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16. Abstract <p>The work undertaken in this project had the purpose of determining what needs existed within Texas Department of Transportation (TxDOT) units concerned with the planning, design and operation of the state maintained highway system. It discusses the process of interviews used to determine the needs for visualization technology and capabilities that might exist within the various operation units. The report also reviews the existing automation resources of the department and their ability to produce visualization products. The findings of the investigations are reviewed and the needs as identified are described. In the concluding sections, a benefit to cost assessment and a demonstration project using 3-dimensional graphics as a design tool are presented to compare and illustrate the needs for visualization capabilities.</p> <p>The report concludes that visualization technology (3-dimensional graphic environments) has numerous benefits for TxDOT and will likely become the design environment of the future. Implementation, on the other hand, should be staged beginning with the units identified as having the highest immediate pay back costs. This strategy also allows TxDOT to evaluate the tools more carefully while developing a more detailed strategy for implementation.</p>					
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**Evaluation and Development of
Visualization Technology
for
Highway Transportation**

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Research Report 1284-1F

Research Study Number 2-19-91-1284

Sponsored By

Texas Department of Transportation
in cooperation with the U.S. Department of Transportation
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Implementation Statement

The report concludes that visualization technology (3-dimensional graphic environments) has numerous benefits for TxDOT and will likely become the design environment of the future. Implementation, on the other hand, should be staged beginning with the units identified as having the highest immediate pay back on costs. This strategy also allows TxDOT to evaluate the tools more carefully while developing a more detailed strategy for implementation.

TABLE OF CONTENTS

List of Figures and Tables	v
Introduction:	1
Overview of Visualization Technologies	3
TASK 1: Determine the Department’s Needs for Visualization Capabilities	6
TASK 2: Review of Automation Resources Related to Visualization Needs	16
TASK 3: Summary of Findings and Description of Visualization Needs	19
TASK 4: Benefit Cost Analysis	24
TASK 5: A Three Dimensional Analysis of Sight Distance on Interchange Ramps and Connectors.	37
Conclusions	38
Appendix A: Transcription of District Interviews	
Appendix B: Recommendations Section of Task 5 Thesis	

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

in ²	square inches	645.2	centimetres squared	cm ²
ft ²	square feet	0.0929	metres squared	m ²
yd ²	square yards	0.836	metres squared	m ²
mi ²	square miles	2.59	kilometres squared	km ²
ac	acres	0.395	hectares	ha

MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft ³	cubic feet	0.0328	metres cubed	m ³
yd ³	cubic yards	0.0765	metres cubed	m ³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
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LENGTH

mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

mm ²	millimetres squared	0.0016	square inches	in ²
m ²	metres squared	10.764	square feet	ft ²
km ²	kilometres squared	0.39	square miles	mi ²
ha	hectares (10 000 m ²)	2.53	acres	ac

MASS (weight)

g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m ³	metres cubed	35.315	cubic feet	ft ³
m ³	metres cubed	1.308	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

LIST OF FIGURES AND TABLES

Table 1: Primary and Secondary Audiences of Department and District Units	9
Table 2: Utilization of Graphic Products by Divisions and Districts	10
Figure 1: Products Available from Two and Three Dimensional Data Bases	15
Figure 2: Tabulation of Costs for IH-45 and U.S. 59 Corridors	35
Figure 3: Tabulation of Benefits for IH-45 and U.S. 59 Corridors	36

INTRODUCTION

Projects to improve and expand the state and national highway transportation system are increasingly complex and often slowed or even stopped by adverse public reaction. The increased resistance, particularly in urban/suburban areas, is a function of the need for complex grade separated interchanges, elevated highway sections, increased regulation, and concern for the environment. The issues of structural and environmental complexity are further complicated by an increasingly vocal and demanding public.

The increased complexity of highway transportation facilities has been accompanied by a rapid change and evolution of the tools used in design and design communication. The principal shift has been from the traditional drafting room environment to the computer based "CADD" environment. However, there is strong evidence to suggest that this technology will continue to evolve into an area called "Visualization". In the context of this study the term "Visualization" includes the entire tool palette that can be used to create graphic products and visual simulations of the highway transportation environment.

It is the purpose of this study to examine the emerging visualization tool base in the context of the highway transportation design process and make recommendations for the integration of visualization technology. Specific objectives include:

1. To determine the Department's needs for visualization capabilities.
2. To work with the Department's representatives to evaluate current graphic capabilities, ie. computer software and their translatability to visualization applications.
3. To develop, with Department staff, suggestions for the most cost effective means to meet the visualization needs identified in objective 1.
4. To develop evaluations of the value of using visualization applications in cooperation with Department staff and make further recommendations of acquisition and development of the technology.

This report summarizes the results of work conducted during fiscal 1991-1992. It is divided into five sections. The first section provides an overview of the various technologies that comprise the visualization "tool palette." The final five sections follow the five primary tasks outlined in the original proposal: Task 1: Determine the Department's Needs for Visualization Technology, Task 2: Review Automation Resources Related to Visualization Needs, Task 3: Summary of Findings and Description of Visualization Needs, Task 4: Benefit Cost Analysis and Task 5: A Three Dimensional Analysis of Sight Distance on Interchange Ramps and Connectors.

OVERVIEW OF VISUALIZATION TECHNOLOGIES

Since the science and technology of visualization is not well defined it is appropriate to preface this report with a brief discussion of the specific technologies considered in this study. The tools used for visualization in this context are drawn from analog video technology and digital computer technology. No consideration was given to other forms of technology, such as satellite and land based navigation technologies or spatially referenced data management systems (GIS), which can also be used to acquire, manipulate and display design information in 3-dimensional contexts.

Specifically, the work in this study focused on those technologies that can be used to generate 3-Dimensional or 3-Dimension like images of design proposals. In general terms these technologies can be categorized as video, image paint, video overlay and computer animation.

Video

Video is the standard medium for recording motion and/or events of historical and/or temporal interest. It is unsurpassed for demonstrating existing conditions and illustrating day to day conditions of the transportation corridor. Video technology is available in VHS, SVHS, 8mm or similar commercial and professional grades of equipment. Current equipment provides ease of recording with automatic exposure and from .5 to 3 hours per tape. Editing equipment is also available for editing and adding special effects for specific applications.

Video offers the advantage of flexibility and ease of use, but it is limited to recording existing events and the image quality, ie. color and clarity of the image will vary widely with the quality of the equipment used.

Image Paint

This technology, sometimes called "Image Capture", provides a single still image which

combines proposed design elements with an existing, photographic background. The background image is either scanned in from a photograph or captured as a single frame from a video tape. The proposed design elements are then added to the captured image by painting on the image in the same sense that an artist would paint on a canvas with a brush, or by importing a 3-Dimensional model from a CADD package. These combined images can be retouched and other details added until the desired degree of realism is reached.

Image paint technology is relatively fast. That is, a single image can be generated in a matter of hours to days depending on the level of complexity. In addition the level of realism in the images, given an experienced operator, approaches photographic quality. The disadvantage of this technology is that the image quality depends a great deal on the quality of the equipment and software used and the skill of the operator. It must also be used with caution since very realistic images can be created that do not represent the conditions that would result from a design proposal.

Video Overlay

Video overlay utilizes the same basic tools as the image paint technology except that a moving video sequence, rather than a static image, is used as the background. In this case the image used to overlay on the video sequence is most often a model imported from a CADD system. When the combined sequence is played, it gives the appearance of an animated sequence because the traffic and other elements appear to be in motion.

The video overlay technique adds a sense of realism that simply is not possible in a still image. However, the view is limited to a single camera placement which is required to obtain the original video footage. It is not possible to move the camera in the sequence, and it is not cost effective to add other moving objects to the sequence.

Computer Animation

Computer animation is a completely synthetic image, based on a mathematical description of all components in the scene. This would include the highway, topography, and the surrounding context at varying levels of detail. Then, based on the view points and paths of interest, a "camera" can be positioned and moved along a specified path within the model.

This technology is most demanding on the computing and video resources, and it requires a three step sequence to produce a series of images. First a full 3-Dimensional description of the space must be constructed. This is usually done in a CADD system that has 3-dimensional capabilities. Next a set of instructions must be developed to guide the movement of the camera through the model. When this is complete the information is transferred to rendering module where the colors, surface materials, shadows, reflections, light sources and other effects are specified and the images created. The level of detail in the final images is directly related to the complexity of the information in the 3-dimensional model and the sophistication of the effects specified in the rendering module.

Computer animation is the most flexible and accurate means of viewing a design proposal in 3-dimensions over time. It provides complete control of the camera and viewing conditions so that the designer can see a structure from any desired point of view in the data base. On the other hand, developing the model data base is currently very labor intensive, and the level of detail required in a scene results in near exponential increases in the time requirements for input and computing. In short, animation is the most expensive option requiring high level equipment and a well trained, specialized staff.

TASK 1: DETERMINE THE DEPARTMENT'S NEEDS FOR VISUALIZATION CAPABILITIES

Conducting Interviews

Visualization technology is one of the more democratic of the computer based systems. That is, the need for visualization products, ie. images of what is and what could or will be, transcends the boundaries of traditional engineering drawings. Images of bridges and highway structures, the character and quality of neighborhoods, before and after a project, all have application across numerous disciplinary areas within the Department. Recognizing this the research team undertook a series of interviews at the district and divisional levels.

The purpose of the interviews was to introduce a variety of department staff to the visualization tool base and to have them react to how one or more of the technologies could be applied in their day-to-day activities. Based on recommendations from the technical panel chairman, six key districts were selected for interviews and four state level divisions. The districts selected were: San Antonio, El Paso, Dallas, Ft. Worth, Houston and Austin. The divisions were: Maintenance and Operations (D-18), Right-of-Way (D-15), Bridge (D-5) and Design (D-8).

The interviews were conducted in the offices of the districts and divisions. In order to achieve the greatest level of participation and input from staff, the groups were deliberately kept small, 6-10 per session. Insofar as possible, the groups were made up of more than one discipline. The order of business and key questions discussed at each session were as follows:

1. Review of the Types of Visualization Technology.

Each group meeting began with a brief overview of current visualization technology supplemented by video taped and hard copy examples of various products. The outline of the presentation generally followed that of the first section of this report.

2. Key Questions About the Use of Visualization Technology.

There were several areas of concern that would have a bearing on the need for and the ultimate use of visualization products in the Department. However, the interviewers did not want to discourage open discussion that might uncover concerns that were not anticipated, so discussions were not managed in a strict question and answer format. On the other hand there were several key questions that were asked of every group during the course of each meeting. These are as follows:

- a. What group(s) do/does your division/section communicate with on a regular basis?
- b. What graphic products do you currently use for the communicating design or other concepts?
- c. How often do you need graphic products in the performance of your duties?
- d. How much time do you usually have to prepare the graphic products when they are needed.
- e. Which of the visualization techniques described here would, in your opinion be of the greatest benefit in your day to day work?
- f. What specific application do you have in mind?
- g. How many times a year would you have need of these sorts of products?

The interviews were conducted between November of 1991 and March of 1992. The proceedings of each of the interview sessions were recorded and transcribed. The summary transcriptions of these tapes are included in Appendix A of this report. The following sections summarize the findings of these interviews.

General Information from Interviews

Primary Audiences

The primary audiences with which the various divisions and sections communicate varies widely by mission. The divisions and sections involved in the tasks related to early project development communicate with a variety of extra-departmental audiences including municipal and county elected officials, public agencies and special districts, special interest groups, the media and the general public. The divisions and sections most closely associated with the physical design of facilities are most often concerned with intra-departmental communication. However, there is evidence in the larger districts and at the state level, D-8, that design professionals are becoming increasingly involved in extra-departmental communication activities.

