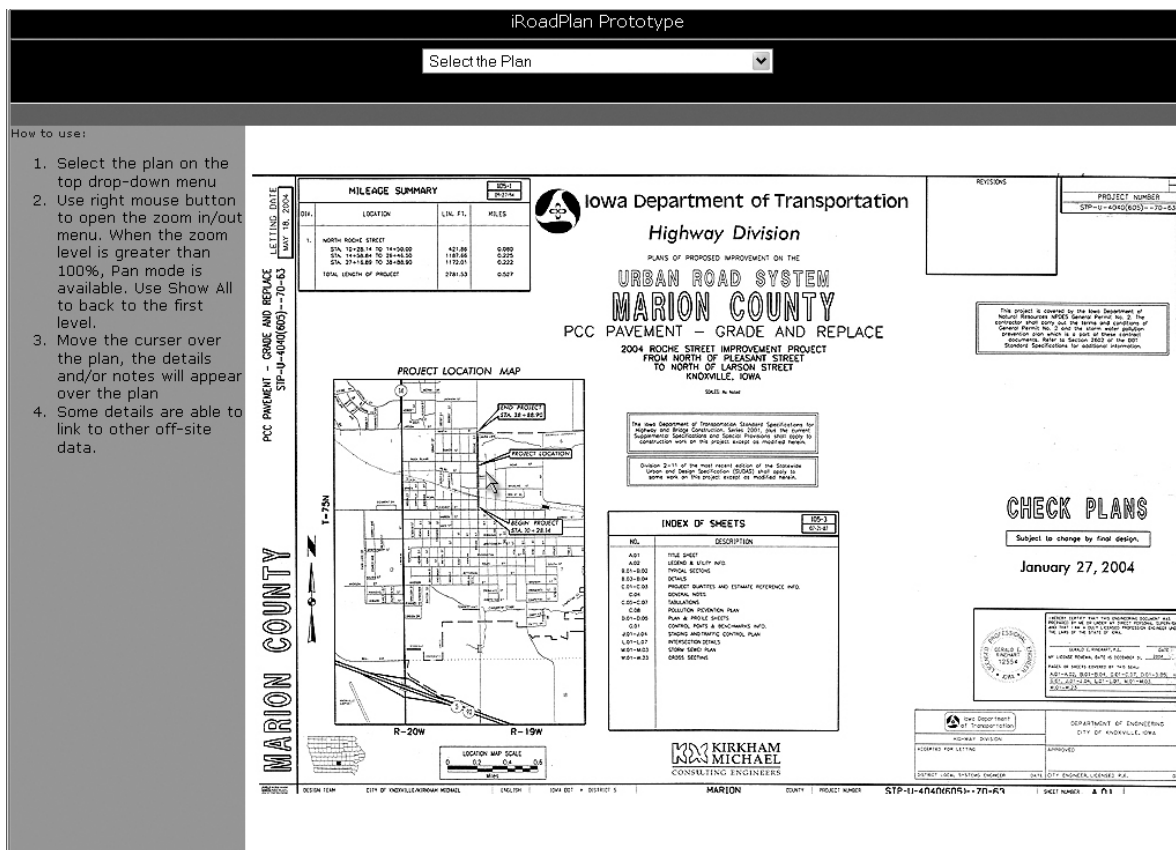
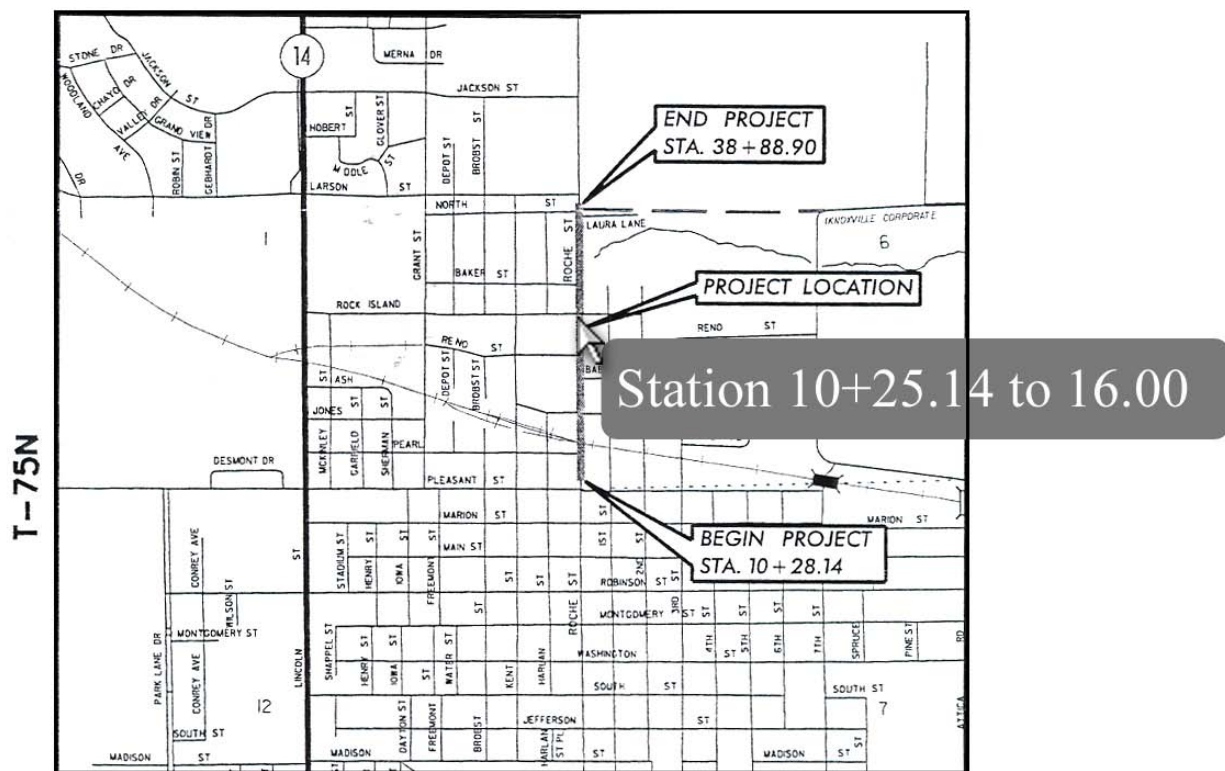


Figure 19. The iRoadPlan title page

The difference between iRoadPlan and traditional plans is that this system has hot links to information that allows the user to drill deep into the details and look at the pertinent specifications. Another feature is that this system can efficiently connect information from different sheets of the drawings. Examples of these items include showing details and profiles in pop-up windows when the user clicks on sections of the road and identifying incidental bid items included in the unit prices.

Figure 20 shows a close-up view of the project location map from Figure 19. As the user moves the mouse pointer along the road section, pop-up windows appear indicating that there is a detail view available for that section. Clicking on the section from station 10+25.14 to 16.00 takes user to Figure 21.



**Figure 20. Project location map**

Figure 22 shows a close-up view of part of Figure 21. As the user moves the mouse pointer along this section of the road, pop-up windows are shown that contain the profiles of the road at that section. Normally, the user would need to manually find these section profiles elsewhere in the plans. Here, iRoadPlan ties the information together. Figure 23 shows the resulting profile view from positioning the mouse at station 13+72.50.

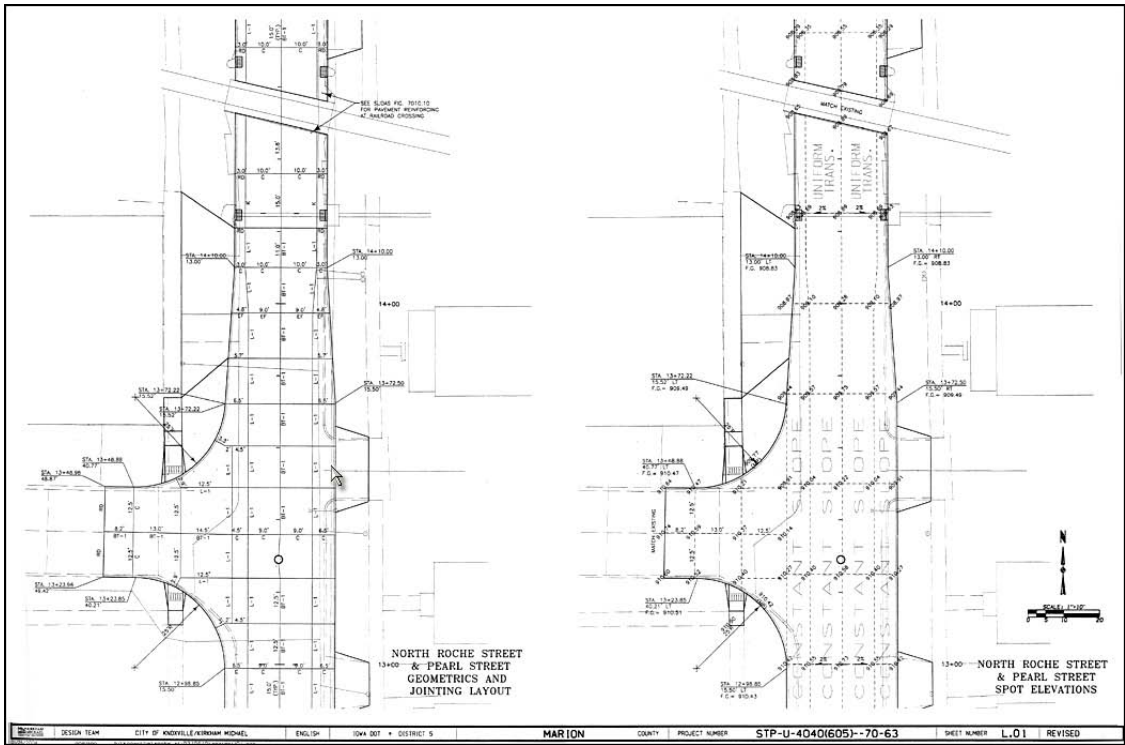


Figure 21. Plan view of selected road section

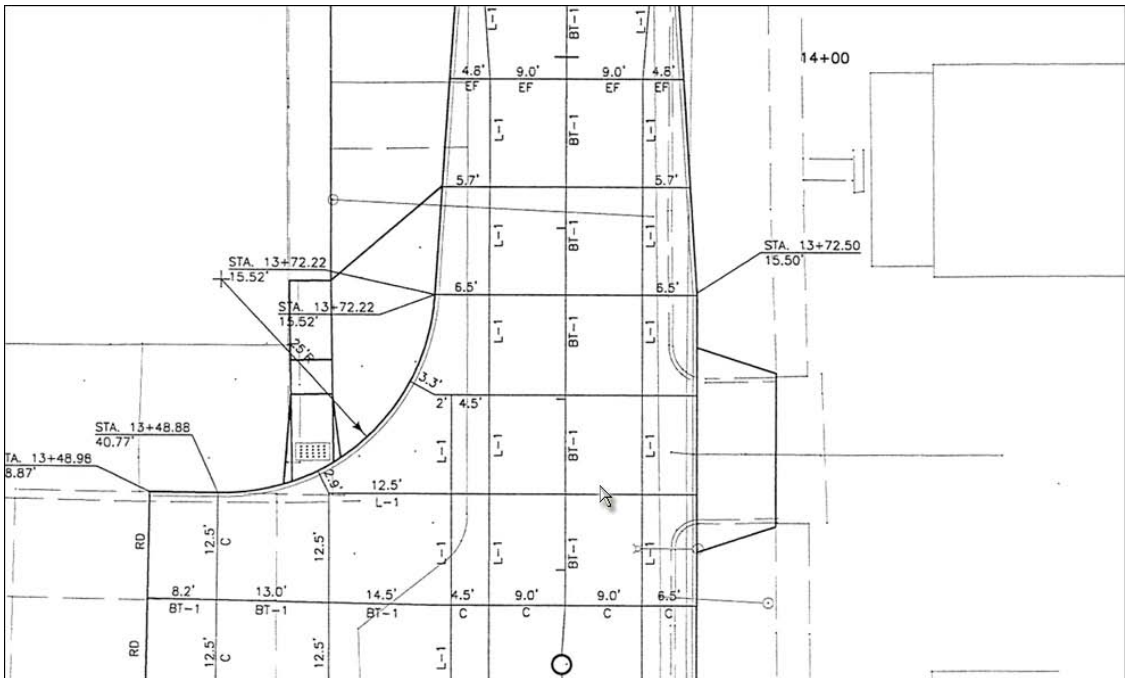
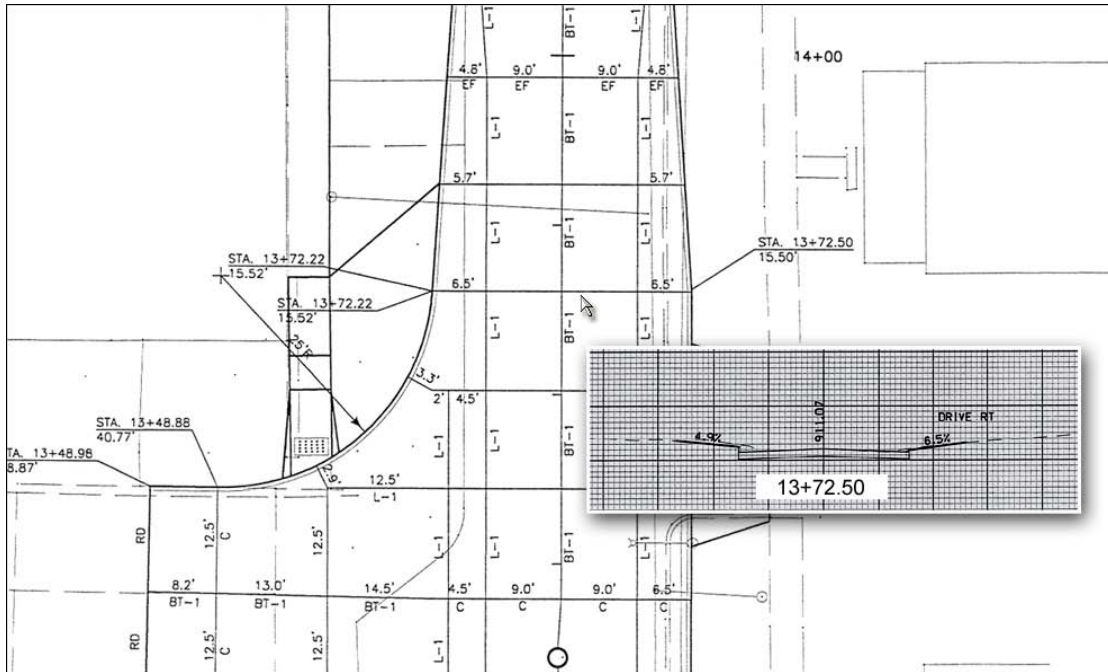


Figure 22. Close-up view of part of Figure 21





**Figure 23. Profile of road for selected segment**

Another common feature of road construction plans is shown in Table 7. This table lists the standard road plans that are considered applicable to the project and the date of the standard that applies. Another feature of iRoadPlan is that it links these items to the actual standard in order to better enable contractors and inspectors to quickly review the road standard.

