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16. Abstract

This third iterim report documents the user interface concepts for the Interactive Graphics Roadway Design System (IGRDS) portion of the overall package of programs that make up the Interactive Graphics Aided Design System (IGADS). IGRDS provides designers with interactive graphics input/ouput capabilities for use with the Roadway Design System (RDS). RDS is an integrated system providing the user with calculation tools for most areas of highway design. IGRDS utilizes graphics terminals to allow the user to input data for processing with RDS in an interactive environment and to view the graphics results of the calculation immediately.

This report gives the interrelationship of all of the programs that make up IGADS and the definition of interactive graphics computer systems used. The definition discusses response to the user as a measure of interactivity of computer systems and the difference between interactive systems and interactive graphics systems.

The concepts that interactive graphics could provide in the process of designing a highway from location studies to construction of the facility are provided. They are the result of interviews with engineering users and include the priority the users placed upon the development of the various interactive graphics functions.

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INTERACTIVE GRAPHICS AIDED DESIGN SYSTEM
GENERAL SYSTEM DESIGN

By

William L. Crawford

Research Report 520-3

Development of an Interactive
Graphics Aided Design System

Research Study 1-19-75-520

The contents of this report reflect the views
of the author who is responsible for the facts
and the accuracy of the data presented herein.
The contents do not necessarily reflect the
official views or policies of the Federal Highway
Administration. This report does not constitute
a standard, specification, or regulation.

Implementation

Organizations that are interested in implementing the Interactive Graphics Roadway Design System (IGRDS) being developed in the project should implement the Roadway Design System (RDS) to allow their personnel to become familiar with its operation and concepts. RDS provides productivity improvements in the design of highways over conventional methods. A commercial interactive graphics drafting system could also be implemented in anticipation of the use of IGRDS. The drafting system should provide the functions outlined in the report and run on a minicomputer capable of running RDS. The project staff should be contacted concerning the minimum requirements. A method for obtaining the geographic data base (survey data) could also be implemented in advance. Alternative methods for obtaining the geographic data base include implementing the Texas Automated Mapping System (TEAMS) or using a commercial interactive graphics drafting system.

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I. Introduction

The Texas Department of Highways and Public Transportation began representing highway design computer output in graphical form in September, 1964, when experimentation was begun on plotting cross-sections by digital plotter. In February, 1965, the first production job was plotted. These initial cross-sections were plotted on a digital drum plotter at a service bureau from tapes generated on the Department's computer system.

In January, 1966, the Department installed its own digital drum plotter with one shift each day handling the work load. Demand for plotting grew rapidly; consequently, in September, 1966, a second shift plotter operator was employed. The demand for plotting has steadily grown. The current equipment used by the Department consists of a high speed drum plotter and a precision flat-bed plotter in the central computer center and drum plotters operating remotely in several District offices. The Department also projects installing flat-bed plotters in several regional locations in the future.

The reason for this plot utilization is that digital plots are an integral part of most of the Department's engineering computer systems. This interest in graphic output also has prompted the Department's move to interactive graphics utilizing cathode ray tubes. The development in interactive graphics by the Department is primarily in three areas: automated mapping, automated drafting, and roadway design. There are several reasons for this progression, but one of the most important is ecomomics.

For example, thirteen cartographers were required to support the photogrammetric mapping operation of the Department utilizing the manual procedures of scribing. This staff has now been reduced to three people with the implementation of automated mapping and an interactive graphics drafting system. In addition to the economic benefits in converting the Department's photogrammetric operation from a manual to an automated process, the product is now a digital data base of the topographic features utilized for highway design. Figure 1 is a graphical representation of a typical geographic data base produced from the Texas Automated Mapping System. All of the detailed information shown on the map is stored with feature codes in the data base to a third order survey accuracy. That is, to a sufficient accuracy for an engineer to scale coordinate values from the plots of the data base for such functions as alignment determination and right-of-way and geometric calculations.