Table 1 summarizes the most common audiences identified by the various divisions and sections. A distinction is made between a primary and secondary audience. A primary audience is one where the respondents indicated that there was frequent monthly contact with a particular audience in the conduct of normal business. As secondary audience designation indicates that there is frequent contact, but that it is not on a regularly basis, or that there is an increasing communication with a particular audience. If no contact is indicated, it means that contact with a particular audience is not common in day-to-day activities.

Table 1. Primary and Secondary Audiences of Departmental and District Units

Audience	Advanced Planning	Design	Bridge Design	Public Affairs	Right of Way	Maintenance and Operations
Elected Officials (Municipal and County)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Special Interest Groups	<input checked="" type="checkbox"/>	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>	
Neighborhood Groups	<input checked="" type="checkbox"/>	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
General Public	<input checked="" type="checkbox"/>	<input type="checkbox"/>		<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inter-Departmental Groups	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Municipal Operations Units		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Media	<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Agencies and Special Districts	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

- Primary Audience of Division or Section
- Secondary Audience of Division or Section

Types of Graphic Products Currently Used

Without exception the primary graphic tool used by the Department's districts and divisions is the right-of-way map (row map) and the plan-profile sheet (PP). There were isolated instances, usually in right-of-way and advanced planning, where graphics were prepared over aerial photographs, artists renderings and sketches, scale models and some computer generated video graphics. However, these were usually cited as exceptions to normal procedures, and there was no indication that these practices were integral to the overall process of design communication. Table 2 summarizes the types of graphic products

used for design communication by division or section.

Table 2. Utilization of Graphic Products by Divisions and District Sections

Types of Graphic Products	Advanced Planning	Design	Bridge Design	Public Affairs	Right of Way	Maintenance and Operations
Plan-Profile Sheets	■	■	■	■	■	■
Aerial Photo/Graphics	□	□	□	□	■	
Artist Sketches	□			□	□	
Right-Of-Way Maps				□	■	
Scale Models	□			□	□	
Computer Video Graphics	□				□	

- Frequent use
- Some use

Time Related Considerations

Several of the questions asked dealt with time considerations related to the frequency of use and the time available for preparation of the various graphic products. For the majority of cases, groups felt that there was at least two weeks available to prepare graphic products, and times ranged to as high as a year. Frequency of need also varied from unit to unit and district to district. For the most part, these variations seemed to be attributable to the current design and construction load of the various districts. For example, District 12, Houston seemed to be much less optimistic about the time available to prepare graphic products than some of the districts with less construction activity.

No measure of a typical time frame for production was found, nor was it possible to

make any determination of how many or how often graphic products were likely to be required. In this regard it seemed that time constraints were most often related to problems associated with characteristics unique to a specific project. Without exception, it was observed that the more complex the project, the greater the need for graphic products and the greater the time constraints for preparation.

Application of Specific Techniques

The final questions were directed toward getting reactions from the groups about what specific applications would be of the greatest value to them in their daily activities if they were available. During this part of the interview a second video segment was used to review the various techniques and to guide the discussion.

These discussions did not, as we had originally thought, produce any consensus about the applications of any of the technologies to any specific areas. Again, it seemed that each group that was interviewed could see an application for each technology in the context of their duties. What was very apparent was that the need for these capabilities extended across a wide variety of Department activities.

Major Findings from Interviews

Inadequacy of Current Communication Media

The primary document used for communication of highway transportation proposals by the Department is the Plan-Profile sheet. While there can be little doubt it is and will continue to be the primary instrument for construction documentation, there was general consensus that it is not an effective means of communicating design intent at public meetings and in other arenas such as special commissioners hearings and in trial litigation.

In most cases the areas most affected were advanced planning, right-of-way, and public affairs. Other areas such as design, bridge design, and maintenance and operations expressed little initial concern about the ability of the traditional methods of communication. However, there was an overwhelming consensus across all areas of operation when it came to the inability of the plan-profile sheet to clearly communicate design intent to the general public.

Need for Visual Realism

There was a general feeling among the units that deal with the public on a day-to-day basis that realism was very important to the success of any communication medium¹. It was frequently suggested that the lack of realism, characterized by cartoon like drawings of artists renderings, often leads to a mistrust of the image.

Among the design and operational units, the need for realism was not apparent. The concerns were more focused on the accuracy of the image and the ability to view the data base from a variety of positions within the model. The feeling was that it would usually be professionally trained individuals using the information and that realism would in some cases actually be less desirable.

Increased Need for Communication with the Public

The responses from the interviews clearly support the primary thesis of this study for the need to develop and integrate better visual communication tools into the Department's design process. As suspected, the primary need is in communicating project impacts and character to the special interest groups and the general public.

¹ In this context "realism" is would be the ability to produce synthetic or composite images that would be difficult or impossible to distinguish from true photographic images of the same scene.

Based on the comments offered about recent experiences in several districts and from the Design Division in Austin, there is much to suggest that many of the misunderstandings that have occurred have resulted because the traditional graphic tools have simply been insufficient to convey the extent and visual character of the proposal.

A related observance by many of the district level personnel was that they believed that contact with the general public would continue to increase and play a major role in the Department's activities over the next two decades. This feeling was based on the fact that most development will be taking place within established corridors, many of which have become intensively developed. Because of the intensity of development, the impact on individuals and businesses will be much greater than in the past. The trend is exemplified by the North Central Expressway project in the Dallas district.

Increased Use of Advanced Visualization Technologies in Litigation

In recent years there has been a new trend in cases brought against the Department. These cases center on three major questions:

1. What will the project look like from the property in question?
2. Will the property in question be visible from the new highway, and will its access be adversely effected?
3. Will the use of the property be effected by the taking of a portion of the land adjacent to the project?

The number of cases going to litigation is increasing dramatically in major urban areas of the state. As these cases increase there is an increasing use of advanced visualization methods to support the cases of the plaintiffs, and resulting awards suggest that these devices have been effective. More importantly, it should be recognize that the awards are being made on the basis of "Visual" damages to the sites in question.

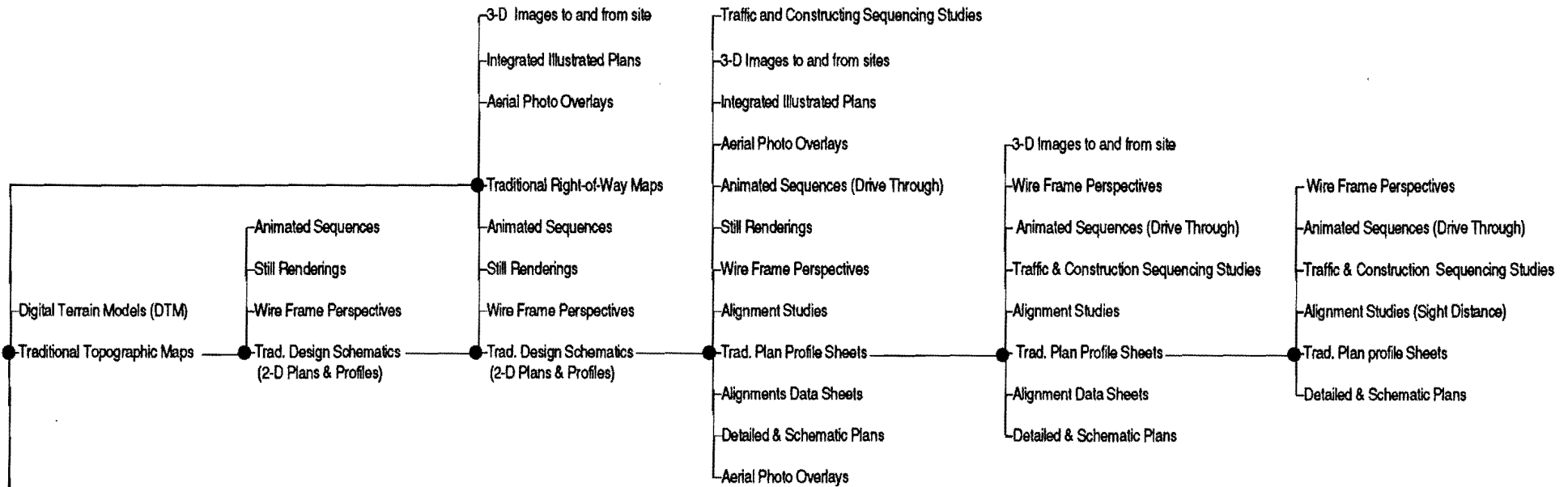
Potential Life Cycle of 3-Dimensional Data Bases

The least anticipated and probably most significant finding of this study is the implication of the life-cycle time and value of a 3-dimensional data base. As noted in earlier discussion, every operational unit of the Department, including resident engineers, indicated an interest in and suggested an area of application for one or more of basic technologies. The primary obstacle to the ready incorporation of the technology into the every day activities was the lack of an existing 3-dimensional data base that could be accessed and quickly massaged to provide the necessary graphic product(s).

The perception at all operational levels is that the costs associated in constructing a 3-dimensional data base are cost prohibitive and not cost effective. On the other hand, these assumptions are based on the direct costs associated with that single use of the information. No consideration had been given to the uses that either preceded or came after the needs of the unit in question.

The fact that all operational units could articulate a use for 3-dimensional graphic products strongly suggests that attempting to base decisions on the cost effectiveness of integrating visualization capabilities into the day-to-day operations of the Department should be reconsidered. The diagram in Figure 1 illustrates the life span of 2 and 3-dimensional data sets and the product options available from each data set.

PRODUCTS AVAILABLE FROM THREE DIMENSIONAL DATA BASE



CARTOGRAPHY

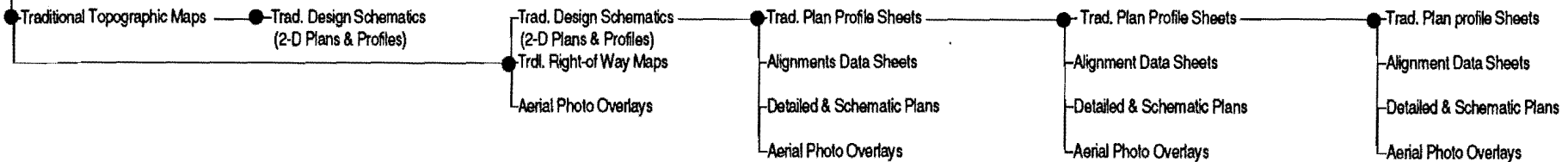
ADVANCED PLANNING

RIGHT-OF-WAY

DESIGN

CONSTRUCTION

MAINTENANCE & OPERATION



PRODUCTS AVAILABLE FROM TWO DIMENSIONAL DATA BASE

Figure 1. Products Available from Two and Three Dimensional Data Bases

TASK 2: REVIEW AUTOMATION RESOURCES RELATED TO VISUALIZATION NEEDS

Graphics Computing Environment

TxDOT is essentially a single vendor shop (Intergraph) with respect to CADD and graphics operations. At this time the Automation Division, D-19, has committed to the use of two primary software tools sold and supported by Intergraph Corporation DP Studio and Model View. DP Studio are programs that can be used to do image paint and video overlay; Model View is the basic product used to generate 3-dimensional graphics and animation. The hardware platform recommended by D-19 running these software packages is the high end Intergraph workstation with a minimum of 600 MB of disk space and an Image Grabber board. The software and hardware tools for generating visualization products are adequate and at the high end of the Intergraph line. As might be expected, they also carry high end price tags for acquisition and maintenance.