**Table 7. Table of road standards applicable to project**

STANDARD ROAD PLANS					
					105-4
					12-03-96
The following Standard Road Plans shall be considered applicable to construction work on this project.					
NUMBER	DATE	NUMBER	DATE	NUMBER	DATE
RB-1	02-11-00				
RB-3	01-12-99				
RB-6	04-15-03				
RC-16A	10-27-98				
RC-16B	09-21-99				
RH-6	04-15-03				
RH-50	04-27-99				
RH-51	04-30-02				
RH-52	08-20-96				
RL-2A	04-03-01				
RS-26B	10-28-97				

Figure 24 shows the standard road plan RH-6, which is one of the standards listed in Table 7. Instead of stopping at this point, iRoadPlan continues by linking information to this standard. As an example, consider Detail 'A' of Figure 24, which is shown in Figure 25. If the user is interested in the meaning of note 7, he or she only needs to move the mouse over note 7, and the contents are available in a pop-up menu. Figure 26 shows the results of selecting note 7.

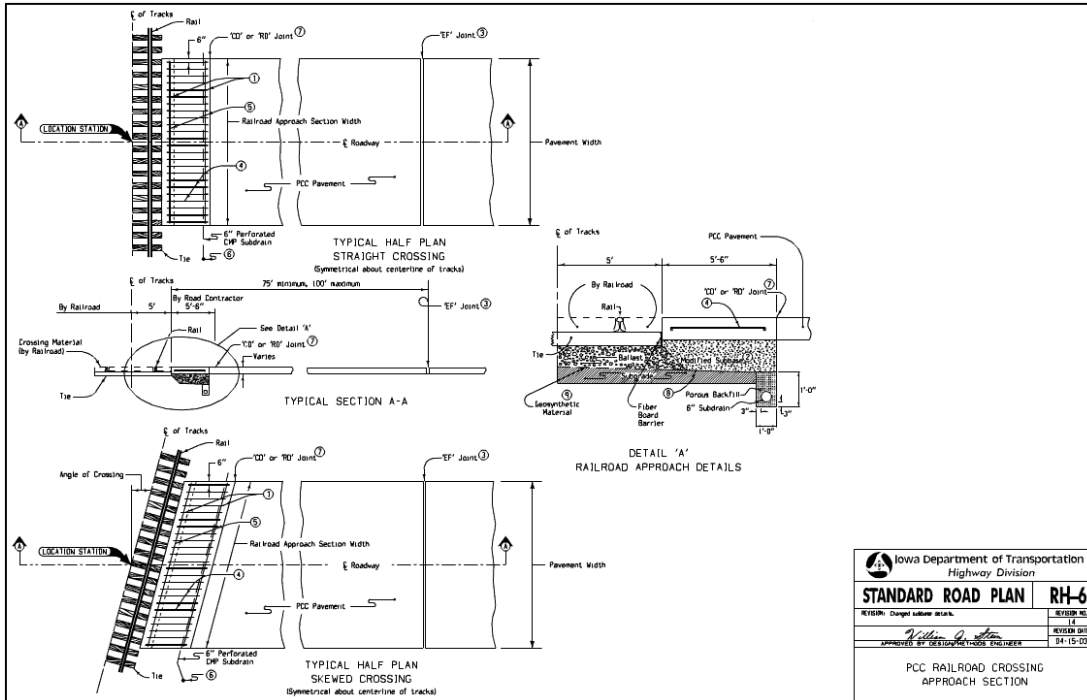


Figure 24. Road standard RH-6

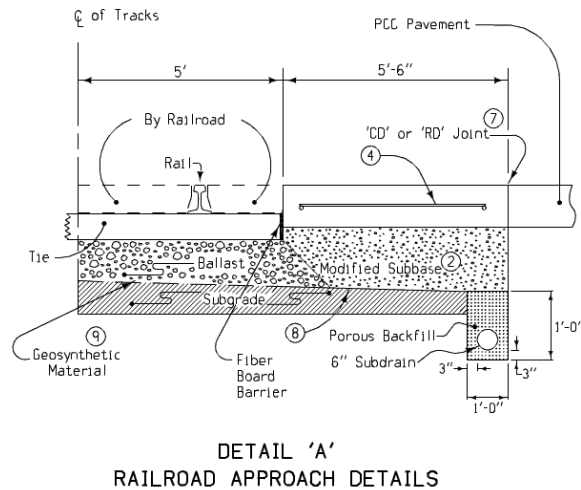


Figure 25. Detail A from RH-6

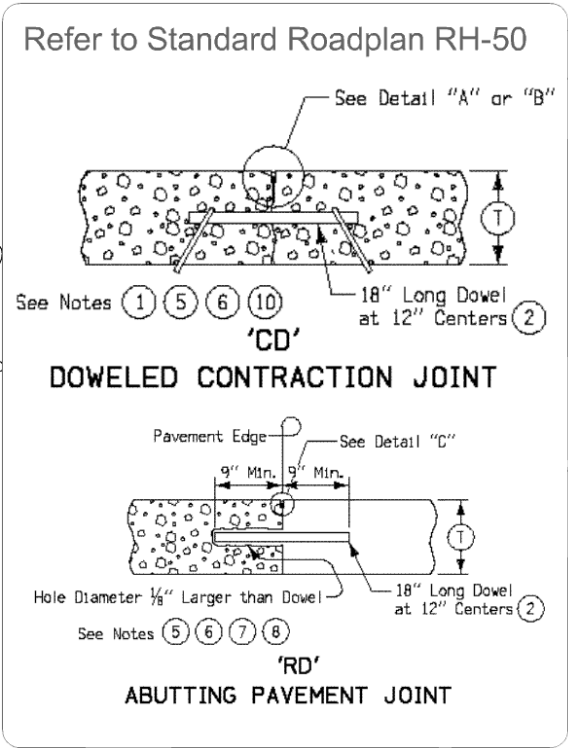
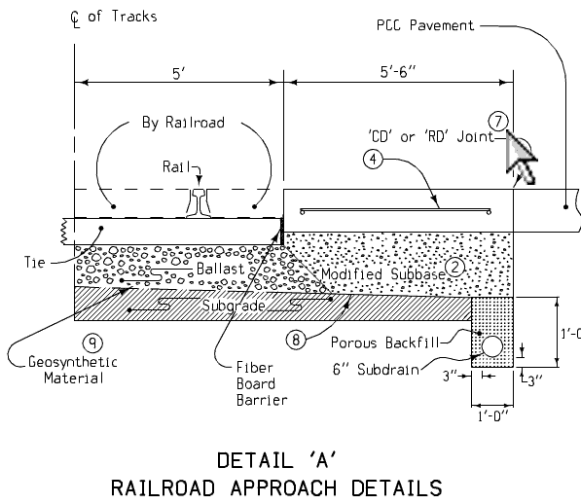


Figure 26. Pop-up window for detail note 7

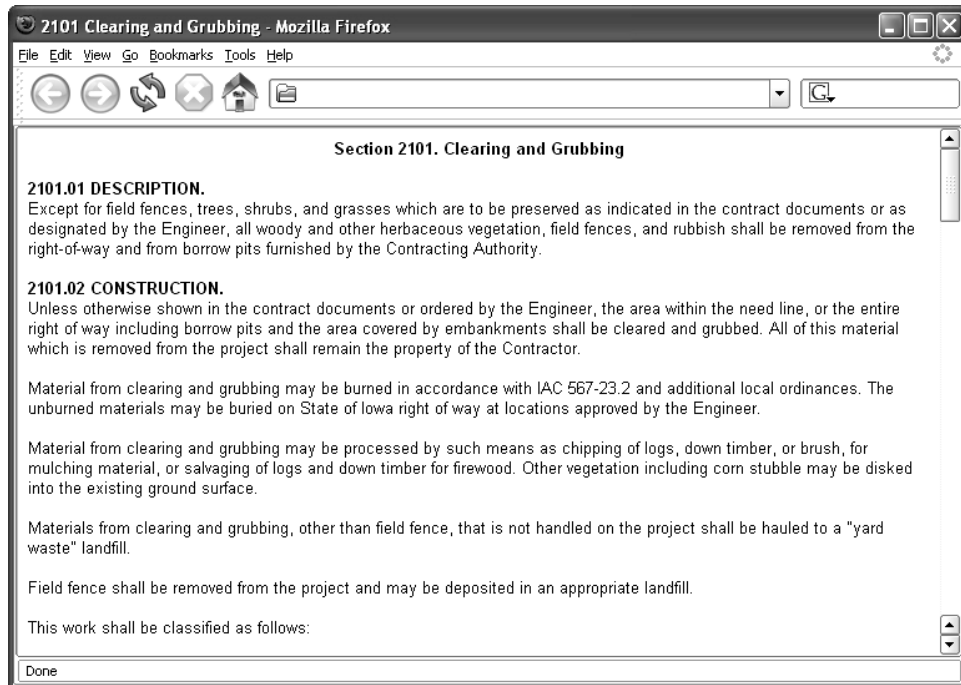
Figure 27 shows the bid item list, which is a standard part of road plans. Each item in the list is linked to a corresponding BIAS (Bid Item Activity Schedule) number, which in turn corresponds to a particular section of the standard specifications. If the user wants to know what work items are included in item 1, which is for BIAS number 2101-0860001, the user needs to click on that item to bring up a view of standard specification section 2101. Figure 28 shows the action of selecting the desired bid item, and Figure 29 shows the resulting view of the specifications.

ESTIMATED PROJECT QUANTITIES				ESTIMATE REFERENCE INFORMATION		
ITEM NO.	BIAS NUMBER	DESCRIPTION	UNIT	DIVISION 3 S11 ITEMS	DIVISION 2 NDV/S1P ITEMS	TOTAL
1	2101-0850001	CLEAR+GRUBB	AC	1.24	0	1.24
2	2102-2710070	EXCAVATION, CL 10, RDWY+BORROW	CY	2986	0	2986
3	2102-2710090	EXCAVATION, CL 10, WASTE	CY	2987	0	2987
4	2105-8425015	TOPSOIL, STRIP, SALVAGE+SPREAD	CY	620	0	620
5	2107-0875000	COMPACTION W/ MOISTURE+DENSITY CONTROL	CY	2987	0	2987
6	2113-0001100	SUBGRADE STABILIZATION MATERIAL, POLYMER GRID	SY	2117	0	2117
7	2115-0100000	MODIFIED SUBBASE	SY	2930	0	2930
8	2301-1033070	STD/S-F PCC PAV'T, CL C CL 3, 7"	SY	8738	0	8738
9	2301-1083070	STD/S-F PCC PAV'T, CL M CL 3, 7"	SY	314	0	314
10	2301-6911722	PCC PAV'T SAMPLE	LS	1	0	1
11	2401-6745650	REMOVAL OF EXISTING STRUCTURE	LS	1	0	1
12	2401-6745760	RMVL OF INTAKE	EA	0	13	13
13	2401-6745980	RMVL OF UTILITY ACCESS	EA	1	0	1
14	2502-8213208	SUBDRAIN, PVC, STD, PERFORATED, 8"	LF	2787	0	2787
15	2502-8220193	SUBDRAIN OUTLET (RF-19C)	EA	11	0	11
16	2503-4460010	INTAKE, TYPE M-A	EA	10	0	10
17	2503-4460030	INTAKE, TYPE M-C	EA	2	0	2
18	2503-4460040	INTAKE, TYPE M-D	EA	1	0	1
19	2503-4460050	INTAKE, TYPE M-E	EA	1	0	1
20	2503-7181034	RMV STORM SWR PIPE C/A TO 36"	LF	256	0	256
21	2503-7290112	SMR 20000 STORM 15"	LF	6	0	6
22	2503-7290125	SMR 20000 STORM 18"	LF	251	36	277
23	2503-7320118	SMR 20000 STORM 18"	LF	33	0	33
24	2503-7320124	SMR 20000 STORM 24"	LF	59	0	59
25	2503-7320448	SMR 20000 STORM 48"	LF	56	0	56
26	2504-7080156	RMV SAN SWR PIPE C/A TO 36"	LF	0	2980	2980
27	2504-7080158	SMR PLASTIC SAN 18"	LF	0	1429	1429
28	2504-7080162	SMR PLASTIC SAN 12"	LF	0	290	290
29	2504-7080176	SMR PLASTIC SAN 15"	LF	0	884	884
30	2504-7398700	SAR SERVICE SAN, RELOCATE	EA	6	82	88
31	2504-8463500	UTILITY ACCESS SAN, SWR, STD	EA	0	11	11
32	2510-6745850	RMVL OF FAY	EA	8663	0	8663
33	2511-6745900	RMVL OF SIDEWALK	SY	199.5	0	199.5
34	2511-6745904	SIDEWALK, PCC, 4"	SY	212.8	0	212.8
35	2515-2470108	DRIVEWAY, BCC, 6"	SY	793.4	0	793.4
36	2515-2470109	DRIVEWAY, BCC, 7"	SY	228.7	114.7	343.4
37	2515-6745900	RMVL OF PAVED DRIVEWAY	SY	1100	114.7	1214.7
38	2516-7243132	RMVL OF CONC. STAIRS	CY	1	0	1
39	2516-7243133	RMVL OF CONC. STAIRS	CY	1	0	1
40	2517-4225110	RAILROAD APPROACH SECTION, PCC	SY	76	0	76
41	2520-2300016	FIELD OFFICE	EA	1	0	1
42	2520-0000100	LOOP DETECTOR (ADD/REPLAC/TO EXIST SYS)	EA	1	0	1
43	2548-8445110	CONSTRUCTION SURVEY	LS	0.7	0.3	1
44	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
45	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
46	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
47	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
48	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
49	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
50	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
51	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
52	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
53	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
54	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
55	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
56	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
57	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
58	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
59	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1
60	2548-8445110	TRAFFIC CONTROL	LS	0.7	0.3	1