The roadway design area of interactive graphics development of this contract will take advantage of this geographic data base and eliminate as much as possible the use of computer input forms and replace them with a prompted interactive type of input utilizing current technology in computer terminals. Roadway design in Texas is highly decentralized and performed in the various districts of the State with some of the design offices as much as 500 miles away from the central computer. The Department has provided its design engineers with interactive input utilizing ROSCOE (a proprietary system of Applied Data Research) and remote batch terminals. The Department is moving towards distributed
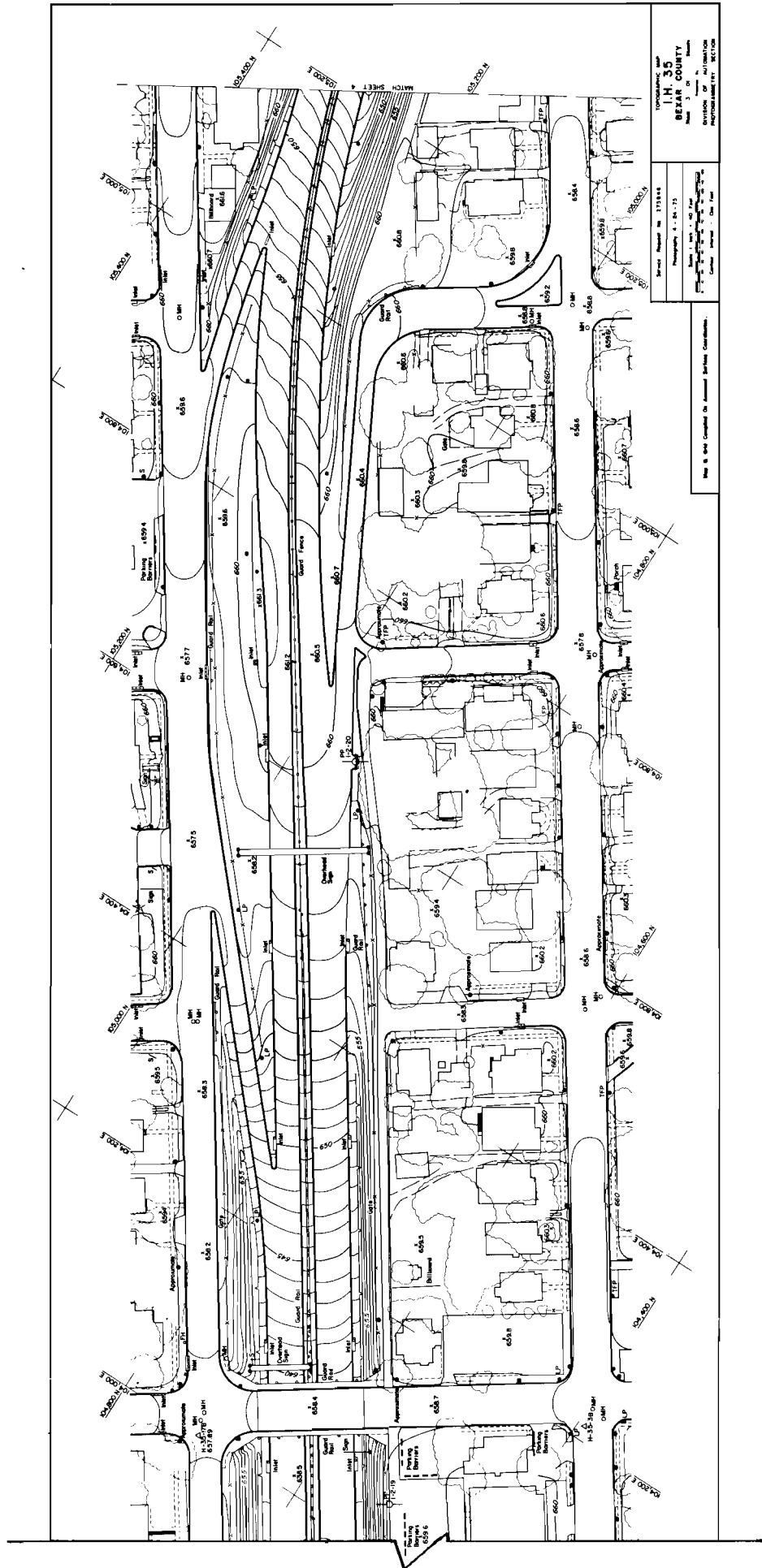
Figure 1. Graphical Representation of the Geographic Data Base

data processing, to distribute the processing between the large central site computer and small computers located remotely utilizing the relative powers of each. With the current resolution of graphics terminals, it is possible also to provide a display of complex drawings such as the design map shown in Figure 1 and to extract or "electronically scale" coordinate values with sufficient accuracy for roadway design.

In the automated map, drafting and roadway design applications, it is intended that design personnel work at a graphics terminal (or station) like that shown in Figure 2. The station will provide the interaction with input prompting, editing, and local calculation capabilities. When required, the main-frame computer will provide the power and computer memory needed for large design programs utilized in highway design.