In addition to the basic hardware and software, access to a variety of peripherals is also necessary for capturing images. These include peripherals such as a good quality video camera, high resolution scanner, digitizer, color graphics printers, video editing controller, video editing deck, VCR players, and an animation controller. All of this equipment is currently available through D-19. However, no administrative decision has yet been made regarding the centralization or distribution of overall production capabilities.

Characteristics of Other Automation Environments

Since the interviews clearly demonstrated that the need for visualization capabilities cuts across all activities and levels of the Department, it was important to look at other graphic production tools and procedures used by the Department. The purpose of this step was to determine what steps might be taken to integrate visualization with on-going activities.

Primary Production Tools

The primary production tool used by the Department for all PS&E work is the AASHTO, IGRDS system. IGRDS is a program enhancement package that rides on top of Intergraph's Micro-Station CADD package. The IGRDS package provides all of the primary geometric inputs to the system and Micro-Station provides all of the graphics functions necessary to produce graphics and text output.

Non-graphic operations associated with the preparation of other contract documents, special specifications, notes and conditions, quantities, etc. are handled in a separate, non-connected mainframe environment using ADABase. While there are some efforts underway to develop some software links to ADABase, they are not operational at this time.

Automated Plan Preparation (APP)

In addition to the basic functions accomplished in IGRDS and Micro-Station, the Department is also developing an additional enhancement package referred to by its acronym "APP" or Automated Plan Preparation. This is a series of software routines and enhancements that takes basic project data and assembles the information into a standardized set of contract documents. It includes such features as an automated title block and border insertion, automated sheet segmenting, automated quantity take off, automated schedule preparation, etc. This system is currently being implemented and will result in significant labor saving in document preparation as well as reducing errors and omissions. However, the lack of a direct link between ADABase and the primary CADD system will have to be overcome before the system can reach its full potential

Potential for Integrating 3-Dimensional Visualization Capabilities

Time and Labor Considerations

The primary draw back to integrating 3-dimensional capabilities into normal CADD operations is the time associated with the construction of 3-dimensional rather than 2-dimensional data sets. Without software enhancements, a simple 3-dimensional data set will require approximately twice the time needed to build a standard 2-dimensional drawing. For example, it would require approximately 8 hours, to construct a relatively detailed schematic 2-dimensional data set for a 1 to 1.5 mile section of divided highway with two simple diamond interchanges and direct overpass bridges. To build this same data set in 3-dimensions with the current Micro-Station tools, it would require approximately 16 hours.

In cases where complex alignments are involved, the times for developing a 3 dimensional data set can triple or quadruple. The time increases are a function of the need to construct the computer models point by point around complex curves with super elevated cross sections, such as those associated with interchange ramps.

However, both of these examples assume that no three dimensional data is available in the initial digital cartographic data or other data sets that precede the immediate operation. For example, the 1 to 1.5 mile divided highway scenario assumes that no existing grades are available in the cartographic base data. For this reason the operator will have to generate the base plane as well as the new grades associated with the highway section. On the other hand, if the cartographic data set had carried 3-dimensional information about existing conditions it would have resulted in a reduced time demand for the advanced planning operator.

Software Considerations

The basic tools necessary to build 3-dimensional data sets exists in the current Intergraph, Micro-Station environment. Therefore, it is not essential that other software

products be acquired to generate the 3-dimensional data sets.

The process of "Lofting" a 2-dimensional drawing into a 3-dimensional drawing is a routine, point by point, series of repetitive, operations. Because these tasks are repetitive they can be automated. Thus, it becomes a question of benefit/cost effectiveness with respect to the time and expense involved.

Thus the primary problem is that no software enhancements have been developed that will allow the existing software to be used more efficiently in developing 3-dimensional, rather than 2-dimensional, data sets. This same realization is what led to AASHTO's development of RDS and later IGRDS.

TASK 3: SUMMARY OF FINDINGS AND DESCRIPTION OF VISUALIZATION NEEDS

Introduction

The needs for visualization capabilities identified in the interviews and the subsequent relation of these needs to the existing resources of the Department are best related in terms of the division of tasks reflected in the Department's structure. These divisions are: Advanced Planning / Schematic Design, Right-of-Way, Design, Bridge Design, Maintenance and Operations, and Public Affairs. These six divisions encompass the primary units in which specific needs for visualization capabilities were identified.

We have noted that Construction is not included on this list. This is not an oversight; there was simply no evidence that construction personnel felt a significant need for visualization capabilities existed in their day-to-day activities. However, it is important to note that two resident engineers interviewed suggested that field communication with contractors and owners of adjacent properties would be enhanced during the construction

process by having access to visualization capabilities. These observations were unique to the Houston District, and since it was not suggested in other districts, it was not included in the overall list of needs.

Advanced Planning / Schematic Design

The advanced planning sections of the districts interviewed indicated that there were visualization needs in two areas, public education and evaluation of alternatives and aesthetic concerns.

Public Education

The most consistent and important need for visualization capabilities at this level of activity was in the area of public education. Every advanced planning section in every district interviewed indicated a need for better tools to communicate the impact of design proposals to the public. The problem is that highway structures have become more complex, which limits the utility of two-dimensional media to effectively communicate three-dimensional concepts. With the concerns of the adjacent property owners, local elected officials and special interest groups related to visibility, access and design impacts simply can not be effectively answered with plans-profiles sheets.

Evaluation of Alternatives and Aesthetic Concerns

An increasing concern, primarily with major urban projects, is with reaching consensus on an acceptable solution to a problem. These solutions, in an increasing number of cases, involve aesthetic and non-engineering related concerns which are not always the least expensive or most cost effective alternatives. With better visualization tools, there is a feeling that negotiations and deliberations could be handled in such a way that optimum solutions could be reached more quickly and with greater cost effectiveness.

Design

Design sections in the districts and at the Divisional level have indicated a need for visualization capabilities in two areas: Public Education and Design Evaluation.

Public Education

The need to maintain public contact is increasingly extending well into the design process. On numerous occasions design sections would begin by indicating that they had little contact with the public and upon further discussion would realize that an increasing amount of their time is being spent in public education activities. The primary difference between design section contact and that of advanced planning is that a greater percentage of the design sections time seems to be spent with education of elected officials and public employees. This is due to the contact necessary to work out specifics in construction sequences and details related to non-department structures and utilities.

Design Evaluation

The increasing complexity of multi-lane highway structures with their ramps, embankments, safety devices, guardrail, information standards and the like, often lead to inadvertent errors in geometric design. In many cases these are not oversights; they are simply the result of complex geometrics that fall outside the boundaries of existing geometric standards. Task 5 of this study is an illustration of such a condition. In this case it was demonstrated that the placement of standard safety barriers could limit SSD to the center line of a ramp even though the AASHTO standards for horizontal and vertical alignment were met. The only way to detect the deficiency was through the use of a three-dimensional graphic.

Bridge Design

The needs of the bridge design sections and the Bridge Division were essentially the same as for design. The most notable exception was the increased focus on bridge aesthetics. Clearly there is increasing public pressure for the Department to produce bridges with more architecturally pleasing characteristics. There was also a great deal of interest expressed by bridge design sections for better tools to evaluate bridge geometry and to identify possible alignment and clearance conflicts. However, the overwhelming need seemed to center on the issue of aesthetics.

Right-of-Way

The right-of-way sections of the districts interviewed all expressed immediate interest and expressed an overwhelming need for the development of visualization capabilities. The needs identified in this case were public education, special hearing and litigation support.

Public Education

The public education activities of the right-of-way sections is more of a one-on-one activity with individual property owners than that of the advance planning sections or design and bridge sections. In general the right-of-way engineers are dealing with single owners and the impacts on a single parcel. In these cases there is a need for flexibility and the ability to produce a variety of products quickly and at different levels of complexity. It is also important to note that right-of-way frequently deals with information beyond the immediate limits of the proposed right-of-way which is often not available in the topo maps from schematic design.

Special Hearings and Litigation Support

All forms of visualization technology are being used in special hearings and in

litigation proceedings brought against the Department and state. In many cases right-of-way staff recounted cases that the state lost due to the effectiveness of the visual simulation materials that were used by the plaintiff's attorneys. More importantly there were several cases mentioned where the staff felt that the representations used in court were incorrect but were still successful in influencing the final award from the jury. Clearly there is a need to develop a level of visualization technology in this area that will at least allow the Department personnel to answer the allegations being brought against the Department's proposals.

Maintenance and Operations

There were two primary areas of concern to maintenance and operations personnel: public education and safety.

Public Education

It was most interesting to note that need for public education carries well into the maintenance and operations functions of the Department. The primary difference in the activities at this level and at the design or planning levels is the need of institutional memory. People do not always remember the issues resolved ten years prior to a highway being put into operation. Likewise, there are often many changes during construction and in property ownership and landuse along a highway corridor over the period of construction. These changes often lead to questions or misunderstandings about what is or should be happening. These same concerns will often come back into play when major maintenance activities or projects are initiated. It was often suggested that if a good three-dimensional data base for the original project were available it would be very useful in exploring options as the environment of the highway corridor changes over the years.

Safety

Safety was the primary area of activity housed in maintenance operations where there

was a well defined application for visualization technology. Safety personnel indicated that the ability to do drive through studies of various signing, striping and other traffic control schemes would be most valuable. They also expressed a great deal of interest in the ability of the systems to deal with simulations of complex lighting and material reflectance problems.

Public Affairs

The primary function of the public affairs section in a district is public education. However, the actual activities of public affairs sections vary markedly with the personality of the district and political structure of the community served. Even though the difference between districts is marked, several general observations can be made. First there is a need for a wide variety of graphic products to support the public affairs mission in the districts that for the most part does not exist. This can be attributed in some cases to a lack of staff and in other cases to a lack of basic tools to accomplish the job. Overall the basic tools that support the other activities of the Department are generally inappropriate.

A second observation that is significant is the feeling that the proactive public affairs programs have been the most effective. That is, getting information out about construction sequences, new projects, closures, etc. have been very effective. In order to reach the highest level of effectiveness in these public affairs activities, there is a need to develop some unique, less expensive visualization capabilities.

TASK 4: BENEFIT COST ANALYSIS

After reviewing all of the findings it became clear that the potential for use of 3-dimensional data files far exceeded any early expectations. In short 3-dimensional data files seem to have applications in practically every operational unit of the Department. For this reason the demonstration of application(s) became secondary to the question of how much the Department might benefit by adopting a three dimensional graphics environment. Thus Task 4 was redirected to see if a positive benefit cost relationship existed.

Assumptions

In developing the benefit cost analysis the following assumptions are made.

1. **Hardware Costs:** The hardware costs to implement a three dimensional graphics working environment are negligible. The basic Intergraph hardware used by the Department are sufficiently powerful to develop 3-dimensional data bases with no additional cost.
2. **Software Costs:** The Intergraph, MicroStation 32 and IGRDS software currently used by the Department are sufficient to produce primary 3-dimensional data sets. One or two add-on packages may be desirable to provided to each district to accomplish rendering tasks. TTI's current work suggests that these tasks can also be accomplished by in-house improvements to IGRDS and the use of public domain rendering packages at no additional cost.
3. **Training Costs:** Existing CADD operators have the basic skills necessary to develop three dimensional data sets and use of three dimensional tools is already a part of D-19's basic training package. At this writing D-19 is developing more specialized training modules to assist operators in the use advanced 3-dimensional functions of MicroStation 32. Thus there would be little in the way of additional training cost over current 2-dimensional training.