Figure 27. Bid item list

ESTIMATED PROJECT QUANTITIES			
ITEM NO.	BIAS NUMBER	DESCRIPTION	UNIT
1	2101-0850001	CLEAR+GRUBB	AC
2	2102-2710070	EXCAVATION, CL 10, RDWY+BORROW	CY
3	2102-2710090	EXCAVATION, CL 10, WASTE	CY
4	2105-8425015	TOPSOIL, STRIP, SALVAGE+SPREAD	CY
5	2107-0875000	COMPACTION W/ MOISTURE+DENSITY CONTROL	CY
6	2113-0001100	SUBGRADE STABILIZATION MATERIAL, POLYMER GRID	SY
7	2115-0100000	MODIFIED SUBBASE	CY
8	2301-1033070	STD/S-F PCC PAV'T, CL C CL 3, 7"	SY
9	2301-1083070	STD/S-F PCC PAV'T, CL M CL 3, 7"	SY
10	2301-6911722	PCC PAV'T SAMPLE	LS
11	2401-6745650	REMOVAL OF EXISTING STRUCTURE	LS
12	2401-6745760	RMVL OF INTAKE	EA
13	2401-6745980	RMVL OF UTILITY ACCESS	EA
14	2502-8213208	SUBDRAIN, PVC, STD, PERFORATED, 8"	LF
15	2502-8220193	SUBDRAIN OUTLET (RF-19C)	EA
16	2503-4460010	INTAKE, TYPE M-A	EA
17	2503-4460030	INTAKE, TYPE M-C	EA
18	2503-4460040	INTAKE, TYPE M-D	EA

Figure 28. Close-up view of bid item list



**Figure 29. Standard specifications section 2101**

The above examples were given to show some of the potential for a project-specific application of electronic plans. An additional concern is the effort required to produce electronic documents. There are many possible levels of implementation, with each bringing additional impact at additional cost. Future work should categorize different improvements according to effort versus impact. For instance, a first step could be to hot link all of the road and bridge standards directly to the appropriate referenced material. Part of this work has already been accomplished through the ERL development. Additional work would be required to install links to detail notes and general notes. This effort would produce drawings usable on a specific project by linking up the standard road plan table shown in Table 7 to these new versions of road standards. Except for the linking of the table for each project, the remainder of the work that was performed to create updated road standards would be reusable for each project. This would be an example of low effort and high impact. Another low impact item may be to hot link the bid item list as shown in Figure 28. Beyond these, there are opportunities to do project-specific links to highlight the applicability of general notes and to show detail items such as road profiles where they are needed. To make this effort more efficient, future effort should look at features available in Microstation, particularly in version 8, that would help automate the process of creating electronic plans. Some features of version 8 that may help are the following:

- There is no limit to the number of references that can be attached to a DGN file.
- Each element has a unique 64-bit identifier that does not change through the life-cycle of the element. This tag number could be used to link drawing elements to specifications.
- Each element has a time stamp that indicates the time of the most recent change, which would identify changes that occurred during a particular time period.

## CONCLUSIONS

Due to the current inefficiencies with using paper documents (e.g., drawings and specifications), a new approach was discussed that involved object-oriented modeling techniques to obtain information about standard roadside features. In particular, this study involved the investigation of using an object-oriented system to integrate both the Iowa DOT and urban specifications into one graphical database for use by designers and construction personnel involved with any type of transportation project in Iowa. This would centralize the specification process, thus saving on resources and providing a visual format for accessing the specifications. It would also make it easier for designers and contractors to more readily understand project requirements. A prototype object-oriented model was created and demonstrated to potential users representing counties, cities, and the state. A cost analysis was discussed for creating a full-scale system, including maintenance costs. Full-scale development costs were expected to be around \$575,000, with an annual maintenance cost of approximately \$87,000. Discussion with potential users revealed that a system like this could improve productivity to find information by as much as 75% and provide a greater sense of confidence that all relevant information had been identified. It was also apparent that this system would be used by more people in construction than in design. There was also concern related to the cost to develop and maintain the complete system. It appears that the future direction should focus on a project-based system that can help the contractors and DOT inspectors find information (e.g., road standards, specifications, IMs, etc.) more rapidly as it pertains to a specific project. A sample iRoadPlan prototype was revealed that could satisfy potential user requirements.

## REFERENCES

- Alias/Wavefront. 2003. Maya5 White Paper. [http://www.alias.com/eng/products-services/maya/file/maya5\\_apiwhitepaper.pdf](http://www.alias.com/eng/products-services/maya/file/maya5_apiwhitepaper.pdf).
- AutoDesk. 2003. <http://usa.autodesk.com>.
- Bentley. 2003. <http://www.bentley.com>.
- Blaha, M. and W. Premerlani. 1998. *Object-Oriented Modeling and Design for Database Applications*. New Jersey: Prentice Hall, Inc.
- Booch, G. 1990. *Object-oriented design with applications*. Redwood City, CA: Benjamin/Cummings Publishing Co.
- California Software Laboratories. 2003. *Customizing AutoCAD Using ObjectARX*. <http://www.cswl.com/whiteppr/white/autocad.html>.
- Clearform Software. 2003. [http://www.clearform.com/microsoft\\_access.htm](http://www.clearform.com/microsoft_access.htm).
- CTRE. 1999. *Electronic Reference Library: Phase I Report*. CTRE Management Project 98-31. Ames, IA: Center for Transportation Research and Education.
- Decisioneering, Inc. 2001. *Crystal Ball 2002.2 user manual*. Denver, CO: Decisioneering Inc.
- Discreet. 2003. <http://www.discreet.com/products/3dsmax>.
- Fenves, G. 1990. Object-oriented programming for engineering software development. *Engineering Computing*. 6(1): 1-15.
- Harrod, G. 2003. AecXML & IFC. <http://www.cswl.com/whiteppr/white/autocad.html>.
- Iowa DOT. 2001. *Standard Specifications for Highway and Bridge Construction*. Series 2001. Ames, IA: Iowa Department of Transportation.
- Iowa DOT. 2004. *General Supplemental Specifications for Highway and Bridge Construction*. GS-01005. Ames, IA: Iowa Department of Transportation.
- Johnson, R. H. 1989. Engineering data management – what’s needed and expected for the 1990s. *Proceeding of 1989 ASME International Computing in Engineering Conference*: 17-22.
- Kim, J. and C.W. Ibbs. 1992. Comparing object-oriented and relational data models for project control. *Journal of Computing in Civil Engineering*. 6(3): 348-369.
- Luiten, G. T. B., and F.P. Tolman. 1997. Automating communication in civil engineering. *Journal of Construction Engineering and Management*. ASCE. 123(2): 113-120.
- Macromedia, Inc. 2003. <http://www.macromedia.com/support/director/xtras.html>.

- Macromedia, Inc. 2003. <http://www.macromedia.com/software/director>.
- Microsoft. 2003. <http://office.microsoft.com/home/default.aspx>.
- MySQL. 2003. <http://www.mysql.com/products/myodbc/index.html>.
- NewTek. 2003. LightWave 3D Seven.  
<http://www.newtek.com/products/lightwave/product/index.html>.
- Oracle Corp. 2003. <http://www.oracle.com/ip/dep/otn/database/oracle9i/>.
- Peltonen, H., T. Mannisto, K. Alho, R. Sulonen. 1993. An engineering document management system. Paper-93 -WA/EDA-1. Paper presented at the ASME Winter Annual Meeting.
- Softimage Co. 2003. A subsidiary of Avid Technology, Inc.  
<http://www.softimage.com/Products/3d/v4/>.
- Spooner, D., and M. Hardwick. 1993. Using persistent object technology to support concurrent engineering systems. *Concurrent Engineering: Methodology and applications*: 205-234. Amsterdam: Elsevier Science.
- SUDAS. 2004. *Iowa Statewide Urban Standard Specifications for Public Improvements Manual*. 2004 Edition. Ames, IA: Iowa Statewide Urban Designs and Specifications.
- Walters, R. C. and L. Li. 2003. Maintenance of hypertext-based specifications for state highway projects. *Journal of the Transportation Research Board* 1861: 132-139.
- Wasserman, P. A. 1990. The object-oriented structured design notation for software design representation. *IEEE Computing*, March: 50-62.
- Zaneldin, E., T. Hegazy, and D. Grierson. 2001. Improving design coordination for building projects. I: Information Model. *ASCE Journal of Construction Engineering and Management*, 322-329.



## **APPENDIX A. DETAILED DESCRIPTION OF SOFTWARE APPLICATIONS**

### **CAD Packages for Standard Plans**

Currently, many CAD packages available on the market allow a designer to develop drawings and models with minimal programming requirements. The most popular and useful CAD packages are AutoCAD from AutoDesk and MicroStation from Bentley. These packages can be used to view, modify, or develop 2D and 3D architectural and construction drawings. Although these packages provide similar functionality, both Iowa DOT and urban standards use MicroStation as the platform for the standard design. MicroStation is also a good option for this project because it provides powerful 3D and object-oriented environments.

#### *MicroStation*

MicroStation (current version 8.1) is Bentley System's key CAD package for building, civil engineering, transportation, process plants, discrete manufacturing facilities, utilities, and telecommunication networks (Bentley 2003). MicroStation allows users to create 3D models. From design and engineering through construction and operation, these models can contain all information about the design, thus, simplifying project management and making the operation of the facility more efficient and cost-effective. It has the capability to communicate design files with graphical construction systems and process design. It also fully supports AutoCAD DWG format file (although a special tool is needed for complete conversion). This allows users to create new efficiencies for mixed design software environments. Since one project may have more than one drawing file source, it is an important feature of MicroStation's new paradigm, which allows the cross-use of AutoCAD and MicroStation files without loss of data or functionality. MicroStation also allows one to manage the changes within the standard plan files making the changes and updating the process more efficiently. This will be beneficial for the database to (1) track individual changes; (2) undo work that has been already integrated; (3) backtrack to the last approved version; (4) identify change incompatibilities; and (5) track the time sequence of additions and changes.

#### *AutoCAD*

AutoCAD (current version 2004) is AutoDesk's key platform for 2D drafting and detailing and 3D design (AutoDesk 2003). It provides native DWG compatibility, plus capability to personalize or program the software or add a third-party application. It also provides useful productivity tools, presentation graphics, CAD standards, and data creation and sharing. Its Express Tools, including layer management and dimensioning, reduce the number of steps required to perform a task. Its true color catalogs and presentation graphics allow for high-quality presentation drawings without exporting files. In order to exchange the design data safer and more efficiently, AutoCAD provides several useful tools: (1) Enhanced multisheet DWF (Design Web Format) file format for securely transmitting drawings over the Internet to view and plot, but not edit, drawings; (2) Digital signatures for validating the origin, authenticity, and

unaltered state of the drawings; (3) AutoCAD DesignCenter and DesignCenter Online for sharing pre-drawn content; and (4) The CAD Standards Manager for ensuring that the entire work conforms to the same standards.

## **Model Streaming**

Bentley Model Streaming provides users with the capability to interact with high-quality 3D models via a standard Web browser (Bentley 2003). Instead of loading an entire model locally, Model Streaming provides access to the model from a server through a Web browser. From the user's perspective, no pre-installation of software is required since model streaming operates on a java capable Internet browser such as Internet Explorer and Netscape Navigator. Also, the user only needs to download the visible portion of a drawing, which reduces waiting time. Model streaming models can contain important attributes from the original design, which describes each component and allows users to view the information just by a click. The major advantages of Model Streaming are listed as following:

- A high-speed connection is not required. Since the model is being streamed to the user, Model Streaming begins with a low level of detail, and progressively fills in the details, which reduces the waiting time needed to download a model. This means high-speed performance can be accomplished using a low-speed connection.
- Engineering data is integrated with the model. Model Streaming allows the developer to include valuable information for each component of the original design. This data supports queries for further interaction.
- No CAD software is required on the user's end, and the user will always see up-to-date and accurate information.

Despite the benefits listed above, Model Streaming provides limited database functionality, which limits its application for this project. Instead of using the Model Streaming package from Bentley, the combination of several software packages can be used to fulfill the project purpose.

## **Multimedia and 3D Modeling Software**

3D CAD models are widely used today by architects to illustrate the final look before a project starts. By using software modeling techniques, designers can build objects and reshape them, and then simulate events such as earthquakes, nuclear explosions, or even tsunamis. It is these incredible features that make 3D modeling software valuable to many industries.

There are three steps needed to create a model using 3D authoring tools. The first step is to create a wire frame consisting of polygons. The next step is to assign textures (i.e., colors) to each polygon. After the model is properly colored, then the model is exported to W3D format. The W3D files are imported into Macromedia Director, which associates the objects with the

database and creates a Shockwave file. The Shockwave file can be viewed by anyone who has an Internet browser with the free Shockwave plug-in.

For this project, objects in the 3D model must be labeled with identification tags. These are used to synchronize with the database with the 3D objects for specification retrieval. Models in this project were primarily created for using in Director within the Shockwave3D (W3D) format. Shockwave3D can be created by many leading 3D authoring software packages in the market. However, each software package has its own advantages and disadvantages that influence the selection process.

The multimedia package should have the capability to build rich content that delivers real results, integrating interactive audio, video, bitmaps, vectors, text, fonts, etc. The products can be deployed on CD, DVD, or corporate intranets, or can be deployed to web users with a free downloadable viewer/player.

Various popular 3D modeling and multimedia tools were considered and evaluated for the project. These included 3ds max by Discreet (a wholly owned subsidiary of AutoDesk, Inc.), LightWave by NewTek, Maya by Alias Wavefront (a division of Silicon Graphics Limited), Softimage by Softimage Co. (a subsidiary of Avid Technology, Inc.) (Softimage 2003), and Director MX by Macromedia, Inc. The following summarizes the major features of some of those programs.

### *3ds max*

3ds max (current version 6.0, formerly 3D Studio MAX) is a product of Discreet Corporate, which is a part of AutoDesk, one of the world's leading design and digital content creation resources (Discreet 2003). 3ds max can easily get 3D models from CAD packages such as AutoCAD and MicroStation. Therefore, many 3D models made from 2D drawings in AutoCAD or MicroStation can be efficiently converted into 3D models, which saves significant time to generate 3D models. Although, 3ds max is an all-in-one software for modeling, animation, and rendering, only the modeling part is used in this project. The price of 3ds max is \$3,495 for professional version. The education version is available for \$700.

3ds max has many advantages such as the following:

- Easy to use and is widely used
- Flexible with object-oriented format, so the object's parameters can be changed later
- Equipped with ready-to-use tools for 3D modeling
- Seamlessly integrates models from AutoCAD
- Supports Max script for automating tasks
- Supports export function to Shockwave3D

### *LightWave3D*

LightWave3D (current version 8), from NewTek, is a 3D modeling, animation, and rendering software that is fully equipped with many useful tools for artists (NewTek 2003). LightWave 3D is also used to create graphics for print, web, industrial design, architecture, medical imaging, and more. LightWave3D is easier to control than other competitor software on the market. The price of LightWave 8 is \$1,595 for professional version and \$500 for the educational version.

LightWave3D has many advantages including the following:

- Equipped with ready-to-use tools for 3D modeling
- Supports LightWave script for automating tasks
- Built-in particle visual effects for generating particle objects such as fire or snow
- Built-in sky effect for generating sky in the animation
- Supports export function to Shockwave3D

### *Maya*

Maya (current version 6) is the most high-end offering of all the 3D authoring software on the market, and has been called the best 3D authoring software (Alias/Wavefront 2003). After Alias Research and Wavefront Technologies merged into Alias in 1995, Maya was released and became the most popular 3D software. Maya plays a critical role in the film making industry (Alias 2003). Although Maya is the best 3D software, Maya's learning curve is very steep. Also, the price of Maya is \$6,999 for Maya Unlimited 5 and \$1,999 for Maya Complete 5.

The advantages of Maya include the following:

- Equipped with ready-to-use tools for 3D modeling
- Equipped with Visual Effects for simulating particles and fluids such as fire, snow, and water
- Support Maya script for automating tasks
- Support export function to Shockwave3D

### *Director MX*

Director MX, developed in 2002 by Macromedia, Inc., is one of the most famous authoring tools for developing rich interactive content for both fixed media and the Internet and has been used for presentations, interactive entertainment, and educational products (Macromedia 2003). Director MX can actually incorporate photo-quality images, full-screen or long-form digital video, sounds, animation, 3D models, text, hypertext, bitmaps, and Macromedia Flash content (Macromedia 2003). Director also provides a rich suite of tools to control how and when these

elements appear, move, sound, and change while the movie plays because director is usually used to aggregate and shape many different multimedia files into a single coherent presentation. With Director MX, one can create full-featured applications that access, launch, and control other applications from within the Director MX executable. This is ideal for creating a streaming, interactive, multi-user, and real-time 2D/3D animation.

The major features of Director MX are user-friendly interfaces, interactive 3D, end-user products, and the useful language script. Each of these features is summarized as follows:

- Many frequently used functions are available to drag-and-drop a command icon to an object. The design is in a familiar, integrated workspace, and collapsible and dockable group panels are available for a smooth, highly configurable workflow.
- Many 3D interactive features are available to build the model faster. The dynamic creation of geometry at runtime can save time by building primitives and scenes. Multi-resolution mesh (MRM) can control the number of polygons depending on the conditions such as the distance from the camera. With certain components, a real-time interactive physics effects can be added for unprecedented realistic motion and interaction.
- The end-user product of Director can be published to be a Projector (a program is able to be opened without using another program) or the Shockwave format, which is widely used on the Internet. It also integrates HTML contents and XML parsing, which can maintain full control of link references without large downloading.
- Director MX provides a language tool for advanced use. Usually, Director MX supports the functions that can import and control 3D models (users can control 3D models by adding behaviors by drag and drop command icons into 3D models). For the further functions, which do not appear in the behaviors list, users can write their own Lingo scripts.

Director MX supports plug-ins, which are called Xtras, that can be used to access a database. There are many database Xtras which are different in features and prices. The popular database Xtras are ADOXtra by Xtramania and DataGrip by DataGrip, LLC. Benefits of these two Xtras are the ability to communicate to major databases such as Microsoft Access, [IBM] DB2, and MySQL, Oracle, etc.

Based on the analysis above, any one of these packages above can accomplish the 3D modeling for project. By communicating between these programs (3ds max, LightWave, Maja) and Macromedia Director MX, Shockwave 3D (W3D) format was determined to be a file format used, which is the format for the final product viewer, Shockwave player. The Shockwave player can be downloaded for free from the Macromedia website. All of 3D authoring tools that can export to Shockwave 3D format will make the same final product. So, the 3D authoring tool for the final product depends on the cost and skills of developers, and especially on its capability in the transportation area.

Among these packages, 3ds max became the choice for choosing the modeling software for the project because of its flexibility to integrate with many CAD packages. Director MX was chosen to be the multimedia authoring software for this project.

## **Database Software**

Because of the limitation that specifications have been used in the construction site usually without network connections, standalone databases must be considered along with a network server. Theoretically, a standalone database can be created using programming languages such as C++ or Java. However, this approach is time-consuming and requires a strong understanding of database contents and how to organize the database. On the other hand, database packages are widely used nowadays because of data structures and an ability to work well with other software. The major databases available in the market are IBM DB2, Microsoft Access, Microsoft SQL Server, MySQL, Oracle, and PostgreSQL. The capabilities and limitations of each type of database are summarized below.

### *Microsoft Access*

Microsoft Access (current version 2002) is a database that comes with the Microsoft Office package developed by Microsoft Corporation (Clearform 2003). Microsoft Access can work as a standalone database or a network database that is accessed through the Internet or intranet.

The advantages of Access include the following:

- Easy to use and maintain. Microsoft Access provides many useful tools for creating databases. Most inexperienced database users can learn it in few days. Also, it is a famous application for creating a database prototype.
- No need for an additional purchase for computers that have Microsoft Office Professional Package installed. The price of Microsoft Office Professional is \$499 and \$199 for a standard version and an academic version, respectively.
- Seamless connection to other databases. Microsoft Access has an ability to connect to other database applications such as Microsoft SQL Server, Oracle, and MySQL via own scripting language. Therefore, a Microsoft Access database can be easily upgraded to any other robust database such as SQL Server with the purpose of expanding database size and increasing the number of users over Internet or intranet. At the same time, for the users in the field without Internet connection, they can connect to Internet when available to download updates to the specifications. Access can be programmed to update data itself from SQL Server automatically. Then the users can easily get the latest version of the specifications.

The limitations of Microsoft Access include the following:

- The file size is limited to only 2 gigabyte (within a DVD-ROM's capacity).
- It works well only with up to 25,000 records in the file, although Microsoft claimed that it can append 100,000 records (from tests, the performance will decrease after 25,000 records).
- Low concurrent database usage. Microsoft Access works well until there are 50 concurrent users. Microsoft claims that Access supports up to 255 concurrent users, but the performance will decrease after 50 concurrent users.

### *MySQL*

MySQL (current version 4.1.0) is the world's most popular open source database. It has been developed by MySQL AB (MySQL 2003). It is free of charge under the license of GNU General Public License. The advantages of MySQL include the following:

- Costless. It can be used under license of GNU free of charge. However, it can be purchased for commercial licenses for \$440 and \$220 for MySQL Pro and Classic, respectively.
- Workability. It works with many major platforms such as Windows, Linux, and UNIX.
- Unlimited database size. It has the limitation at 8 terabytes (8 trillion bytes) in table size. However, the operating systems may have their own file-size limits.
- It can be used as a server database or standalone database called an embedded database library.

### *Microsoft SQL Server*

Microsoft SQL Server (current version 2000; also known as SQL) is a powerful database from Microsoft Corporation (Microsoft 2003). It is another database that is considered for the project because of its capabilities, and it works seamlessly with other Microsoft products. When there are more than 50 concurrent users who access on the Internet or intranet, SQL Server should be considered to be used. However, the price of SQL Server is \$1,489 for the Standard Edition. The advantages of SQL Server include the following:

- Unlimited database size
- Supports more than 100 concurrent database users per second
- Recognized for the security
- Recognized for the connection speed

## *Oracle*

Oracle (current version 9) is a most powerful high-end database in the market. Oracle is recognized for its reliability, security, and speed. Oracle claims that it costs less than SQL Server and DB2, considering the hidden costs of downtime and security breaches. However, the cost of Oracle Database Standard Edition is \$15,000. The advantages of Oracle are basically the same as of Microsoft SQL.

Among those databases that met the requirements, Microsoft Access is a good choice due to its standalone capability and availability everywhere. Because it comes with Microsoft Office, no additional purchase is required for potential users of the product. Furthermore, although the limitation of Access is 2 gigabyte in size and 25,000 records, Microsoft Access has an ability to connect to other network databases such as Oracle and Microsoft SQL server and retrieve data.

## **Format Conversion Tools**

The information for the project may come from different sources associated with different software. In order to deal with file format issues, two solutions were considered. The first is the Industry Foundation Class (IFC) objects and the second is aecXML objects, serving as the means of communicating between the various applications. These are two of a few solutions that introduce a new standard that will be truly cross-system and vendor-neutral (Harrod 2003).

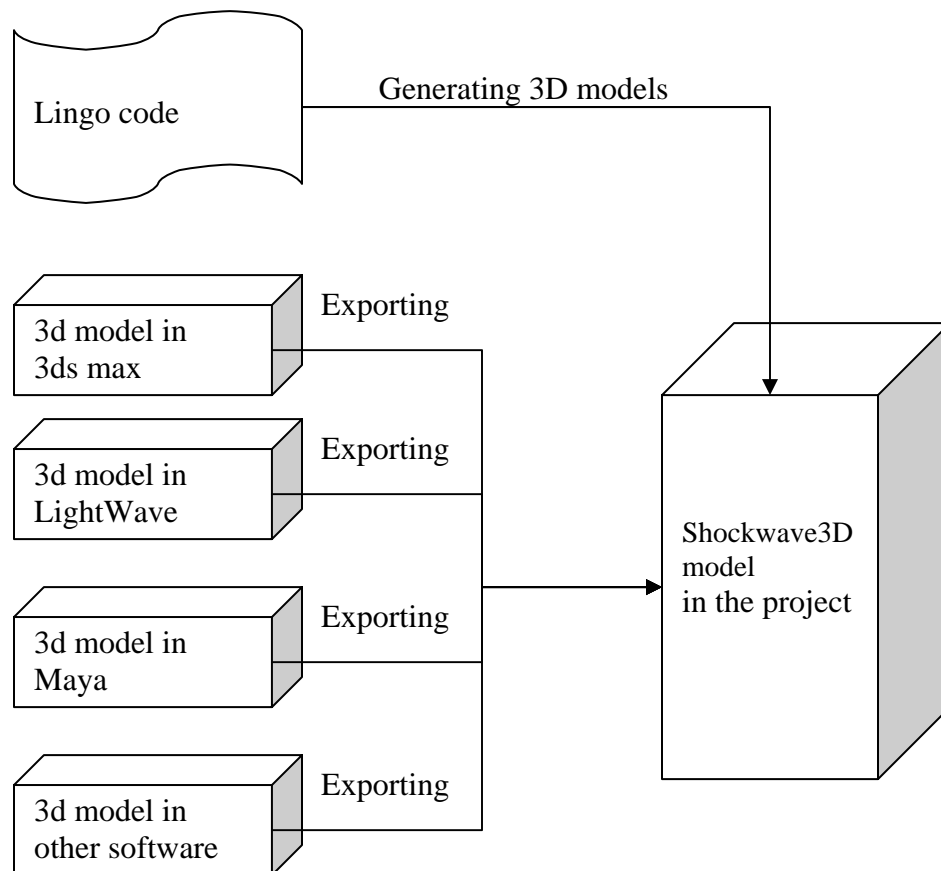


## APPENDIX B. TECHNICAL CONSIDERATION FOR PROTOTYPE DEVELOPMENT

This section describes the technical detail related to development of the prototype model such as 3D modeling techniques and programming skills.

### Models Creation

The Shockwave3D models in the project can be created in several ways. The Shockwave3D models are created using Lingo codes or exported from numerous 3D modeling software. Many 3D modeling packages can create Shockwave3D models. Modelers can use their familiar software, which will save the 3D modeling time by reducing learning time. The method of using Shockwave3D is illustrated in the Figure B-1.



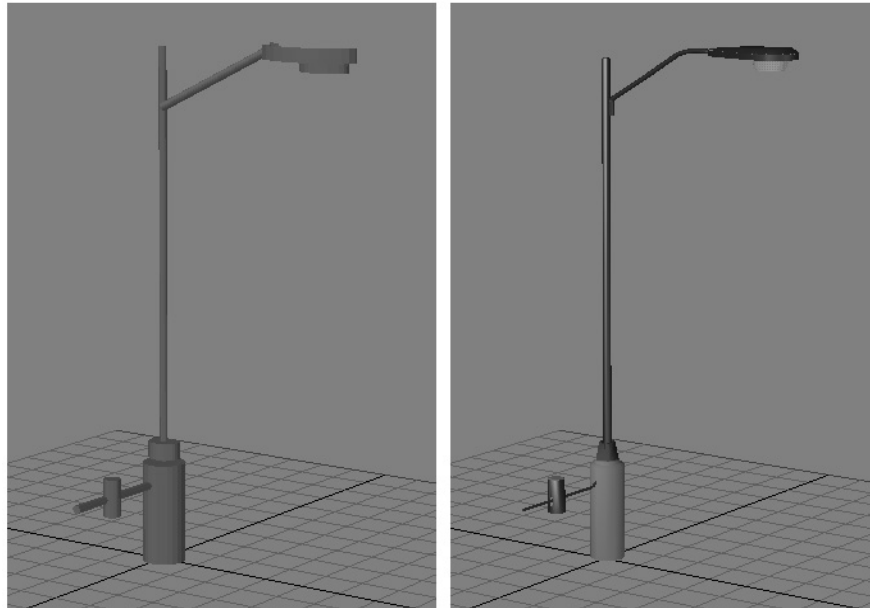
**Figure B-1. Illustration of creating the W3D models**

Metadata embedded in each 3D model is fundamental for software to communicate with each other. Metadata is defined as data used for exchanging data. In this project, the metadata is recognized by names of models. A polygon name in 3ds max becomes a metadata name in Shockwave3D. Similar to 3ds max, a layer name in LightWave turns into a metadata name in Shockwave3D. Either one polygon in 3ds max or one layer in LightWave is one object in Shockwave3D.