Costs Considered

Labor is the primary consideration in developing the cost side of the equation. The cost increments are considered for the following areas of activity:

1. Aerial Photogrammetry and Mapping The cost increment for the development of 3-dimensional topographic materials or "Digital Terrain Models" (DTMs). These materials would provide the base for building 3-dimensional design schematics and right-of-way maps.
2. Lofting Schematics and Maps The cost increment for preparing 3-dimensional materials over the current practice of preparing 2-dimensional materials. The cost increment assumes using available software, intergraph micro-station and IGRDS, with enhancements to affect the 3-dimensional translation. No consideration is given to the use of more efficient 3-dimensional software.

3. Preparation of 3-Dimensional Design Data The cost increment of lofting conventional plan-profile materials into 3-dimensional data sets. The cost increment assumes using available software, intergraph micro-station and IGRDS, with enhancements to affect the 3-dimensional translation. No consideration is given to the use of more efficient 3-dimensional software.

Clearly there can be costs variations related to the complexity of corridors and the level of detail desired at the edge and off the right-of-way. However, once the detailed design data set is in place most of the costs associated with working in 3-dimensions will have been incurred. Likewise, in current practice little information is added to a data base by other operating units after a project is constructed.

Derivation of Costs

For this study the base cost "Cost" will be computed by using an estimated cost increment for developing a 3-dimensional data set over the conventional 2-dimensional data set for each of the tasks outlined above. The cost increments will be added to the actual costs for project development on two sample highway corridors, US-59 and IH-45, District-12, from IH-610 north to Beltway 8. The projects included for IH-45 are: 011004140, 011004142, 011005075, 011005076, 011005078, 011005079, 050001102, 050001105, 050003442, 050003443, 050004080. The projects included for the US-59 corridor are: 002712075, 0027113155, 008909053, 017705066, 0177005067, 017706058, 017707057, 017707074, 017707077, 017707088, 017707092, 017707093, 017711126. Since the costs for corridors such as these share costs across various function codes, the totals under each function code are shown as a single value.

Cost Variables

The cost variables are based on a simple percentage increment in cost assessed to each activity that would incur costs as the result of working in a 3-dimensional environment. These would generally be the operations that use the IGRDS system in their duties.

100 Series, Preliminary Engineering

110 Route and Design Studies (Cost)

This function code includes costs for: route location studies, traffic evaluations and projections, design criteria, preliminary cost estimates, design schematics, preliminary right-of-way requirement, design concept conference, phase and soil testing, and core drilling.

Since this activity includes cost incurred for design schematics and preliminary estimates, the move to a 3-dimensional environment will result in a net increase in labor costs for plan preparation. Using minor software enhancements and existing technology, experience suggests that the increase is about three percent (3%), over the cost of conventional 2-dimensional methods.

$$110:RouteDesignStudies \times 3\% = NetCostIncrease$$

130 Right-of-Way Data (Cost)

This function Code includes: acquisition of ownership data, ROW map, utility locations/layout, field notes, property ties - boundary data, and stake ROW.

Right-of-Way mapping will experience some increase in costs in conjunction with the preparation of exhibits for reviews with owners, special hearings and court cases. However, having 3-dimensional media in the form of DTMs available from the early surveys will serve to limit the overhead costs. Assuming that most right-of-way mapping in smaller and rural districts will continue in the traditional form, the cost increases should be modest. However, in major urban centers where 3-dimensional graphics will likely be necessary for a majority of the work more substantial increases should be expected. The estimates used reflect the

heaviest cost increases which are estimated to be about five percent (5%), greater than current costs.

$$130:ROWData \times 5\% = NetCostROWData$$

150 Field Surveying and Photogrammetry (Cost)

Field Surveying and Photogrammetry establish control lines, establish benchmarks, controlled photography, topographic - planimetric mapping, establish original cross-sections and profiles, survey contracts, survey work by department personnel or consultant in support of or for other preliminary engineering function codes except for FC-130 ROW data.

The process of developing DTM's is being progressively automated. At this time the Department has state-of-the-Art equipment and software for developing DTMs. Because of the capabilities there will be no direct cost in flying the imagery; the cost are only related to building the full x,y,z data set. It is estimated that for the average urban project it would increase the mapping costs by three percent (3%) initially. There is some speculation that after converting to a 3-dimensional environment throughout, there might actually be a reduction in the overall mapping costs. However, there is not sufficient experience with these media to show the outcome as a cost reduction with any degree of confidence.

$$150:FieldSurvey/Photogrammetry \times 3\% = NetCostFieldSurvey/Photogrammetry$$

160 and 163 Road Design Controls (Cost)

This function code includes costs for all: roadway design controls (computations and drafting), geometric design, horizontal alignment and vertical alignment.

This is the activity code that carries the primary activities associated with the production of graphic products. At this time this work is accomplished using the IGRDS system as noted in earlier discussion. Based on direct experience with complex urban projects the development of a 3-dimensional data set for a project would result in a three percent (3%) increase in overall costs. This does assume using some software enhancements to the existing IGRDS and MicroStation systems. While this may seem to be low at first it must be remembered that this estimate assumes that the designer would be working from 3-dimensional schematics and field survey information.

$$160:\textit{RoadwayDesignControls}\times 3\% = \textit{NetCostRoadwayDesignControls}$$

170 Bridge Design (Cost)

This function code includes all costs for: preliminary studies and layouts, foundation studies, detailed design and drafting and bridge inspection.

The time and associated cost increases for Bridge Design are related to data base construction for structures in a 3-dimensional environment. Unlike other parts of the process, bridges do require more time to build and reflect the highest increase in labor cost. Based on direct experience with complex urban projects, the development of a 3-dimensional data set for a complex bridge would result in a six percent (6%) increase in overall costs. This does assume using some software enhancements to the existing IGRDS and MicroStation systems.

$$170:\textit{BridgeDesign}\times 6\% = \textit{NetCostBridgeDesign}$$

The Cost Equation

Thus the estimated total cost for working in 3-dimensional environment can be expressed as:

$$C_{3D} = \sum C_n$$

Cost Relationship

Where:

C_{3D} = The total estimated cost for working in a 3-dimensional environment.

C_n = The "Escalated Function Code Value" for services for selected function codes.

Derivation of Benefits

The dollar value of benefits to be accrued from working in a 3-dimensional environment are primarily related to savings that will be derived from reduced labor costs associated with design communication activities or from reduced costs associated with Right-of-Way acquisition.

Design communication is cyclical and occurs through the entire process of advanced planning and schematic design through preparation of final P.S. & E. At each step in this process there was overwhelming consensus that 3-dimensional capabilities would be of great value and would result in some savings of time and confusion in moving toward the final contract documents. The actual savings would of course vary from task to task. For example, the potential savings from the use of 3-dimensional drawings to check plans for

conflicts in structural elements on a complex interchange would likely be small compared to the time and labor savings that might accrue from having good 3-dimensional graphic products available for public hearings on controversial projects.

The savings on right-of-way acquisition would accrue from being able to secure more favorable judgements from special commissioners courts and awards in trial litigation. The use of video and computer generated imagery is quite common in court and special commission hearings. When it is used, the evidence suggests that awards are substantially increased. However, recent work with the Houston District suggests that the ability to produce high quality, mathematically accurate representations of projects can be effective in minimizing cost over-runs.

Benefit Variables

Placing dollar values on benefits is subjective but there are some function codes where it is reasonable to expect some cost reductions. In this case the following codes were selected as likely to have some measurable benefit accrue by having 3-dimensional information available through out the project development process.

120 Social, Economic and Environmental Studies and Public Involvement (Benefit)

The availability or desire to have 3-dimensional media in all 120 activities was identified by department personnel in every district visited. Without exception it was believed that communication to outside agency reviewers such as Texas Parks and Wildlife, EPA, FHWA and others would be reduced and simplified in most cases. Thus there should be a direct labor saving in this area. Keeping in mind that three dimensional products would have to be produced and thus have some costs associated with the production of these media, a benefit of only three percent was used for this function code.

120:Social/Economic/EnvironmentalStudiesx3% = NetBenefitSocial/Economic/Environmental

180 District Design Review and Processing (Benefit)

There was not unanimous agreement among the districts on the benefits of having 3-dimensional media available to engineers in the design review process. However, as the interviews progressed and more departmental interchange occurred over the course of the year it seems that enthusiasm for the possibility grew. The agreement to value was almost unanimous when the design engineers realized that they would not have bear the overhead to generate the entire 3-dimensional data base and that there would likely be some savings in having a better, more finished product from the schematic design phase of the work. Because the greatest benefits under this item would likely be most closely related to savings in the construction period, a conservative figure of five percent (5%) was suggested for this code.

180:DistrictDesignReviewx5% = NetBenefitDistrictDesignReview

181, 182, 183 Austin Office Processing (Benefit)

This code includes the costs for project review in Austin. The differences are related to who prepares the drawings, the department, consultants or bridge design consultants. It is suggested that the review process will be enhanced and some labor savings will result by having access to 3-dimensional graphics. This is particularly important on complex urban sections when it may require a substantial amount of time to understand a proposal from traditional 2-dimensional media. In this case the savings would be slightly more than those at the district level review process, or about seven percent (7%).

400 Parcel Acquisition Cost (Benefit)

$$181-3: \text{AustinOfficeProcessing} \times 7\% = \text{NetBenefitAustinOfficeProcessing}$$

It is anticipated that this area will contribute the most significant monetary benefit. It was very clear during the field investigation that the costs of right-of-way acquisition associated with awards from special hearings and jury trials have escalated. Along with this increased cost there are the associated costs for staff time and labor. To derive the benefit value the Assessed Valuation for the parcels is subtracted from the Parcel Cost to obtain the "Gross Benefit." The other parcel costs are incremented by a factor of ten percent and subtracted from the "Gross Benefits" to obtain the "Net Benefit."

$$\text{ParcelCost} - \text{AssessedValuation} = \text{GrossBenefit}$$

$$\text{GrossBenefit} - (\text{OtherParcelCosts} \times 10\%) = \text{NetBenefit}$$

The Benefit Equation

Thus the estimated total benefits for working in 3-dimensional environment can be expressed as:

$$B_{3D} = \sum B_n$$

Cost Relationship

Where:

B_{3D} = The total estimated benefit value for working in a 3-dimensional environment.

B_n = The estimated value of benefits for the selected function codes.

Tabulation of Costs and Benefit Values

The costs of working in a 3-dimensional environment for the selected study area are shown in Figure 2. Figure 3 is a tabulation of the benefit values that would be anticipated from working in a 3-dimensional environment.