Preparing 3D models to cover every single object is vital in this project. Before modeling 3D objects, planning to divide object into sub-objects is important. As previously mentioned, each object is represented by the name itself. The more subjects are required, the more objects are also needed. However, the object can be divided or combined later, when there are changes of the original specifications.

### *3D Modeling Technique – Modeling*

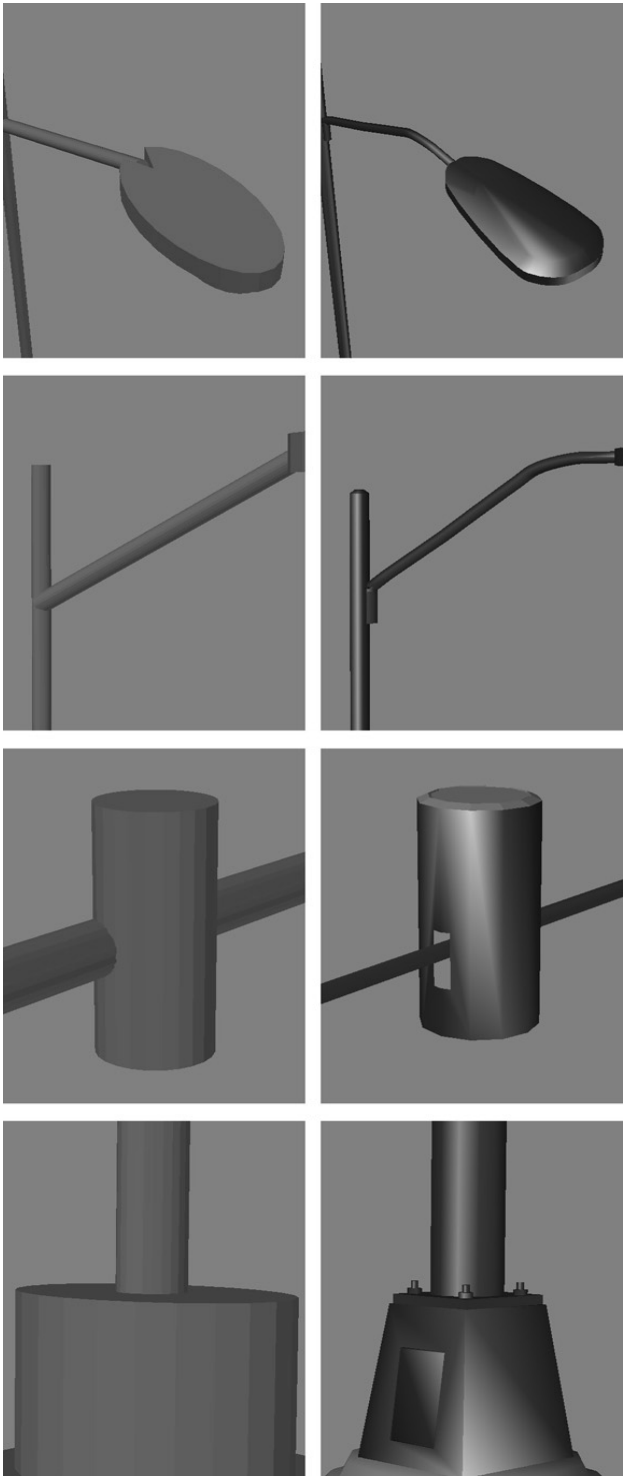
One of the commonly used 3D modeling methods is a creating primitive object method. Using primitive objects such as boxes, cylinders, and spheres to create models is simple and easy to understand as shown in the Figure B-2. Complex objects, such as union or intersection between two or more objects, can be made by using Boolean operations.



**Figure B-2. Eight primitive models initially generated (left) and light pole model (right)**

Eight cylinder-shaped objects combine into a light pole shape initially, as shown in Figure B-2. Then, they are modified into the final look by adding, subtracting, and reshaping, as shown in Figure B-3. The light fixture in the top image is reshaped by bending the end part of the fixture. The arm curve, in the second to top image, is bent for smoothness. The handhole and conduit in

the third image is reshaped. And base in the last image is tapered. Bolts and washers are added. Finally textures are applied to the objects, as shown in Figure B-4.

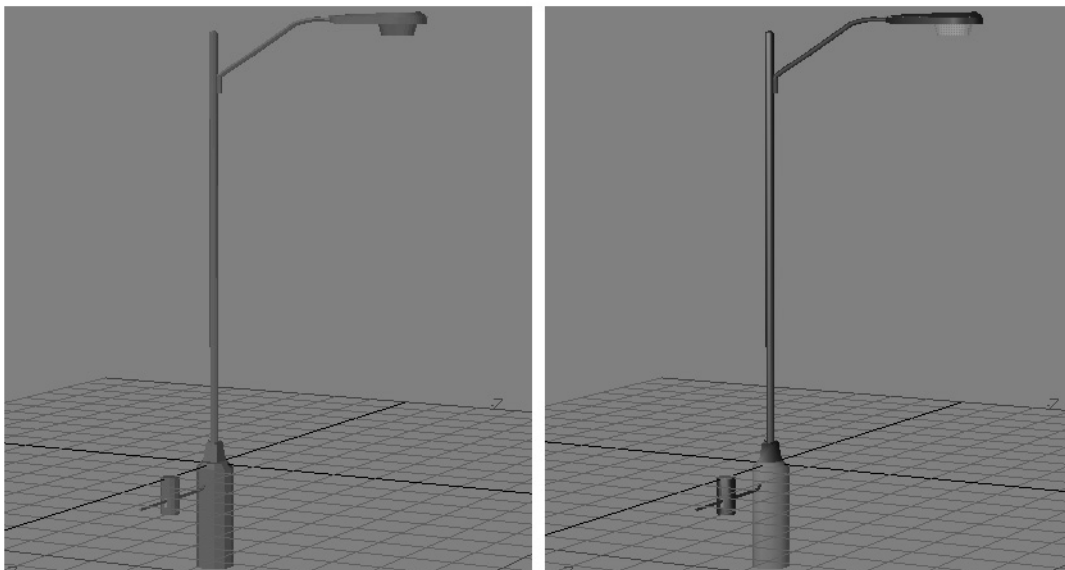


**Figure B-3. Primitive models (left) and detailed models (right)**

### *3D Modeling Technique – Applying Surface*

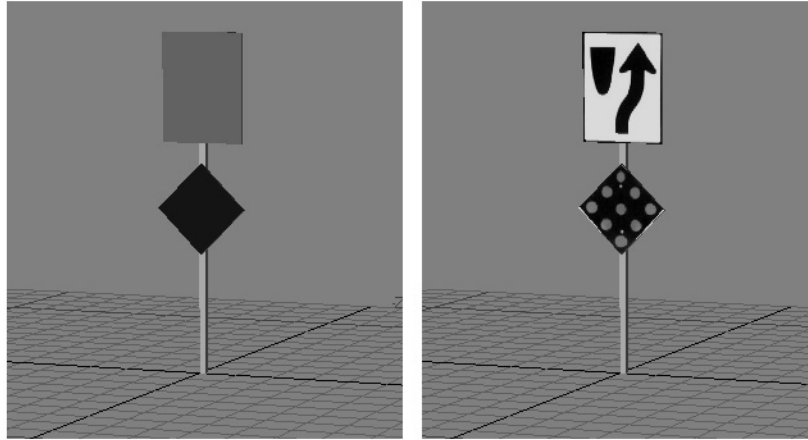
Finishing 3D modeling process implies applying surfaces to objects. The surface of the 3D model is similar to the skin of a human. Different surfaces make different looks. The purpose is to make the object more meaningful and realistic.

There are two types of surfaces: texture surface and image map surface. The texture surface is controlled by various factors including color, luminosity, transparency, glossiness, and reflection level. With a different value, the same 3D model can be changed from a metal to a plastic look, or even a water look. The Figure B-4 demonstrates the same model with texture surface (the left image) and without texture surface (the right image).



**Figure B-4. Texture surface**

Unlike the texture surface, the image map surface is controlled by overlaid images. An object surface is placed by an image. Figure B-5 shows an example of an image map surface. Two photos are used as image map surfaces on the keep-right sign.



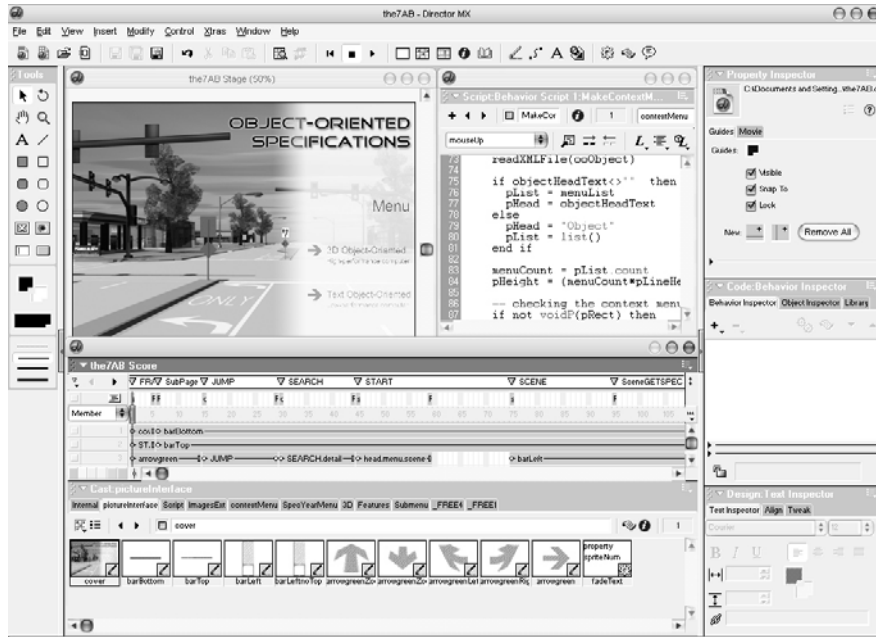
**Figure B-5. Image map surface**

The major drawback in applying textures to a surface is that some information is lost when models are saved in Shockwave3D. Some texture properties and objects' shadows are not available in Shockwave3D. The bump map texture, a texture property for generating difference levels on the surface, is an example of a texture which cannot be used in Shockwave3D. Image map surfaces with the picture of bump texture will be used instead. The objects' shadows are not possible to cast in the Shockwave3D. Making a fake shadow in Shockwave3D can be done by adding an object in black color texture and then using it with the main object.

### **Programming Considerations**

Programming is the core of the project. Director works by managing many casts such as texts, images, 3D models, sounds clips, VDO clips, and programming language named Lingo. Combination of different file types became one organized file type under one project in Director. The output can be either a standalone application (EXE extension for Windows) or Shockwave file (DCR extension), which run on Internet browsers with the Shockwave plug-in ready.

Director workspace is composed from Menu bar, Tools bar, Stage, Score, Script, Cast, and Properties, as shown in Figure B-6. The Director nature works as a timeline controlled by the Score dialogue. It starts from frame 1, and then continues frame by frame similar to a slideshow in the order of the frame number.



**Figure B-6. Director workspace**

The Tool bars are on the top and in the left column. The Stage, the main screen on the top left, shows the final product look. The Script on the right displays codes embedded in objects. The Score, a window shown by horizontal bars in the middle of the screen, shows the timeline of the whole project. The pointer starts from frame number one and goes until the last frame that an author defines. The pointer flows continually from frame to frame until it finds the stop code; the stop Lingo code is defined by the function “go to the frame.” The Cast, a window with pictures displayed on the bottom of the screen, contains objects (which are also called casts) used in the project. Properties, in the right column, display properties of casts.

Using Lingo scripts in Director requires a specific code type at the beginning of every Lingo code. This code is called *handler*, which represents a starting point and explains how the code starts. Without handlers, no commands are able to run. Examples of handler codes are listed below:

- on mouseUp—The function after the handler starts when user clicks and releases left mouse button.
- on mouseWithIn—The function after the handler starts when cursor is moved over the cast.
- on exitFrame—The function after the handler starts when the frame pointer exits the current frame.

In the 3D Web-based Highway Specifications project, there are four main stages. In the title stage, as shown in Figure B-7, there are two menus for supporting both high-performance

computers, which run 3D object-oriented specifications, and low-performance computers with plain text object-oriented specifications, which is a choice for the future development. Next, the scene selection stage is shown in Figure B-8. In the pilot study, there is only urban intersection scene. At the top right corner, the Search function is displayed. To search the specific specifications, Lingo calls HTML Help. After a selection is made, the users will go to the next stage.



**Figure B-7. Title stage**



**Figure B-8. Scene selection stage**

## Scene Stage

The Scene Stage, as shown in Figure B-9, is a stage for the user to browse and navigate around objects. It is composed of three modules: the main 3D scene model, the top function menu, and the left navigation menu. In this stage, there are two main Lingo codes running at the backend. They are the codes to retrieve the model properties and to add the sky into the scene.

To retrieve the model properties, the mouse location is monitored. When the mouse cursor is over a model in the scene, Lingo will check the object which has the same location. Then it returns the name of that object back to the Lingo. After that, the name is checked in the list of the specification objects. If it matches, the Lingo changes the mouse cursor to a finger instead of an arrow. Afterward if the user clicks on the model, Lingo carries the name of the object to the next function in the Object Stage. The selected object is also displayed in the next stage. If it does not match, Lingo returns nothing to the Scene Stage and waits for further command. Examples of objects not listed are commercial buildings or trees which are not related to the highway specifications.

A sky bitmap image is imported and placed as a backdrop of the 3D model. The area without models in the scene is replaced by the backdrop. The backdrop is a property in a camera item of 3D models.



**Figure B-9. Typical scene stage—urban intersection scene**



Moreover, there are Lingo codes working at the backend of the menu and navigation bars. The top function menu contains the UTILITY function displaying road utilities detail and SEARCH function which is the same as the one in the Selection Scene Stage. The road utilities in the urban intersection scene are simulated at one end of the road, as shown in the Figure B-10. The previous approach for displaying road utilities is shown in Figure B-11. The pavement, subgrade, and subbase are removed to show the utilities' details beneath. From experts' feedbacks, they prefer the first approach.



**Figure B-10. Scene stage with road utilities detail**



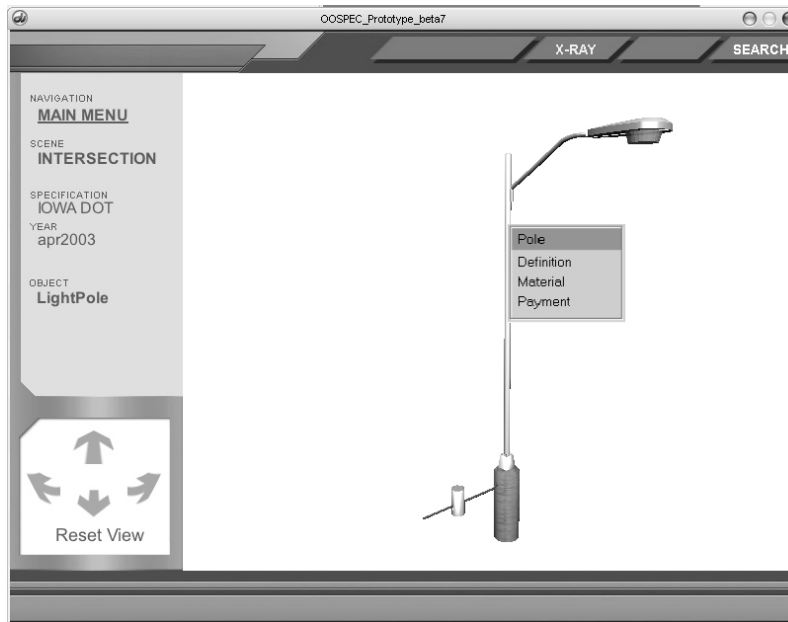
**Figure B-11. Scene stage displays utilities detail**

The navigation menus, descriptions, and the embedded commands are explained below:

- NAVIGATION MAIN MENU – Go back to main menu. Lingo changes the frame pointer into the position of the main menu.
- SCENE – Display the current scene name. Lingo changes the frame pointer to the position of the beginning of the current scene.
- SPECIFICATION – Select a type of specification from two main specifications which are Iowa DOT and SUDAS. Lingo keeps the specification type information and carries this parameter for browsing the specification in the Object Stage.
- YEAR – Select a version of specification from different versions. Lingo keeps the specification version information and carries this parameter for browsing the specification in the Object Stage.
- Arrow Up and Down Icons – Dolly the positions of the camera in 3D scene in and out. Lingo changes the value of horizontal camera position. It works when the left button of the mouse is pressed over any of these arrow keys.
- Arrow Rotate Left and Right Icons - Pan the position horizontally of the 3D scene left or right. Lingo changes the horizontal angle value of the camera. It works when the left button of the mouse is pressed over any of these arrow keys.
- Reset View – Return to the beginning position. Lingo changes the position and angle of the camera when the left button of the mouse is clicked and released over the word.

### *Object Stage*

A typical Object Stage is shown in Figure B-12. Many functions in the stage work with the parameters carried from the Scene Stage including a main object (a Light Pole), a specification type, and a specification version. Changing the appearance of 3D models is done by zooming in or out and rotating them. The function menus on top are displayed and changed according to a current 3D model. It displays more functions when the model requires more functions to display covert details. An example in Figure B-12 shows a special function X-RAY because the light pole model contains special information. When the user selects the X-RAY function, the footing of the light pole will disappear and the rebar cage and anchor bolts will be revealed. Similar to this, the function SLICE reveals the cross section of the intake.



**Figure B-12. Typical object stage—light pole object**

The Object Stage is composed of three modules: the main 3D model, the top function menu, and the left navigation menu. In the stage, there are two main Lingo codes running at the backend. It is the code to query the specifications that the object and sub-object users choose and to create context menu.

To query the specifications, a sub-object checks that embedded specifications exist when the user selects the object. Then, Lingo links the model information to the data information which is discussed in the next section in Linking Models to Specifications. After that, Lingo retrieves the frequently used information from the data source and displays it as a context menu (pop-up menu) over the 3D model. Finally, the data of the selected menu, the main object, the sub-object, the specification type, and the specification version are sent to generate the specification from the data source. If either the specification type or version is not selected, Lingo will alert users to choose any of them. The output format can be any of the HTML Help, Shockwave, and Windows application which depends on the output parameter in Lingo.

Lingo creates a context menu from the small portions of bitmap images in rectangular shapes and text. Lingo generates the menu separately by creating rectangular boxes over the 3D models. It creates the light-gray solid rectangular bitmap image. Then, it overlays another dark-gray solid rectangular bitmap image at the mouse position for highlighting a header. The mouse position is checked for enough space on the right or bottom. After that, the text menu is overlaid one by one. Finally, the context menu is ready for users to select. If the user selects the menu, Lingo checks the mouse position. Then, it calculates the position of the selected menu by line numbers. If the user chooses another model, Lingo will generate new screen by clearing overlays. The source code is adapted from the context menu from Chrome Lib for Macromedia by Karl Sigiscar (<http://www.chromelib.com>).

Two main functions in the stage, X-RAY and SLICE functions, are shown on the top. The CRITICAL CHANGES! function appears on the left navigation menu, as shown in the Figure B-13.



**Figure B-13. Typical object stage—intake object in cross-section**

With the X-RAY function, the user is able to see through some solid objects. Lingo works by hiding specific defined objects in the scene. Then overlapped objects can be seen. When X-RAY function is selected again, Lingo reveals those 3D objects.

With the SLICE function, the user is able to see the cross-section of the 3D model, as shown in Figure B-13. The Lingo works by switching between two models: a full model and a cross-section one. When the SLICE function is selected, Lingo reads the camera position and the angle of the current model. Then, the two models are switched. The new model with that camera position and angle shows. So, the two models are switched seamlessly.

With the CRITICAL CHANGES! function, the critical changes in specifications are flashed on the 3D models. Lingo checks differences between current and previous versions of specification. When they are found, then Lingo changes the texture values for critical changes.

The navigation menus on the left and the embedded commands are listed below:

- NAVIGATION MAIN MENU – Same as the command in Scene Stage – Go back to main menu. Lingo changes the frame pointer to the position of the main menu.

- SCENE – Same as the command in Scene Stage – Displays the current scene name and also sends users to the opening of the scene. Lingo changes the frame pointer to the position of the beginning of the current scene.
- SPECIFICATION – Select a type of specification from two main specifications, Iowa DOT and SUDAS. Lingo keeps the specification type information and carries this parameter for browsing the specification in the Object Stage.
- YEAR – Select a version of specification from different versions. Lingo keeps the specification version information and carries this parameter for browsing the specification in the Object Stage.
- Arrow Up and Down Icons – Moves the camera into and out of the 3D scene. Lingo changes the value of camera position in the 3D model.
- Arrow Rotate Left and Right Icons – Rotate the 3D object left or right. Lingo changes the rotation value of all 3d models.
- Reset View – Reset the view to the initial view. Lingo resets the position and angle of the camera when the left button of the mouse is clicked and released over this word.

## HTML Help

HTML Help is an application for organizing data. It is also known as HELP in the Windows operating system. It is a stand alone application with CHM extension which is created by HTML Help Workshop provided by Microsoft Corp. The HTML Help Workshop kit is a freeware available at the following Web site:

<http://msdn.microsoft.com/library/en-us/htmlhelp/html/hwMicrosoftHTMLHelpDownloads.asp>

The major advantage of this application is that it provides well-organized data under one or more files. The user can browse the data by using the supplied chapter and sub heading content table, search by index, or search by keyword. With these methods, data can be used easily in the well-organized HTML Help.

The limitation of the HTML Help is that it works on a Windows operating system only. However, HTML Help can be deployed on the Internet by using it as a Web page. It runs on a browser which is supported by a Java Environment, which can be downloaded free of charge from the Java Web site ([www.java.com](http://www.java.com)). Unfortunately, the Search function is not supported on the Internet.

Using HTML Help as a backend of other software can be done via Application Programming Interface (API). In the project, the HTML Help is called from Director via Xtra, working as the API for Director. It is called to display the table of contents, index with/without specific word, and search tabs. HTML Help Xtra is built in the project by using XtraBuilder and Visual C++ software. XtraBuilder is a stand alone application by Gary Smith (<http://www.mods.com.au/XtraBuilder>) for creating ready-to-use Xtras. Some of the HTML Help API commands used in this project are as follows:

- HH\_DISPLAY\_TOC—API function to open the table of contents tab
- HH\_DISPLAY\_INDEX—API function to open the index tab
- HH\_DISPLAY\_SEARCH—API function to open the search tab
- HH\_KEYWORD\_LOOKUP—API function to open the index tab with a point at the specific word as defined
- HH\_FTS\_QUERY—API function to open the search tab to search the specific word as defined

Although, the HTML Help supports the HH\_DISPLAY\_SEARCH and HH\_FTS\_QUERY API commands, Microsoft announced a problem with this method in 2002, as shown in the following Web site:

<http://support.microsoft.com:80/support/kb/articles/Q241/3/81.ASP&NoWebContent=1>

## APPENDIX C. TIME AND COST ANALYSIS METHOD AND ASSUMPTIONS

Due to the uncertainty and variance of objects in the full OODAS system, compared to those in the case study, there is no way to use point estimates to specify the time for future development. Therefore, a range estimate method is employed with assumptions of the researchers' best judgments, which are based lessons learned during the pilot study. The procedure for this method includes the following considerations:

- Tracking the time and cost for case study and categorizing them
- Separating the meaningful time from that spent on the pilot project but not applicable for the full scale system development
- Making assumptions to develop a set of time modules for different levels of objects
- Making assumptions and defining the total number and complexity of objects for the full scale system
- Simulating the time ranges for developing the full OODAS system and its cost

The case study provides the authors with a possibility to assume the minimum, maximum, and an inspired guess of the time required to develop an object with an assumed complexity. This falls into the scope of statistical triangular distribution because the tracked data meet the three necessary conditions for a triangular distribution:

- The optimistic (minimum) effort-hours needed to develop an object is known (best assumed).
- The pessimistic (maximum) effort-hours needed to develop an object is known (best assumed).
- The most likely effort-hour falls between the optimistic and pessimistic values, forming a triangular shaped distribution, which shows that values near the optimistic and pessimistic values are less likely to occur than those near the most likely value.

During the process, the decision-making software—Crystal Ball (Decisioneering 2001)—was used for simulation.

## APPENDIX D. TYPICAL OBJECTS IN FULL OODAS SYSTEM

**Table D-1. Rural objects scene**

Classification n (1)	Objects (2) (3) (4)			Complexity Level		
				High (5)	Moderate (6)	Low (7)
<b>Freeways/Expressways</b>						
1	Typical four-lane PCC roadway			x		
	Lane Pavement and Shoulders					
	Segments					
	Joints					
	Dowel bars					
	Subbase					
	Subgrade					
	Treated Soil					
	Undisturbed Soil					
2	Subdrain				x	
	Longitudinal subdrain					
	Backslope subdrain					
	Foundation subdrain					
3	Median (depressed, closed)				x	
	Opening					
	Turnaround					
4	Ditches				x	
	Foreslopes					
	Backslopes					
5	Weigh station			x		
6	Rest area			x		
	Interchange					
7	One-lane ramps and loops			x		
	Interstate system					
	Non-interstate system					
8	Two-lane ramps			x		
9	Accesses dikes				x	
10	Safety dikes				x	
11	Two-lane highway or country road			x		
12	Bridge			x		
	Intersection					
13	Right turn lanes				x	
14	Left turn lanes				x	
15	Median storage				x	
16	Adding				x	
17	Dropping				x	
18	Redirecting				x	
	Traffic control devices					
	Pavement marking					
	19 Lane lines					x



	20	Edge lines		X
	21	Centerlines		X
	22	Pavement arrows		X
	23	Word messages		X
	24	Raised pavement markers		X
	25	Delineators		X
	Signs			
	26	Regulatory signs (15)		X
	41	Warning signs (8)		X
	49	Guide signs (6)		X
	55	Specific services signs (2)		X
	57	Directional signs		X
	58	Interest area signs		X
	59	Emergency signs (3)		X
	62	Channelizing devices		X
	63	Warning lights		X
	64	Floodlights		X
	65	Arrow display		X
	66	Changeable message		X

---

**Super-two/Two-lane Highways**

	67	Typical two-lane HMA roadway	X	
		Lane Pavement and Shoulders		
		Subbase		
		Subgrade		
		Treated Soil		
		Undisturbed Soil		
	68	Subdrain	X	
	69	Median (painted)		X
	70	Ditches	X	
		Foreslopes		
		Backslopes		
	Intersection			
	71	Major right turn lanes	X	
	72	Minor right turn lanes	X	
	73	Auxiliary left turn lanes	X	
	74	Stop-sign islands	X	
	75	Railway crossing	X	
	76	Rumble strips	X	
	Traffic control devices			
	Pavement marking			
	77	Lane lines		X
	78	Edge lines		X
	79	Centerlines		X
	80	Pavement arrows		X
	81	Word messages		X
	82	Raised pavement markers		X

	83	Delineators							X
Signs	84	Regulatory signs (12)							X
	96	Warning signs (7)							X
	103	Guide signs (9)							X
	112	Signs at intersection							X
	113	Directional signs							X
	114	Interest area signs							X
	115	Emergency signs (2)							X
11									X
7		Channelizing devices							X
11									X
8		Warning lights							X
11									X
9		Floodlights							X
12									X
0		Arrow display							X
12									X
1		Changeable message							X
Total	12					9	18		94
	1								