Figure 2 TABULATION OF COSTS FOR IH-45 AND U.S. 59 CORRIDORS

U.S. 59 Corridor from Loop 610 North, North to Beltway 8					
Function Code	Actual Cost	Escalation %	Cost Increase	Projected Cost	Average % Increase
110: Route and Design Studies	\$202,525	3%	\$6,076	\$208,601	
130: Right-of-Way Data Acquisition	\$97,941	5%	\$4,897	\$102,838	
150: Field Survey and Photogrammetry	\$361,305	3%	\$10,839	\$372,144	
160 and 163: Road Design and Control	\$1,525,848	3%	\$45,775	\$1,571,623	
170: Bridge Design	\$470,075	6%	\$28,205	\$498,280	
Totals	\$2,657,694		\$95,792	\$2,753,486	3.60%
IH-45 Corridor from Loop 610 North, North to Beltway 8					
Function Code	Actual Cost	Escalation %		Projected Cost	
110: Route and Design Studies	\$27,896	3%	\$837	\$28,733	
130: Right-of-Way Data Acquisition	\$2,278	5%	\$114	\$2,392	
150: Field Survey and Photogrammetry	\$13,692	3%	\$411	\$14,103	
160 and 163: Road Design and Control	\$249,951	3%	\$7,499	\$257,450	
170: Bridge Design	\$53,144	6%	\$3,189	\$56,333	
Totals	\$346,961		\$12,049	\$359,010	3.47%
Total Both Projects	\$3,004,655		\$107,841	\$3,112,496	3.59%

Figure 3 TABULATION OF BENEFITS FOR IH-45 AND U.S. 59 CORRIDORS

Benefit Calculation: U.S. 59 North from Intersection of Loop 610 North, North to Beltway 8						
Function Code	Actual Cost or Parcel Costs	Assessed Value of Parcels	Other Parcel Costs	Other Parcel Costs + 10%	% Decrease	Benefit Value
120: Social, Economic and Environmental Studies	\$3,876				3%	\$116
180: District Design Review	\$71,174				5%	\$3,559
181-3: Austin Design Review	\$37,707				7%	\$2,639
400: Right-of-Way Acquisition	\$44,424,632	\$34,851,698	\$3,891,860	\$4,281,046		\$5,291,888
Total						\$5,298,202
Benefit Calculation IH-45 Corridor from Loop 610 North, North to Beltway 8						
120: Social, Economic and Environmental Studies	\$1,036				3%	\$31
180: District Design Review	\$17,769				5%	\$888
181-3: Austin Design Review	\$10,540				7%	\$738
400: Right-of-Way Acquisition	\$14,941,500	\$10,938,828	\$771,249	\$848,374		\$3,154,298
Totals						\$3,155,955
Total Both Corridors						\$8,454,158

Benefit : Cost Ratio

$$\frac{\text{Benefits: \$8,454,158}}{\text{Costs: \$3,112,496}} = 2.7$$

The 2.7 benefit to cost ratio would argue in favor of moving toward a 3-dimensional working environment. However, the single factor that pushes the ratio into the positive range is the dramatic savings estimated for right-of-way acquisition. If the estimated right-of-way savings were totally dropped from consideration the ratio would drop to less than 0.1. Even though it was felt that the estimated savings of ten percent of the adjusted award amount was reasonable, it must be viewed with caution since it cannot be supported by any real evidence. If a five percent savings is realized for right-of-way acquisition, the benefit to cost ratio remains positive at 1.5. At a savings of 3.2 percent on acquisition of right-of-way, the benefit to cost ratio would reach unity.

TASK 5: A 3-DIMENSIONAL ANALYSIS OF SIGHT DISTANCE ON INTERCHANGE RAMPS AND CONNECTORS

As an additional means of evaluating the possible benefit of using 3-dimensional media in design, a fifth task was added to the project. The study conducted was done independently of the body of the project as a masters thesis.

The hypothesis of the thesis project was that the AASHTO standards for horizontal and vertical alignment could be applied but fail to meet sight distance requirements for safe stopping distance on interchange connector ramps with tight, complex geometries. The project was completed by constructing a series of 3-dimensional data sets for existing interchange ramps. These were then checked by generating eye-level perspectives to determine if a six inch obstacle could be seen per the AASHTO guidelines.

The study demonstrated that there were conflicts in some cases where the super-elevated geometry coupled with barriers at the edge of the driving lane could reduce the safe

stopping distance visibility below recommended minimums. The study also made some detailed recommendations about how to avoid these conditions when using conventional 2-dimensional media. Copies of the conclusions section have been reproduced and included as an Appendix B to the report.

CONCLUSIONS

Given the limited scope of the benefit to cost evaluation and the lack of a good means to operationalize the benefits attributed to the right-of-way acquisition, it is difficult to make a strong case for moving toward a 3-dimensional working environment on the basis of the benefit cost analysis alone. However, there are numerous other benefits noted from the survey. These include uses such as: public participation support, public information, construction support and traffic safety support. Together these constitute a considerable source of demand for 3-dimensional information and graphic products which there was simply no way to consider within the limited scope of the current project. Overall the conclusions can be summed up by the following points:

- The use and value of a 3-dimensional data base would extend far beyond the perceived limits of planning, right-of-way and design. There would be uses for the 3-dimensional information well into the construction and maintenance and operations cycles.
- The availability of 3-dimensional data bases enfranchises and supports a broad spectrum of professionals within the Department. Having 3-dimensional data available, a wider variety of graphic products can be produced for use by other disciplines not necessarily trained to use or understand conventional 2-dimensional media.
- The availability of 3-dimensional data can be useful in solving complex questions of geometry which cannot be handled by simple rules developed in 2-dimensional media. See the sight distance study summary in the Appendix B.
- 3-Dimensional media would be used if it was available in a variety of ways through out the department.

- The availability of 3-dimensional media could potentially result in a significant saving in the acquisition of right-of-way. The potential saving on right-of-way will likely increase because much of the need for new right-of-way is within urban centers where land and property values will continue to rise adjacent to existing highway corridors.

Given the continued development of 3-dimensional software and intuitive user-friendly interfaces, and the continued increase in computational power and speed, it is believed that the 3-dimensional environment will be the design environment of choice within the decade. On the other hand, the question of when and how to accomplish a full switch must be considered carefully.

Recommendation

The photogrammetry section of the Automation Division currently collects sufficient data to develop digital terrain models which is the logical first step in developing a three-dimensional data base for any project. Discussions with personnel in the photogrammetry section have indicated that developing these digital materials is possible now and that the cost of doing so would be negligible from their perspective.

The next organizational units in the project development process are the "Advanced Planning" units of the districts. These are the units that select the corridors and work out the broad scope design parameters. These are also the units that have the greatest contact with the public and local governmental units where, the study suggests, there is a strong demand for the communication capabilities offered by 3-dimensional tools.

From the Advance Planning sections the work becomes more subdivided. That is, responsibilities for the detailed work necessary to affect construction are spread among three different sections: Right-of-Way, Bridge Design and Design. Within each of these units there are needs for the 3-dimensional materials but they tend to be more specialized and much less predictable.

For these reasons it seems most logical to the representatives of the Department and TTI to begin implementation of the 3-dimensional working environment in the Advanced Planning units of the larger districts of the state. As noted there has already been some development of the capability in the Houston district and the Dallas and Austin districts have placed requests for additional equipment that will support such an effort.

Implementation would begin by targeting major projects which will have significant public scrutiny and where it can be determined that there will be a need for enhanced communication materials. Later as projects move into the more detailed stages of development more detailed 3-dimensional data sets can be developed as needs arise.

Specific recommendations for implementation with respect to equipment, software enhancements and operational procedures are beyond the scope of this report. Any mention of the hardware, hardware configurations, software versions and enhancements would be quickly dated and of little value. What is important is that the Department begin utilizing 3-dimensional media in a way that extends the information generated in this study.

Recommendation for Further Study:

The Department may find it to their benefit to track some of the current implementation efforts currently underway in Dallas, Austin and Houston. Things that it would be helpful to monitor would include: labor costs associated with building 3-dimensional data sets, improvements in employee productivity building 3-dimensional materials over time, public reception of the graphic products, internal requests for 3-dimensional products and relative use of the 3-dimensional products in relation to traditional 2-dimensional products.

It may also be advantageous to further operationalize the benefit to cost study to include a larger data set and to track the data over the early stages of implementation. This would be particularly interesting in relation to understanding the value of the 3-dimensional

materials in public forums and contested right-of-way acquisitions.

Appendix A

Austin:

Stacey Benningfield

Russel Lenz

Right-of-way

Who

Right of Way - Jury (Bonnie Lockhart)

Design - Neighborhood Association

City Council

Public

Products

2 dimensions plan sheets

right-of-way map

For pretrial the attorney normal knows about 3 to 4 months before the trial

Media

There needs to be an underlying theme for everything you do and needs to be generated in terms even if you look at it from designer terms or planning terms. Nine times out of ten we are going to be showing a video to neighborhood association, public meeting and hearings. Needs to be generated so that it is not high technology.(Design) The way we handle public hearings is that our office handles all the introduction and all the comments. The technology part of it is, presented by each part of the design that is in charge of that project. The engineers terms are hard for the people in court to understand without the use of good pictures.

Austin:
Tom Word
Debbie Pitts
Right-of-way

Who

Right-of-way: appraisers, landowners, jury
Debbie: media, large groups

Products

Slides of projects
schematics
Aerial photographs

Media

Will do two schematics one on a graphic file and for public hearing which is for visual use but not as accurate. Will use the schematic from the public hearing for a introduction of a project and for cross-section. Been lucky on some projects that the contractors have developed 3 dimension models for their selves. Have borrowed these models and used them in some cases. Right-of-way is using the right-of-way maps and schematics. Animation won't be as helpful to us as would be a paint process over a video camera where you could show what it is going to look like. (Debbie) Need something that will show the roadway and on the intersection that has labels on them. We either don't have time or the computer graphic program. We need any kind of graphics. Animation would be good for anything that would give us a visual idea. Videos would also be useful. (Tom) Our problem is one in which the cost which it takes to produce a product. We use to make a lot of visual models but we quit because of the man power it took to do it. It wasn't worth doing but for a few special cases. The direction that we are looking toward now is not to move toward physical models but to move toward technology. The physical models have some advantages that you can show how it relates to something else such as a baseball field that is a block away. There are few projects that we would use three dimensions. Looking at 25% of the total projects using the three dimensions. A lot of what we do now is that people sit down with a piece of paper and draw lines and come up with 15 variations and then someone sits down and wants to try one. It is a lot of trying to visualize and when you start drawing we see that it won't work. This is were we lose 50 hours of work that is 3 dimensions to start with.

Austin
Randall Dillard
Tara Blecker

Who

Court cases
Public hearings
External
Printing Media
Tom handles the city council presentation
Business Groups

Products

Schematics plan
At least two weeks

Media

(Public Affairs) Needs more graphics that can be used to show people visuals. A still image would do good for us. Would be easier for us to explain to people if we had more than a flat schematic to show them what it will look like. Pictures will be good so we could set up a display and leave it for us. Videos would be the best. Some of these things can be used earlier in the planning process and then as we are through with us in the hearings and then maybe we can use them. Now we are just using what we got and if someone else has something we can use we use it. Models are expensive to build but if we could have built a model back in 1978 for the public hearings and now if we had that model that we could have used for ten years now to show off what that project will look like. The advantage of a model is that we can stand there and look at it and not have everything explained to them. We would understand the photo images as well as we would understand a model. (Tara) Photograph overlay would be good for us in court cases. If we could visualize the different options maybe we could see what would work better for that area. This may help the engineers make their decisions quicker. Having problems working with other groups trying to coordinate the two projects that were not all done in the same office.

Austin
Cal Newnam
Elizabeth Hilton

Who

Elizabeth- public, district division staff, attorneys
Cal- Internal agencies, Parks and Wildlife

Products

Schematics drawings, 2 dimensions plan layouts
Aerial photographs

Media

Photos are superimposed. Never dealt with 3 dimensions. Cal does stuff for court as for as producing it. Right-of-way is becoming a major problem. Superimposed photos would be best for public hearing. Don't really think that the animations one would help us very much. It is more representative to look at something that you are familiar with. Videos could help with the realistic. For the projects we have one workstation. For helping us during design, don't think it would help us decide what to build. After we decide it will help us with the planning part. Hard part for us is showing a picture of what we plan to do.