**Table D-2. Urban objects scene**

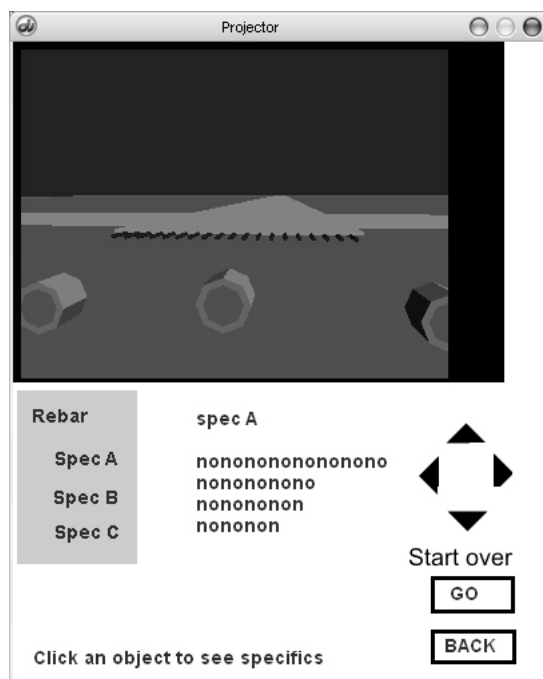
Classification n	Objects			Complexity Level		
				High (5)	Moderate (6)	Low (7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
<b>Arterial Streets</b>						
1	Typical four-lane PCC roadway			x		
	Pavement					
			Segments			
			Joints			
			Dowel bars			
			Subbase			
			Subgrade			
			Treated Soil			
			Undisturbed Soil			
			Curb			
2	Subdrain				x	
3	Median (closed)				x	
4	Intake				x	
5	Storm sewer				x	
6	Sanitary sewer				x	
7	Traffic control poles			x		
8	Light poles				x	
9	Water mains				x	
	Interchange					
	10	Ramps and loops		x		
	11	Bridge		x		
	12	Right turn lanes			x	
	13	Left turn lanes			x	
	14	Median storage			x	
	15	Adding			x	
	16	Dropping			x	
	17	Redirecting			x	
	Traffic control devices					
		Pavement marking				
		18	Lane lines			x
		19	Edge lines			x
		20	Centerlines			x
		21	Pavement arrows			x
		22	Word messages			x
		23	Raised pavement markers			x
		24	Delineators			
		Signs				
		25	Regulatory signs (15)			x
		40	Warning signs (8)			x
		48	Guide signs (6)			x
		54	Specific services signs (2)			x

	56	Directional signs			X
	57	Channelizing devices			X
	58	Warning lights			X
	59	Arrow display			X
<hr/>					
<b>Collector Streets</b>					
60	Typical two-lane HMA roadway		X		
		Pavement			
		Subbase			
		Subgrade			
		Treated Soil			
		Undisturbed Soil			
		Curb			
61	Subdrain			X	
	Median				
62	(painted)			X	
63	Intake			X	
64	Storm sewer			X	
65	Sanitary sewer			X	
66	Traffic control poles		X		
67	Light poles			X	
68	Water mains			X	
	Intersection				
	69	Major right turn lanes		X	
	70	Minor right turn lanes		X	
	71	Auxiliary left turn lanes		X	
	Traffic control devices				
	Pavement marking				
	72	Lane lines			X
	73	Edge lines			X
	74	Centerlines			X
	75	Pavement arrows			X
	Signs				
	76	Regulatory signs (12)			X
	88	Warning signs (7)			X
	95	Guide signs (9)			X
	104	Signs at intersection (5)			X
<hr/>					
<b>Local Streets</b>					
109	Typical two-lane PCC roadway		X		
	Pavement				
		Segments			
		Joints			
		Dowel bars			
	Subbase				
	Subgrade				
	Treated Soil				
	Undisturbed Soil				
	Curb				

110	Typical two-lane HMA roadway Pavement		x		
		Subbase			
		Subgrade			
		Treated Soil			
		Undisturbed Soil			
		Curb			
111	Intake			x	
112	Storm sewer			x	
113	Sanitary sewer			x	
114	Light poles			x	
115	Water mains			x	
	Intersection				
	116	Major right turn lanes		x	
	117	Minor right turn lanes		x	
	118	Auxiliary left turn lanes		x	
	119	Traffic control poles	x		
	Traffic control devices				
	Pavement marking				
	120	Lane lines			x
	121	Pavement arrows			x
	122	Centerlines			x
	Signs				
	123	Regulatory signs (12)			x
	135	Warning signs (7)			x
	142	Guide signs (9)			x
<b>Total</b>		<b>150</b>	<b>9</b>	<b>30</b>	<b>111</b>

## APPENDIX E. DEVELOPMENT PROCESS

Seven prototypes were developed during the case study. Prototype 1 was developed, as shown in Figure E-1. 3D models and specifications data were embedded in the Director environment. A real time 3D interactive world was also developed. Specifications data were kept in a plain text file, which Director manipulated by importing and exporting data. In prototype 2, with the same interface as shown in Figure E-1, Director worked with a database instead of a text file. ADOXtra, a Director plug-in, was selected. The result showed the possibilities of seamless connection between 3D models properties and the database software, which was Microsoft Access at that time.

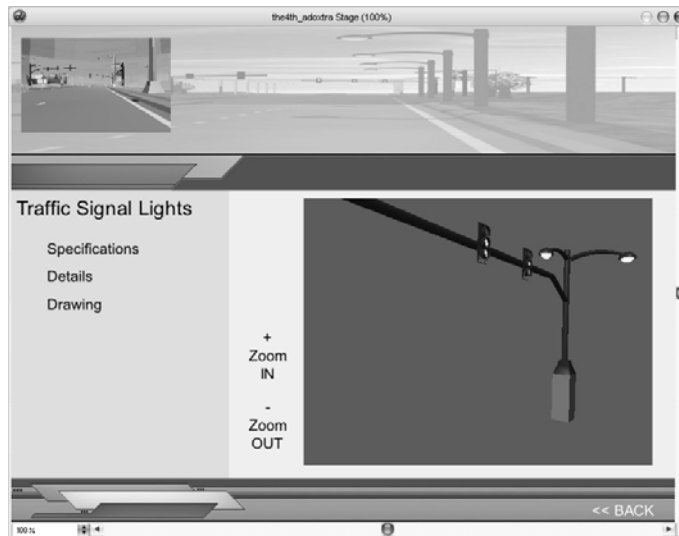


**Figure E-1. A snapshot of prototypes 1 and 2**

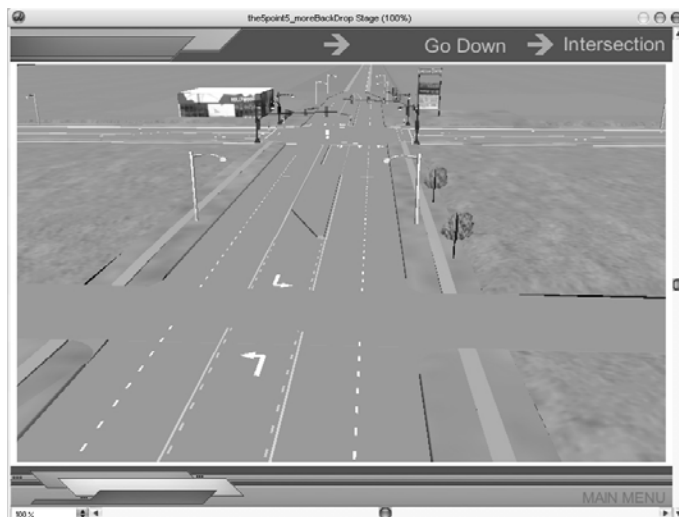
Prototype 3 simulated a typical intersection, as shown in Figure E-2, which included a 3D traffic signal model, specifications in database style, and bitmap image drawings. The users were able to navigate around the intersection scene and then select specification details. Concurrently, prototype 4 was developed. Unlike the prototype 3, prototype 4 used XML data instead of database software. The interface and programming were kept the same. However, at that time, the XML style did not work well because it was hard to manipulate and maintain.

Later, prototype 5 was developed by improving the data structure and complexity of backend programming (Figure E-3). Two databases which were Iowa DOT and SUDAS specifications were developed and stored in Access databases. Data was reorganized by storing only section, subsection, and sub-subsection numbers instead of the whole data. Unlike in the previous

version, Director connected to the database to retrieve a specific section and then connected to the ERL to retrieve specification data. The interface was changed by adding top and bottom navigation menus. The idea of a bird's-eye view was also applied. The prototype included 3D light pole and driveway models. The idea of using a Scalable Vector Graphic (SVG) drawing which is one of the XML schemas was adapted. However, it was no longer used because of the complexity of the SVG structure.



**Figure E-2. A snapshot of prototypes 3 and 4**

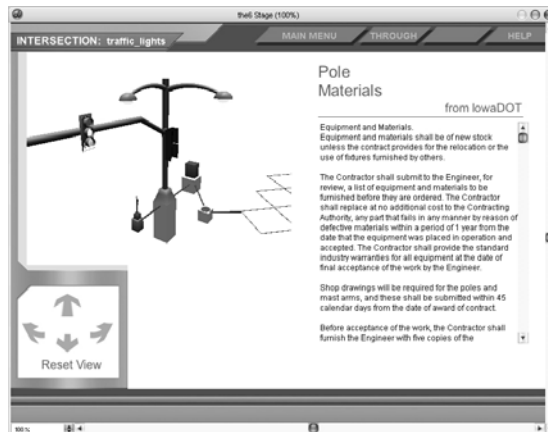


**Figure E-3. The intersection scene in prototype 5**

Prototype 6 was developed with a new interface after improving the stability of the programming language, as shown in Figures E-4 and E-5. A new function, X-RAY, was added for users who want to see hidden or overlapped objects such as a rebar cage in a concrete footing. Also, a SLICE function was added for users who want to see the cross-section of objects. However, the data structure was the same as in the previous prototype.



**Figure E-4. The intersection scene in prototype 6**



**Figure E-5. The model scene in prototype 6**

Finally, prototype 7 was developed by improving the 3D models, interface, and data structure (Figure 6). 3D commercial buildings were added to make the urban intersection scene more realistic. The context menu (pop-up menu) function was developed. The prototype mentioned in the rest of the report refers to this latest prototype 7. The major features of this prototype will be discussed in the next section.



## APPENDIX F. GLOSSARY

3ds max	- 3D modeling software developed by Discreet, formerly 3D Studio Max)
Application Programming Interface (API)	- A set of software functions used by an application program as a means for providing access to a system's capabilities.
Backdrop	- An image that covers the entire screen and occupies the rearmost plane of a workspace.
Bitmap Image	- A graphic image stored as a specific arrangement of screen dots or pixels
Camera	- A simulated camera used in a 3D object controlled by positions and rotations.
Compiling	- A process of programming to converts a source file into a binary file which the computer uses.
Context Menu	- A pop-up menu that appears when you click on an object. It displays a list of functions that can be performed.
Database	- A collection of information organized and presented to serve a specific purpose.
Dolly	- An activity in cinematography to move camera in or out of target.
Director	- Multimedia software developed by Macromedia, Inc. The software works with programming language, 3D modeling, and database
Dynamic Link Library (DLL)	- A file containing a collection of Windows functions designed to perform a specific class of operations
Electronic Reference Library (ERL)	- An electronic specification containing Iowa highway specifications
eXtensible Markup Language (XML)	- A subset of SGML constituting a particular text markup language for interchange of structured data.
Handler	- A Lingo representation of the action to be performed when a function is called
Interface	- An interface is what you see when you look at your monitor
Java Environment	- A computer programming language invented by Sun Microsystems.
Lingo	- Programming language for Macromedia Director
LightWave3D	- 3D modeling software developed by Newtec Inc.
Overlay	- The process of superimposing image over another image or graphic.
Pan	- An activity in cinematography to rotate camera left or right.
Plug-in	- A small piece of software that enriches a larger piece of software by adding features or functions.
Scalable Vector Graphics (SVG)	- A new format for web graphics that uses XML schema to describe the shapes
Search Engine	- A program that searches documents for specified keywords and returns a list of the documents or Web pages
Server	- A computer or device on a network that manages network resources.
Shockwave	- A technology developed by Macromedia, Inc. that enables Web pages to include multimedia objects.

Shockwave3D

- A new format of Shockwave file including 3D models for Macromedia Director version 8.5

SQL

- Structured Query Language. A language used by relational databases to query, update, and manage data

W3D

- An extension of the Shockwave3D file

Xtra

- A dynamic link library plug-ins for Macromedia Applications.

**APPENDIX G. CHANGES OF STANDARD DESIGN DURING 6-MONTH RECYCLE**

**Table G-1. Standard road plan changes for April 2004 letting**

Drawin g	Title	Level of Change	Change Description
(1)	(2)	(3)	(4)
RB-6	Pedestrian Curb Ramp Erosion Control Details for Silt Fence (Engineering Fabric--Machine	Low	Change detectable warning size, spacing, and location
RC-16A	Installation) Erosion Control Details for Silt Fence (Engineering Fabric--Trench	Very Low	Dimension 20' segment skewed toward foreslope
RC-16B	Installation)	Very Low	Dimension 20' segment skewed toward foreslope
RD-33	Wood Post Attachment for Type 'A' Interstate Signs	Very Low	Remove aluminum from hardware labels
RD-61	Special Sign Mounting Brackets	Very Low	Remove aluminum from hardware labels
RE-3A	Permanent Road Closure (Rural)	Very Low	Change length of wood posts from 8' to 10'
RE-44F(1)	Concrete Barrier (Reinforced Half Section, 32" High) (Page 1 of 2)	Low	Convert from New Jersey shape to F-shape barrier
RE-47	Details of Type 3 Object Marker	Very Low	Show dimensions over shading and revise general notes Mark post at both ends. Specify wood spacer block with steel posts.
RE-68	Steel Beam Guardrail Standard Transition Section (STS)	Very Low	
RF-19C	Subdrains (Longitudinal)	Very Low	Specify subdrain outlet (RF-19C) as the bid item for note 8
RF-30A	Pipe Culvert Installation Details (Bedding and Backfill)	-	Correct reference to standard road plan RF-32
RF-30B	Pipe Culvert Installation Details (Cover and Camber)	-	Polymer grid to be bid
RF-38(1)	Intake for Bridge End Drain (Sheet 1 of 2)	Very Low	Revise bridge approach section and general notes
RF-38(2)	Intake for Bridge End Drain (Sheet 2 of 2)	Very Low	Revise general notes Dimension flume, revise bridge approach section, and remove curb location detail
RF-39	Sod Flume for Bridge End Drain	Very Low	Dimension flume, revise bridge approach section, and remove curb location detail
RF-40	Rock Flume for Bridge End Drain	-	Dimension flume, revise bridge approach section, and remove curb location detail
RH-43	Non-Reinforced Four-Lane 48.0' or 49.0' P.C. Concrete Pavement	Very Low	Rename construction progress to traffic
RH-50	Joints (Traverse Contraction)	Very Low	Revise circle notes
RH-51	Joints (Longitudinal Contraction)	Low	Add KS-1 and KS-2 for bridge approach, revise circle notes
RH-52	Joints (Expansion)	Very Low	Add notes, revise terminology
RH-55	Fabrication Details Contraction Joint Dowel Assembly	Very Low	Modify table and revise circle notes

RH-56	Fabrication Details Expansion Joint Dowel Assembly	Very Low	Modify table and revise circle notes
RH-57	Fabrication Details Contraction Joint Skewed Dowel Assembly	Very Low	Modify table and revise circle notes
RH-58	Dowel Assembly Placement Details	Very Low	Revise note number 1
RH-61	Shoulder Rumble Strips (Interstate)	Very Low	Change offset to milled rumble strips on outside shoulders and add bid item for fog seal
RH-62	Shoulder Rumble Strips (Expressways)	Very Low	Change offset to milled rumble strips on outside shoulders and add bid item for fog seal
RH-63	Shoulder Rumble Strips (2-Lane Roadways)	Low	Change offset to 6" and add bid item for fog seal
RJ-34	Partially Paved Shoulder (6" HMA)	Very Low	Changed quantities for granular shoulders
RK-20(1)	Bridge Approach (General Details - Sheet 1 of 3)	-	new
RK-20(2)	Bridge Approach (General Details - Sheet 2 of 3)	-	new
RK-20(3)	Bridge Approach (General Details - Sheet 3 of 3)	-	new
RK-21	Bridge Approach (Abutting PCC Pavement)	-	new
RK-22	Bridge Approach (Abutting HMA Pavement)	-	new
RK-23	Bridge Approach (Multi-Lane, Curbed Roadway)	-	new
RK-30	Bridge Approach (Abutting Pavement Detail)	-	new
RS-10	Traffic Control Layout for Paved On-Site Detour with One-Lane Traffic	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-11	Traffic Control Layout for Unpaved On-Site Detour with One-Lane Traffic	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-15	Traffic Control Layout for Signalized Equipment Crossing	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-5A	Traffic Control Layout for One-Way Traffic on Bridges for 10-Foot Approach Shoulders	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-5C	Traffic Control Layout for One-Way Traffic on Bridges for 6-Foot Approach Shoulders	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-5D	Traffic Control Layout for One-Way Traffic on Bridges for 4-Foot Approach Shoulders	Very Low	Change reference in note 5 to RM-49
RS-5E	Traffic Control Layout for One-Way Traffic on Bridges for Curb Sections	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-66(1)	Traffic Control Layout for Two-Lane, Two-Way Operation (Sheet 1 of 2)	Very Low	Label 4" white edge line
RS-8	Traffic Control Layout for Paved On-Site Detour with Two-Way Traffic	Very Low	Change reference in note no. 4 to standard road plan RM-49
RS-80	Traffic Control Layout for Lane Closure Using Temporary Barrier Rail	Very Low	Change reference in note no. 10 to Standard Road Plan RM-49. Add merge arrow sign and arrow pavement markings.
RS-9	Traffic Control Layout for Unpaved On-Site Detour with Two-Way Traffic	Very Low	Change reference in note no. 4 to standard road plan RM-49

**Table G-2. Standard bridge plan changes for the April 2004 letting**

Drawin g	Title	Level of Change	Change Description
(1)	(2)	(3)	(4)
1008	Bearing Standard	low	1/4" Dia. Drain Hole added to typical pintle detail
1009	Bearing Standard	low	1/4" Dia. Drain Hole added to typical pintle detail
1010	Bearing Standard, Low Profile		<new sheet>
1017	Barrier Rail End Section for 7'0 Wings Barrier Rail L.A. Skewed Stub Abutment with Wing	very low	Changes on note
1018	Extensions	low	5c1, 5c2 bar spacing changed
1021	Welding Details		Changes section G-G
1026	Expansion Device Details Steel Extrusion with Neoprene Gland	low	Blockout Detail Added outside of sheet, Hex head countersunk screw detail added
1035	Temporary Bridge - Wood Piles		<new sheet>
1036			Minor washer size changed, chang to notes about bolt requirements, Seal end of beam at stub abutments
1039	Steel Intermediate Diaphragms for PCBM. Bridges Deck Repair Notes (2 of 2)	low very low	
1041	Deck Repair Expansion Plates Sheet 2	very low	Note changed Bridge roadway changed to bridge Specifications note updated. Minimum splice length changed in general notes. Note added about transition distance of new work.
1043	Culvert Extension Quantities	very low	
1044	Culvert Extension Details	very low	Note added to longitudinal steel is to be extended to back of parapet.
1046	12" Prestressed Concrete Foundation Pile	very low	Bent * anchor size changed to *
1049	FShape Temporary Barrier Rail Concrete	very low	Tie down details deleted and referenced to road standards.
1050	FShape Temporary Barrier Rail Concrete	very low	Tie down details deleted and referenced to road standards.
1054	Deck Drain Details	low	Minor dimensions and plate sizes changed. Added hex head screw detail. Additional beam shapes outside of sheet.
1056	Steel H14X73 Temporary Barrier Rail Standards for Two Way Traffic		<new sheet>
1058	Steel H14X73 Temporary Barrier Rail Standards for One Way Traffic		<new sheet>
1060	Culvert Baffle Details		<new sheet>
1061	Culvert Weir Details		<new sheet>
1070	Flume Details - 3' Height		<new sheet>
1071	Flume Details - 4' Height		<new sheet>
1072	Flume Details - 5' Height		<new sheet>

1073	Flume Details - 6' Height		<new sheet>
1074	Flume Details - 8' Height		<new sheet>
1075	Flume Details -10' Height		<new sheet>
1076	Flume Details - 12' Height		<new sheet>
4305	30' Rdwy. Welded Cross Section	very low	Superstructure notes about welding changed
4306	32' Rdwy. welded Girder Cross Section	very low	Superstructure notes about welding changed
4307	36' Rdwy. welded Girder Cross Section	very low	Superstructure notes about welding changed
4308	40' Rdwy. welded Girder Cross Section	very low	Superstructure notes about welding changed
4309	44' Rdwy. welded Girder Cross Section	very low	Superstructure notes about welding changed
4310	40' Rdwy. welded Girder Cross Section (Symm. Crown)	very low	Superstructure notes about welding changed
4380	30' Rdwy. PPCB (All Beams Integral Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4381	32' Rdwy. PPCB (All Beams Integral Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4382	36' Rdwy. PPCB (All Beams Integral Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4383	40' Rdwy. PPCB (All Beams Integral Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4384	44' Rdwy. PPCB (All Beams Integral Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4385	40' Rdwy. PPCB (All Beams Integral Abut.) Cross Section (Symm. Crown)	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4427	Concrete Slab Barrier Rail 44' Roadway	low	Spacing of 5G1 & 5G2 changed to 1'-0". Variable lengths of 5G2 Bars changed in bent bar details
4447	Concrete Slab Barrier Rail 40' Roadway	low	Spacing of 5G1 & 5G2 changed to 1'-0". Variable lengths of 5G2 Bars changed in bent bar details
4541	Stub Abut. Bearing Details PPCB Bridges / Steel Beam Bridges	low	Drain hole added to pintle details
4556	30' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4557	32' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4558	36' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4559	40' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4560	44' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.) Cross Section	low	Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.

	40' RDW, PPCB ("B", "C", & "D" Beams Stub Abut.)			Footing extended 1" to accommodate C and D beams. Note added to adjust for A and B beams. 110' & 115' B2 Bars added.
4561	CrossSection (Symm. Crown)	low		
4600	LXA Beams Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4610	LXB Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4620	LXC Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4630	LXD Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4636	LXD110 Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4637	LXD115 Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4638	LXD120 Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4650	Bulb Tee Beam Details	very low		Concrete sealer note added. Coil tie pull out capacity changed
4655	Bulb Tee Beam 120' Span			<new sheet>
4656	Bulb Tee Beam 125' Span			<new sheet>
4657	Bulb Tee Beam 130' Span			<new sheet>
4658	Bulb Tee Beam 135' Span			<new sheet>
4659	Bulb Tee Beam 140' Span			<new sheet>
1005A	Bridge Wing Armoring - Water Crossing	very low		Detail "A" Changed to Section A-A
1017A	Barrier Rail End Section for 4'0 Wings	very low		Minor changes to notes
1018A	Barrier Rail R.A. Skewed Stub Abutment with Wing Extensions	low		5c1, 5c2 bar spacing changed
1019A	FShape Barrier Rail Integral Abutment - Urban Approach			<new sheet>
1019B	FShape Barrier Rail Stub Abutment - Urban Approach			<new sheet>
1020A	FShape Barrier Rail Integral Abutment Bridges	low		5c1, 5c2 bar spacing changed
1020B	FShape Barrier Rail 0° Skew Stub Abutments with Wing Extensions	low		5c1, 5c2 bar spacing changed
1020C	FShape Barrier Rail Integral Abutments with Wing Extensions	low		5c1, 5c2 bar spacing changed
1028A	FShape Barrier Rail Sidewalk	low		5c1, 5c2 bar spacing changed. Steel sidewalk rail height changed to 1' - 10". Drain slots moved in typical section. Standard sheet renamed to 1029A.
1029A	Pipe Sidewalk Railing Steel, Raised Sidewalk 1½" Ends	low		Quantity item name changed for steel pipe. Drain slots moved in typical section. Standard sheet renamed to 1029A.
1029B	Pipe Sidewalk Railing Steel, Raised Sidewalk 9½" Ends	low		Quantity item name changed for steel pipe.
1029C	Pipe Sidewalk Railing Steel 1½" Ends	low		Standard sheet named to 1029C. Quantity item name changed for steel pipe.
1029D	Pipe Sidewalk Railing Steel 9½" Ends	low		Standard sheet named to 1029D. Quantity item name changed for steel pipe.
1030A	Lighting Details (1 of 2)	low		Junction box details changed. Anchor bolts to be galvanized. Conduit used for light pole changed from 1" to 2". Anchor plate changed to 3" slot.
1030A	Lighting Details (2 of 2)			<new sheet>

1035A	Temporary Bridge - Single Span - Wood Piles		<new sheet>
1035B	Temporary Bridge - Multiple Span - Wood Piles		<new sheet>
1035C	Temporary Bridge - Steel Piles		<new sheet>
1035D	Temporary Bridge - Single Span - Steel Piles		<new sheet>
1035E	Temporary Bridge - Multiple Span - Steel Piles		<new sheet>
1036A	Concrete Inter. Diaphragms for PCBM Bridges	low	Seal end of beam at plant for stub abutments.
1036BR	Steel Inter. Diaphragms for BTBM Overhead Bridges	low	Sheet renamed to H1036BR. Seal end of beam for stub abutments
1036B W	Steel Inter. Diaphragms for BTBM Water Crossing Bridges	low	Sheet renamed to H1036BW. Seal end of beam for stub abutments
1036CR	Steel Inter. Diaphragms for BTCBM Overhead Bridges		<new sheet>
1036C W	Steel Inter. Diaphragms for BTCBM Water Crossing Bridges		<new sheet>
1036DR	Steel Inter. Diaphragms for BTDBM Overhead Bridges		<new sheet>
1036D W	Steel Inter. Diaphragms for BTDBM Water Crossing Bridges		<new sheet>
4541A	PPC Beam Bridges Pier Bearing Details	low	Drain hole added to pintle details
P10A	Standard P10A Concrete and Steel Piles	low	Spiral pitch changed for type 2 pile. Weights changed in material components box and ASTM No. added for wire spiral.



**Table G-3. Standard culvert plan changes for the April 2004 letting**

Drawing	Title	Level of Change	Change Description
(1)	(2)	(3)	(4)
RCF 0104	Reinforced Concrete Flumes - all sizes		
FBJ 0104	Flume Bell Joints 3' x 3', 4' x 4', 5' x 3' to 5' x 6'		
FBJ 0204	Flume Bell Joints 6' x 3' to 6' x 8', 8' x 4' to 8' x 10'		
FBJ 0304	Flume Bell Joints 10' x 4' to 10' x 12', 12' x 6' to 12' x 12'	Medium	New
RCFB 0104	Reinforced Concrete Flume Basins 3' x 3', 4' x 4', 5' x 3' to 5' x 6'		
RCFB 0204	Reinforced Concrete Flume Basins 6' x 3' to 6' x 8', 8' x 4' to 8' x 10'		
RCFB 0304	Reinforced Concrete Flume Basins 10' x 4' to 10' x 12', 12' x 6' to 12' x 12'		

**Table G-4. SUDAS design standards changed for latest update**

Drawing	Title	Level of Change	Change Description
(1)	(2)	(3)	(4)
3010.1	Pipe Embedment Details	very low	Notes changed
6020.1	Type "A" Manhole	very low	add note "O-Ring or profile gasket per ASTM C 443
6020.2	Type "E" Manhole	low	Change thickness of top from 9" to 10"
6020.3	Type "F" Manhole	low	Change thickness of top from 9" to 10"
6020.13	Type "M-B" Manhole	low	Change thickness of top from 9" to 10"
6020.14	Type "M-C" Manhole	low	Change thickness of top from 9" to 10"
6020.21	Connection to Existing Sanitary Manhole		<new figure>
6030.15	Type 3 and Type 4 Intake Grate	very low	Notes changed
6030.16	Grate Intake Boxouts	very low	Notes changed
7020.1	Asphalt Pavement Sections	low	Correct the width of cub to 2.5'
7020.2A	26' B/B & 31' B/B A.C. Concrete Pavement	very low	Notes changed
7020.7	Curb Details for Asphalt Cement Concrete	very low	Change thickness from 7" to varies
7030.3A	Residential Driveway, Type A Grind/Saw Existing Curb	low	Specific 18" width of under pavement
7030.3B	Residential Driveway, Type B; Boxout Curb	low	Specific 18" width of under pavement
7030.4	Commercial/Industrial Driveway	low	Specific 18" width of under pavement
7030.8	Classes of Sidewalks and Recreational Trails	low	switch with 7030.9 and add some sections
7030.9	Type of Pedestrian Ramps Outside of Intersection Radius	low	switch with 7030.8 and add some sections
7030.10	Preferred Pedestrian Ramp Within Intersection Radius for Class A Sidewalk Optional Pedestrian Ramp Within Intersection Radius for Class A Sidewalk Preferred Pedestrian Ramp Within Intersection Radius for Class B or C Sidewalk Optional Ramp Within Intersection Radius for Class B or C Sidewalk Detectable Warnings (Truncated Domes) Brick Sidewalk Curb Details for Class A Sidewalk	Medium	Change the new type of intersection ramps and add more details and key section detail
7030.11			
7030.12			
7030.13			
7030.14			
7030.15			
7030.16			
10000.1	Utility Service Locations; Sanitary Sewer Located Outside of Street Paving	very low	Correct Typo
10000.2	Utility Service Locations; Sanitary Sewer Located in the Center of the Street	very low	Correct Typo