Austin
Becky Hall
Joe Tejidor

Who
Public, attorney, city council

Products

live video
Photograph

Media

Visibility is where we are losing our cases at. The closer we can get to realistic the better it will be for us. Want to make things look real. Cost is so expensive for the cases. Technology has grown in the past few years. Right-of-way for courts tries to have time to do our work on whatever we are doing. We feel that we can justify a machine to keep someone working on that unit at all times but it is then debatable from there if we have large projects we need more operators. Doing some 3 dimension training now. We can do model training. Takes a lot longer to do a project in 3 dimensions. People want to know what it will look like. We have a push on things we do because we are environmental.

Houston
Central Design and Bridge

Who

Public

Hearings in Courts been doing it for 2 years
Designer answers question in court
Lack of exhibits in the hearings
Exhibits show two dimensions drawings

Product

Copy of the right-of-way map with shaded areas to take into court
AG's has a certain amount of time for every case
Uses pictures and videos in court hearings

Media

In hearings, if we present ourselves well we will get more money. Fancy videos wouldn't make a difference but if it went to a grand jury it would make a difference because a private citizen is listening to both sides to make a decision. Design involvement is going to continue as long as we are turning the larger volume in plan production as we are in putting as much up in contracts in the short period of time as we are and the demand to the right-of-way. Needs a person knowledgeable of design to appear in the hearings to explain details and answer questions to defend ourselves. Three engineers for the months of January and February and have 2 to 3 trials a week. 20 to 30 people in each section working on 3 projects at a time, all projects are major and require right-of-way. We don't prepare the exhibits, right-of-way does, 3 to 4 hours to get drawings together and to color if needed. Advance planning should be developed in three dimensions.

Houston
PAO and Schematic Design

Who

Public- has direct questions and normally answered by a fax sheet
City Council- we want just the details to be dangerous
Media- asks every single question we can think of, want videos

Products

Handouts
Schematics and Cross Section
Build Models

Media

In public meetings and public hearings we never have a document that the public can walk away with. Don't give handouts with graphics displays. The media liked the pictures of the places that had the before and after pictures displayed. In public meeting didn't show the 3 dimensions animation because the only people who understand is us. Hard to slow it down for other people to understand. Understood the still real well. When going to the public hearings we will show the animation. Technology is there, it is the speed. Working on redesigning all the interchanges around 610. Looking in detail on the North freeway and North Loop. Will start with 3 dimensions. Time and staff would stop us from starting this. We need hard working software. Animation is the best thing but the speed of the computer needs to be faster for the processing part. Every project that is done we have a graphic, but a simple graphic. Don't do schematics on a farm road that is two lanes and that we will be turning it into four lanes. We use a paint brush method which is easier to use. Environmental system does all the projects and call on people in the schematics design to prepare them a cross-section. Environmental does just about everything but the most simple maintenance project. And use schematics on the more complex. For the larger projects, start in the schematics stage and building a 3 dimensions base. Can add details where there are problems. Three-and-a-half miles took about two months. Using 2 dimensions it takes four weeks instead of one week. Using the model 3 and then goes to the 2 dimensions as well. Even though it is 3 dimensions outline or frame the accuracy that the mathematic model needs to produce it. You don't need that accuracy that some of the sub-routine needs. Want something that looks proportional. Most of the options are based on environmental systems. Most of the options are made at the design level. Are forced to make more and more material decisions. Every time before a public meeting we send registered letters to all elected officials in the court from the national level down to the local level and invite them to come out and view the thing before we go to court. The more that we can adapt from what we

are doing to get them to a level of comprehensive the public will accept the better off we are going to be. The public is putting more and more demand on our department to bring it to their level. The worst thing that we have to do is doing city and in-county projects. It is the worst thing to do from a environmental standpoint. People who come to public hearings go into several categories. People who want to know what is going to happen to their property and people who want to visualize what it will look like after it is finished. We should direct our information to the people who are interested. Nothing comes out of the hearings we don't want to hear. Environmental issues say what are you going to do. From a public affairs stand point I can see parts of what we are doing that I can take and do it my own way. I don't need all that hard core detail. But what we are generating I can take and with my own equipment I can take digital information and paint whatever I want. We do have paint equipment and learning more about it now. Also have a microstation and pagemaker. The problem is the difference in software. The budget for the public involvement is coming out of the engineer's budget.

Houston
Safety and Traffic Design

Who

Product

Computer programs
Models

Media

Most of the time in court the people think something is wrong and we prove different. Since 1985 we have had 570 cases and lost 19. Have had a lot of construction planning involving us and the contractors. We have inspectors with video cameras. Have no set time limit when people walk in with something to do.

Houston
Maintenance and Resident Engineers

Who

Dennis- to develop a package to go through the Highway Department system to go to contracts, working on 2 to 3 jobs with him now, and using videos

Internal

Public

Products

videos

graphics

Media

Video works really good, can stop motion on it and decide what dimension. Then take it off and go back to graphics to develop some kind of frame work so we can locate the problems to tell the contractors where to go and what to fix. Using the scanning to get a really good turn out of what the updated image of the road will look like. Sometimes scan and sometimes use electronic information from the District. For current information we get that from photographs. If we had some way of taking a photograph and a digital thing to produce a current definition of what it is that is reproducible could promise some action. Take a video image and convert it to a digital, then it could be printed out and plot a reproducible stress pattern of a section of a freeway. If you could take some of the photographs and turn it into a digital mapping. In the future we are talking airborne GPS which means anytime we click the shutter on the camera we will also record the next two dimensions. Accuracy of one and one thousand. Maintenance projects don't have to be accurate, you're not building the thing, you're making a repair. Could deal with a lot of the problems if we could get a photograph and turn it into a image to be put on a machine. Some people are using aerial photographs, scan aerial photographs to do digitizing. Having colors in the drawing in court impress the jury. Can do a live video on a closed road but will never be just like the real thing at the same location. This allows us to take that information and put it on video. Can take crash test and super impose the live vehicle on the road way.

Houston
ROW

Who

Products

Pictures and Hard Copies

Media

Trying to get approved right now a contract agreement between us and the department of internal office for other things besides graphics. Has no defence in court when it comes to graphics. Armando is the closest we got. He is doing more for the public hearing audience than the jury trials, focus on showing them what the front of the property is. We have been left out because we don't have graphics. We borrow from animation to view a quick two dimension exhibit. We are doing 20 to 30 hearings a month. Will have a fulltime graphic operator. Using a graphic operator from animation 80 percent of the time to do 2 dimensions exhibits. The graphic operator will be busy and hopefully work us into the 3 dimensions which may require another graphic operator to keep up with the 2 dimensions. At the administration hearing level there are no rules. The court has appointed three people to act as commissioners. There is no judge in the room. You can use anything in there. We are having 20 to 30 of these hearings a month. The jury trials are years later. We need to prove that our appraiser is fully aware of all that is going on out there. If we are able to produce a product that is superior and more accurate than theirs, then the jury never see theirs. The hardware is going to take awhile. Can have the software there from them to use if we can have the work station. This would get us started. Don't think that it is a waste of time in the public hearings but it can pay for itself quickly.

Houston
Resident Engineers

Who

Public

Product

Graphics
Uses video cameras very little

Media

Most of our work in the design area deals with the maintenance type projects , small widening projects, and we get into some of the major projects. On FM1960 we had to go out and do a lot of presentation to the associate to let them know what we are doing. Took Armando about a month to feel good about using the 3 dimensions. Because of the residence environment where our contracts go for three years and our design work is short term rather than long term. It would be tough to justify those costs over the long period of time. If there was a group like our advance planning or right-of-way group where if we needed some assistance we could go there. It would be the thing to set up right now.

Dallas
Lina Ramey
Brian Barth
Manny Abola

Who

Public

Products

Plan Sheet
two weeks to prepare

Media

Would very likely never produce anything but the standard PJS. When it gets down to us all it is is the designing project. All of the major decision have been made. It helps us to see something in 3 dimensions. Some schematics we get, they can't be done. Also find at least one conflict in every project. We could show more with 3 dimensions. We are able to find problems ourselves before it gets to the public. Designs starts with advance planning they do all the studies and then it comes to us. We take all the schematics and do all the final work. When it gets to us this is where all the design work is done. After this, then to construction. Bridge is working with us in the design stage. We are not very aware of the projects that we are going to get. If any changes are made in construction they will be returned to us also. The video and overlay would be useful. Three dimensions models would be good. It would help us knowing what it would look like later. If it was there we would use it. Would be helpful when designing horizontal and vertical lining and traffic control. We want to see our options not just one model. We have as much as we need to make changes. There are times that we get involved in parts of the advance planning in things that they have overlooked where corrections are necessary. Hard copies would be good because it would let people see what it will look like. At PJS there are levels of software and DOTS plotter.

Dallas
Sandy Wesch-Scholze
Matthew Holboke

Who

Homeowners, citizens, local government, businesses

Products

Schematics- hard to explain to people so they will understand
Artist in the regional planning office does some work for us
Have about 2 weeks to get ready for a meeting
For bigger projects we have 2 to 3 months

Media

Before we go to the public involvement we go to the local government with the work. Normally at our meetings we display plan sheets. Don't use videos very much just on some projects in which we hire it to be done. We produce graphics for meetings. Normally involved in a project for 2 to 20 years. For a project we request traffic, aerial photography, and graphics for a project. We sit down in a meeting with everyone involved. After this we go back and try to design a project doing environment documentation as we go. So we can see what will work and not work. We go through scoping and then to the schematics stages. A problem we have is when we are ready to go to local government there is normally five local governments wanting something different. About the animation, there are things that we don't know about drawing. We would rather go to public meetings with photographs rather than schematics. The more people can visualize the better things are for us.

Dallas
Charlie Myers
Kelley Karrenbrock
Laura Moore

Who

Public, city groups and council, media

Products

Slides

2 weeks to prepare

Media

We make a lot of presentation. If we could provide a tape for the media, it would be great for us. We do a lot of slides. Slides are drawn from maps and we add color. We do graphics and line art. We have the project person submit any information that they can find (slides, plans, aerial photographs). We are just now getting into video. We have sent some people to do videos and start training. But we have not done our first production with it. We are trying to move toward video overlay. Need things that will help people understand what is going on. Visualizing is a problem for people.

Dallas
H. Stan Hall
Wallace Heimer
Terry May
Travis Henderson

Who

local government officials, private citizens, internal

Products

Schematics, plan sheets
To get exhibits ready we have 2 months
6 months to get ready for big projects

Media

We provide all the presentation. We provide 2 dimensions plan sheets and profiles. Exhibits are being used very little. We get information from talking to each section. The more facts and truth we can show the better we look in court. Need something to show the people what it will look like (examples). Exhibits for commissioners hearings are much less formal then jury trials. In jury trials we have to point out everything and be very formal. We have had about 150 commissioner's trials.

Dallas
Jim Reiser
Kim Carroll

Who

Contractors
Local government

Products

two dimensions plans
black and white plan drawings

Media

We put together plans for contractors. In complex situation the black and white plan drawing may not be the best. We let the public works department go over the final work. We do a lot of steps in between the final plan. One is comparing the bridge layout. We have to give all the information we have, vertical and horizontal, to the bridge station. We are now leaning more toward graphics. Twice a month we have to make graphics. Sometimes we have the graphics but we have to do work on it. Would like the three dimension models for major interchanges. We conduct our survey information from surveys crews. Sometimes we just go out to look at a place without the survey crew. That is done just to help us out. Engineer overlooks the area of sequences of work. We have good technology now to get by with what we need. If we could use the three dimension on some projects but not all projects would it be good. We produce plans for contractors in two dimension. We are always changing software. We don't do any model building now. Three dimensions would be good if it isn't too complex as far as training someone.

Dallas
Barbara Shamburger
Phil Ullman
Van McElroy

Who

ROW- city , public, individual property owners
Bridge- public
planning- public, city, property owners

Products

Right-of-way maps
very little models
profile sheets
photographs

Media

Showing people what a place would look like after all the work has been done would be good. We are just now starting the training of the three dimensions animation modeling. We don't have "what if" exhibits but it is a good idea to have in the right-of-way section. We try to show and explain to property owners what a place will look like. We produce graphics materials once a month in planning. The time it takes to do a project varies from a few days to a year. It depends on the amount of time we have. For a public hearing we normally know two months ahead. For meetings it varies from two weeks to two months.

Fort Worth
Group #1

Who

community, public, property owners, and media

Products

right-of-way maps with plan view
video camera
graphics, photos

Media

At a start of a project we go out and video the property and later on if we can't remember something it will save us a trip to the field. And people who know the place can show it to other staff workers and it will help with doing the right-of-way maps. We use some of the videos in jury trails. We can't explain something unless we have photos. Line drawing would be simple but we just don't have time. Our regional planning office is trying to help do some of this work. But our newspaper people want graphics. Putting things in the newspaper helps us because it limits questions from the public. For the media a size of 8 1/2 by 11 would be fine but for a presentation something larger would be needed. We send information to media and go talk to groups to get things out to the public. The information getting out early has saved us a lot of problems. We have about six months to get graphics ready. We have a few weeks to prepare schematics. To prepare for a public meeting we have a few weeks to prepare. We just keep things on file for each project and some of the information can be used over and over. By seeing things graphically on video in some situations, people lose the ability to visualize the drawing. We have a 35mm slidemaker that is on the network. It is easier to find something in a model so I think this technology would help the traffic engineer.

Fort Worth
Group #2

Who

public, city, individuals

Products

profile sheet

Media

We recommend for people to use similar type projects and use materials for them. We have public meeting, public hearings, and people come to our office. It would be nice if we had stuff like this (items you have). We have artist do some work. Most of the time we just illustrate what it will look like and we have a hard time getting the idea to the artist that is doing the work. Some people feel if they can't read a drawing that we don't know what we are doing either. We have a hard time convincing the people what it will look like after all the work is done. With the best technology we have we try to show them what it looks like. That is one of the things we try to do but we are not always successful. When we are looking at projects we may not look at every single aspect. We need to be careful of the vegetation. Being able to visualize how a particular structure would be of value and save time. We spend more time in responding to the public than anything. The development of the general public has more knowledge of environmental issues and are aware of cities that have gotten people involved in the actual design. Therefore they are more demanding and some how they want to get involved in the early part of it. I feel if we don't show them something they feel that we are hiding something from them. We don't want to get them involved in doing a project. Some of the projects environmental issues are not the concern but the profile of the roadway is. Our problem is trying to build something as cheaply as we can but still please everyone. We have a need from the driver's view as he goes down the road maybe, not every point but some points. Views off and on the road is something we use also. May not want our technicians to do it because they normally don't see what the public concerns are. Need to generate a picture that the public will be concerned about. Videos would be good for us to have. Anything that is accurate and visible will be good. Video overlay is a good idea. Most of the time we don't know where problems are going to come up. During the advance planning stage if may be wise to have three dimensions of the roadway.

Fort Worth
Group #3

Who

advance planning
internal

Products

plan profile sheets

Media

We do sketch designs on paper and in a short time. Pictures are used a lot. If not pictures, we sketch it. We use two dimensions now. Locations of ramps are a problem in design from advance planning. We are using all the functions in the two dimension yet. We do a lot of work by hand. We could get benefits from three dimensions. We just need to decide where the three dimensions should go.

El Paso
Group 1

Who

internal, city, public

Product

schematics

Media

We have live videos and editing here. But we can't do the overlay. Planning and design both get involved in the public hearings. The people have a hard time understanding the schematics. All they look at is how much property we are taking away from them. It would be great to show a video to a group instead of sign maps which they have a hard time understanding. We displayed drawings of some projects and they turned out really good. The color in the video would be good. We need something to show the people how traffic will be going through during the time we are working on the highway, road, or whatever we are working on. We used PSA for some of the projects. Years ago we had scaled models which were wonderful. But what do with them afterwards and storage was the problem with them. Start with 50 people and up in public meetings. With dealing with the public it is how soon you put out information. Our PSA's had to schedule two or three months ahead of time. Big projects that have a long term affect on traffic would be where we want to use this technology you have. We have about 3 to 4 months to prepare for a public meeting. We could show the public what they want using video. About 20 to 25% of the information for right-of-way goes to commissioners. Right-of-way and plan maps we use to show the people. The people who start asking question soon are the ones we have problems with. In design we aren't supposed to go this far in graphics. I feel that we should show at least two alternatives to the public. The public don't understand the schematics. In design we would need a single block and see things as realistic as possible. In right-of-way a good cross section would be good.

El Paso
Group 2

Who

media
public

Products

two dimension plan views
photographs
right-of-way drawings

Media

If we had a video capability it will help us show how everything is going to lay in plan. The further we get into the jury trials the more we are going to need something. We had displays set up in two dimensions. We give a lot of information to the media. We may be able to use video to show property owners how something will look toward their business. If we had videos for public hearing and meeting it would give more information to the public and we won't have as many problems trying to show them how something is going to be. In the public meeting if we had more information they would feel better about it. The animation would be best for the public meetings. The video overlay may be helpful at times. We have video capability. Animation would be most useful.

San Antonio
Group 1

Who

Large projects - public
Property owners

Products

Models
Schematics drawings

Media

Build models for projects. The images can be made into hard copies. Have two or three public meetings and the public hearing. We have meetings with home owners association, and sometimes go to people houses that have had 25 people there. Builds the models in the schematics stage. Designs are done in 2 dimensions. In public hearings would go full inspection and property owner would be a single image. Design is from hard disk. We have a guy that is doing profile.

San Antonio
Group 2

Who

Property owners
appraisers
court juries (right-of-way)

Products

video overlay

Media

Our traffic section does video tapes and we go as soon as possible following a major accident that involves a fatality. We will go out and video tape that section of the highway. We want take pictures. It will be two to three drive-throughs with video equipment. Right-of-way uses aerial photographs. We are taking photographs. Don't see animation a real use to us. The only two that would have applied to us is still photos dealing with property owners and video overlay in court cases. We have time to get ready for meetings. We have displays of photographs.

Appendix B

The following Report Documentation from Eddie Sanchez, PE Thesis titled "A Three Dimensional Analysis of Sight Distance on Interchange Ramps & Corridors."

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

A series of computerized 3-D one-lane connector models were developed by modifying the vertical K value, the horizontal radius, and the M value in order to determine the physical feature obstructing the line-of-sight. They were also used to measure, as accurately as possible, the actual available 3-D distance between the driver's eye and the object location. The results of the graphical procedure demonstrated that the roadway feature blocking the line-of-sight was the longitudinal barrier for all 48 computer generated 3-D models, including the real world validation models. This indicates that the horizontal features of the alignment (radius and offset distance) determined the design speed of the interchange connectors even though the vertical alignment was designed with the same design speed criteria. In general, when evaluating geometric combinations that contain severe horizontal and crest vertical curvature, the horizontal features of the connector (the radius and the offset distance to the face of the barrier) will probably determine the design speed. If this is the case, as long as the vertical alignment is designed with K values equal to or greater than the design speed of the horizontal alignment, the horizontal features will determine the available SSD. These results also demonstrate the importance of determining the available SSD for both the horizontal and vertical alignments before concluding the design speed of the connector.

The current methodology for determining minimum vertical curvature assumes that SSD will not be negatively affected when combined with a horizontal curve. The current methodology only applies when a crest vertical curve is combined with a horizontal curve that does not require a cross slope. As described

extremely important when trying to determine the physical feature of the roadway obstructing the line-of-sight. However, this procedure is limited in other important areas such as duplicating realistic driving conditions or driver expectancy. As stated earlier, the computer-generated models do not give the true impression of the severity of the geometric combination when compared to actual driving conditions. The steepness of the approach grade and the severe rate of vertical curvature in combination with a sharp horizontal curve cannot be adequately described by non-moving perspective views. This procedure also does not adequately address the problem of driver expectancy for first time drivers within the interchange. Design consistency becomes extremely important in the design of interchanges because drivers become accustomed to driving on mainlanes which have much higher design standards and using substandard criteria on connectors would require a much higher driver workload. The goal of all designers should be to design interchange connectors that would not require first time drivers to expect uncomfortable driving conditions when approaching an area with an obstructed view.

CONCLUSIONS

An evaluation of the 3-D computer models resulted in some interesting conclusions that affect the conventional attitude toward the 2-D design approach.

1. The difference in SSD when measured in the conventional 2-D horizontal plane and the measurement in 3-D is insignificantly small.
2. The line-of-sight is not obstructed by the roadway surface when a minimum vertical curve is combined with a horizontal curve that requires a cross slope.
3. All combinations of minimum horizontal and vertical curvature on a connector with a longitudinal barrier results in the barrier obstructing the line-of-sight.

a problem with design consistency. Drivers would be required to expect a sharper vertical curve when a cross slope is introduced. Drivers would also be required to drive solely on their visual capabilities. This procedure would not reinforce driver expectancy for similar situations because each geometric combination would produce unique driving conditions.

A clarification of the use of SSD would be a more appropriate solution to this problem. The Green Book should indicate that the existing procedure developed from the definition of SSD only applies to the 2-D design approach and that horizontal curves with cross slope would actually provide the opportunity for additional reduction in vertical curvature. However, for design consistency between vertical curves on a straight tangent alignment and a horizontal curve alignment, the 2-D vertical curve procedure should be used for all geometric combinations. This would also support the Green Book's recommendation of designing with "*prevalent expectancies*" because it is one of the most important ways to aid driver performance. The Green Book states that when drivers "*do not get what they expect, or get what they do not expect, errors may result.*"

The possibility of determining or designing a connector with inadequate criteria may be minimized if the existing procedure of using separate design standards for horizontal and vertical alignments were combined. The design of a roadway will always require the use of the vertical alignment K values described in Table 3. However, an inexperienced designer may overlook the procedure, as described in Figures 8 and 9, for determining acceptable horizontal alignments. A new, easily understood design aid is needed that combines the horizontal and vertical design standards.

DESIGN AID

The design aids proposed in this thesis combine the vertical and horizontal information from Figures 6 and 9 for the upper range values of SSD and also combines Figures 7 and 8 for the lower range values. The design aids were developed assuming that the horizontal and vertical procedures used the same value of SSD. However, the existing procedures indicate a slight difference in the value of SSD used in design. For example, the methodology required to develop vertical K values uses the calculated values of SSD and then rounds up the K value to the nearest value of 10. These rounded K values were then used to calculate the equivalent SSD using equation 17. The results, which are listed in Table 3, indicate that when compared to the recommended rounded SSD from Table 2 the calculated SSD values are generally greater for design speeds 45 mph and less. For design speeds greater than 45 mph, the calculated SSD values were greater. The horizontal design criteria uses the recommended rounded values of SSD listed in Table 2. These inconsistencies, even though small, do not allow for direct comparison of SSD.

The approach taken in this thesis was to eliminate this inconsistency and use the same value of SSD for both procedures. For the development of these design aids, the recommended rounded values of SSD were used which required new K values for each design speed. Table 14 lists the new value of K for each design speed in addition to the rounded SSD value and the rounded K value. The results indicate that the new K values are slightly smaller than the rounded K values except for the 30 and 50 mph design speed. The smaller K values would also produce vertical curve lengths slightly smaller than with the use of the recommended rounded K values. The upper range values indicate that the 25, 35, and 40 mph design speeds will also produce smaller vertical curve lengths whereas the 30, 45, and 50 mph design speeds will produce larger vertical curve lengths. These results

again demonstrate the inconsistency in the use of SSD in design. However, the difference between the two values of SSD is small and undetectable to the driver.

TABLE 14. New Values of K Based on Rounded Values of SSD

Lower Range (Minimum) Values						
Design Speed (MPH)	25	30	35	40	45	50
Rounded SSD (ft)	150	200	225	275	325	400
Rounded K Value (%)	20	30	40	60	80	110
New K Value (%)	16.93	30.09	38.09	56.9	79.47	120.38
Upper Range (Desirable) Values						
Design Speed (MPH)	25	30	35	40	45	50
Rounded SSD (ft)	150	200	250	325	400	475
Rounded K Value (%)	20	30	50	80	120	160
New K Value (%)	16.93	30.09	47.02	79.47	120.38	169.75

Figures 20 and 21 are the design aids proposed in this thesis. An effort was made to simplify the appearance of the graph in order to provide a user friendly design aid. The diagonal lines on the graphs represent lines of equal value of stopping sight distance for different values of M. They were calculated by combining the sight distance equation for crest vertical curves (equation 17) and the horizontal sight distance equation (equation 20). The following equation results when combining the two equations and solving for M:

$$M = R * (1 - \cos[(\frac{90}{\pi R}) * \sqrt{K * 1329}]) \quad (26)$$

where,

- M = middle ordinate of curve (ft),
- R = radius of curve to the centerline of the inside lane (ft), and
- K = rate of vertical curvature (length (ft) per percent of A).

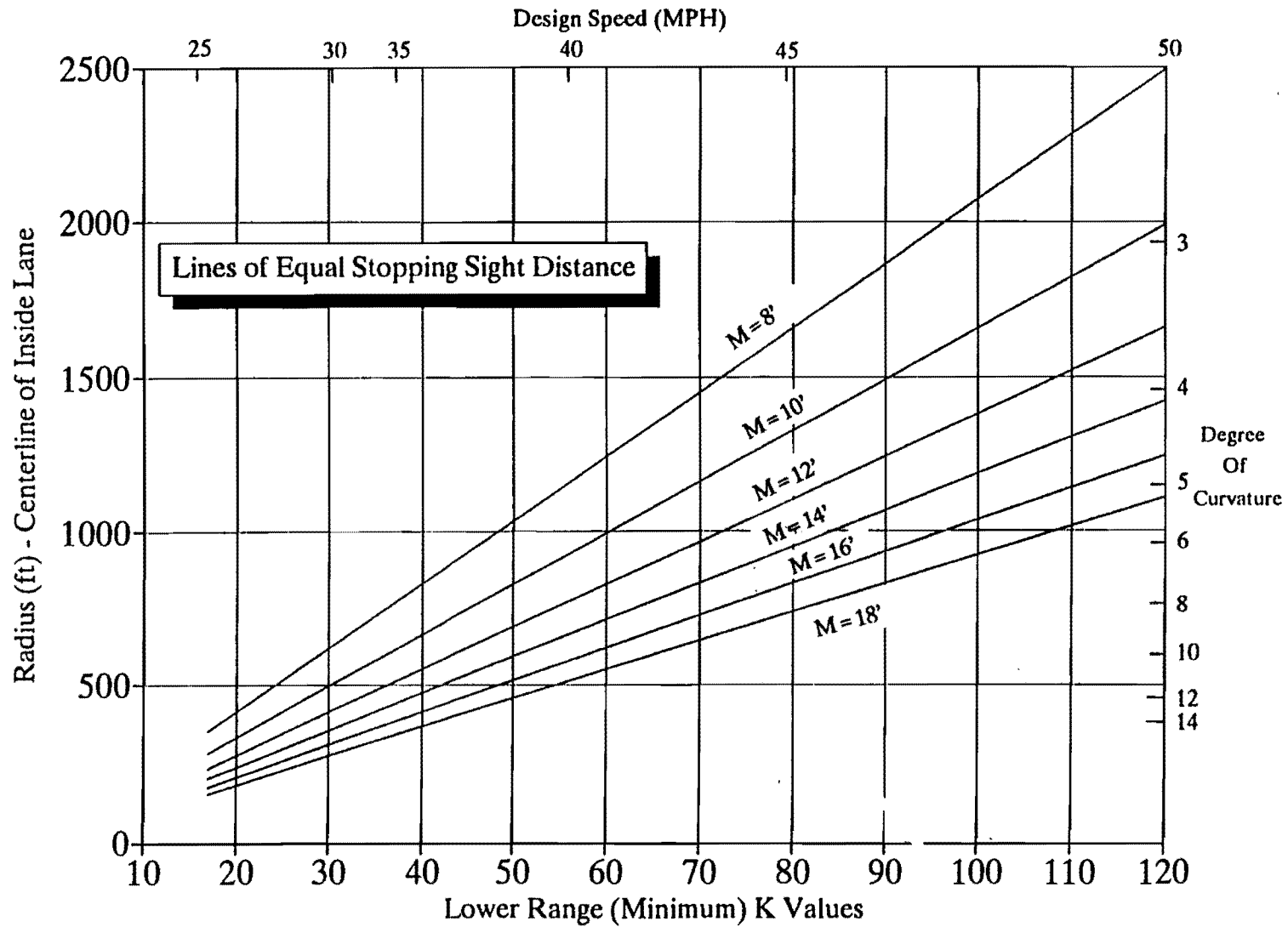


FIGURE 20. Design Controls for Horizontal and Crest Vertical Curve Combination, For SSD on Interchange Ramps and Connectors Lower Range of SSD Values

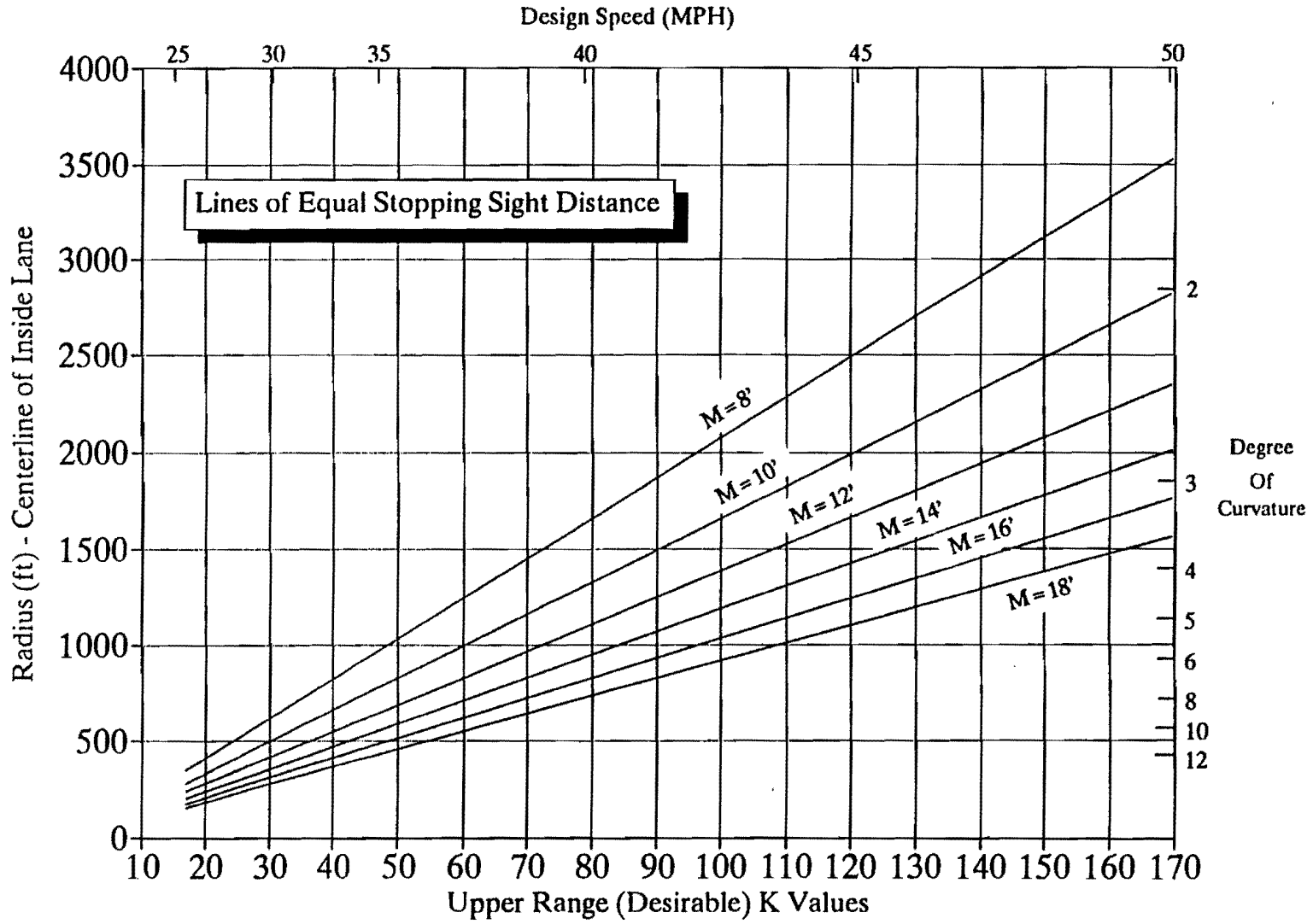


FIGURE 21. Design Controls for Horizontal and Crest Vertical Curve Combination, For SSD on Interchange Ramps and Connectors Upper Range of SSD Values

This equation will allow the designer to calculate any one of the variables given the information for the other two variables. For example, if the design speed was desired knowing the horizontal radius and offset distance to the barrier, the equation can be modified to solve for the K value which could be used to determine the design speed. The procedure for solving the horizontal radius is slightly more difficult. The procedure for determining the radius consisted of incrementally modifying the radius value until the equation solved for the desired M value. This procedure, however, is easily programmable on a calculator or a spreadsheet.

The graphs can easily be used in the design process or to evaluate an existing geometric condition. The design process usually consists of knowing the minimum acceptable design speed and shoulder width. With this information, the M value and K value could be used by projecting a line down from the design speed or up from the minimum K value until the desired M value line is intersected. The next step would be to project the line across horizontally until the horizontal radius is determined. This horizontal radius would represent the radius to the centerline of the inside lane. The K value would be used to determine the minimum vertical curve length. Another way of using the graph in the design process would be to determine the minimum K value knowing the horizontal radius and M value. A horizontal line is projected from the radius point until it intersects the line with the proper M value. A vertical line is then projected down until a K value is determined. A vertical line projected up would also indicate the design speed of the horizontal curve. Exact solutions would also be attainable through the use of equation 26.

The procedure for evaluating an existing geometric combination consist of calculating the vertical K value and then determining the point where the horizontal radius intersects the M value line. An intersection point to the left of a vertical line representing the K value would indicate a horizontal design speed control. A point to the right would indicate a vertical design speed control.

A designer should always be cautious when using a graph or table in the design process. A designer should also have a full understanding of the design limitations of any design aid in order to prevent its misuse. These design aids are limited to horizontal curves in combination with crest vertical curve on roadways with lateral obstruction such as a long bridge connector in an interchange. They also assume that the vertical curve is contained within the limits of the horizontal curve and less than the desired SSD. Other use of this design aid may result in undesirable alignment combinations.