Report Purpose

The first report on the project (Departmental Research Report 520-1, "Conceptual Design of an Interactive Graphics Aided Design System") (Ref. 4) discussed the proposed development concepts and identified existing programs to be used as part of the overall system. Departmental Research Report 520-2, "Interactive Graphics Aided Design System-Summary of the General System Design," (Ref.5) was written as a summary preview of this report. Familiarity with the existing computer systems to be used in the development, in particular the Roadway Design System (RDS) and Automated Mapping System (TEAMS), is important in understanding the proposed design. It is suggested that reports 520-1 and 2 be studied to obtain this background. This report is intended to

Figure 2. Example of a Graphics Terminal (Station)

provide (1) the user interaction definition for the development of detailed systems design; and, (2) information for potential users of the development to review and offer comments on the concept prior to the detailed design being finalized. When reviewing the previous reports on the project, the reader should keep in mind that the project was suspended for almost three years; and, due to technological advances, some of the concepts have changed. This report will supercede the previous reports and some revisions to the concepts presented here can be expected during the detailed system design and development.

This report also attempts to define the major capabilities that would be beneficial in a total interactive graphics design system for highway design. However, since it is not possible to develop a system covering the broad area of highway design under this one contract, those capabilities to be developed will be identified.

Some of the major points to be covered include: (1) system objectives and requirements, (2) user interaction with the design modules, and (3) graphics manipulation requirements.

Definition of Interactive Graphics

In a meeting attended by the author, a presentation was given which illustrates the differing images the use of the term interactive graphics conjures up in different individual's minds. The presenter produced a slide with three columns of three words each.

interactive	mapping	system
automated	drafting	display
integrated	graphic	plot

He called the grouping an "Instant Description Generator". By combining a word from each column, one can produce a similiar and yet a unique image in each one of our minds. For example: Interactive Drafting System, Automated Graphic Display, Integrated Mapping Plot, etc. It is rather alarming that from this example we can have 27 combinations of phrases forming a cloud of confusion around the topic. All of the potential combinations of descriptors from the chart form a correct description of an application of interactive graphics, but none define interactive graphics. This is the reason that the second report of the project (520-2) attempted to provide a definition of interactive graphics. The following is intended to expand upon that definition. It is considered important that the definition of interactive graphics used for this project be understood so that the design presented in this report can be followed.

An earlier study performed for the National Academy of Sciences, NCHRP 20-8, provided a general design of an "Interactive Graphics Roadway Design System". Unfortunately the report was never published; however, the project team does have a copy of the proposed report and has used it to an advantage. While technology improvements have revised some of the concepts, the definition developed for interactive graphics is basically still valid and is paraphrased and used in the discussion below.

The term "Interactive Graphics" implies the use of a computer and, in a more expanded form, would be expressed as interactive computer graphics. It defines a particular form of

communication between the user and the computer. Punched cards are one of the most widely understood forms of such communication. The word "interactive" implies that the user and the computer work in conjunction with each other in the solution of an application. That is, the user expects a response from the computer when he enters an instruction. The response may be the numeric answer to a requested calculation and its corresponding graphical representation, or it could be just recognition that the information entered was received and some means provided to verify that it was entered correctly. The term "Interactive Graphics" also implies that the user must be satisfied with the time required for the computer to respond to his command and provide him the results. The effect of interaction is to cause the computer to take advantage of the user's judgement and decision making ability, and to allow him to "direct" the computational and data handling power. The word "graphics" in the term describes one form of communication between the user and the computer. Graphic communications take the form of lines forming pictures together with alphabetic and numeric characters forming notes, dimensions or text to supplement the pictures. A computer driven display device acts as an intermediary between man and computer, providing the user with a visual picture of the information for him. The effect of interactive graphics is to provide the user computational results in the likeness of traditional graphical engineering representations. The difference between the screen and the traditional drawings is that the screen will be dynamic

in the sense that it will be changed at the command of the user to show whatever computed results he desires. In the most advanced form of interactive graphics, he points to portions of the graphic display, as a means of conveying an understanding to the computer of the effect of these user operations and of their use as combinations of information and commands.

Interactive graphics provides a means of communication from the user to the computer that is unique insofar as traditional computer techniques are concerned. The screen display of graphic images, although similiar in appearance to computer plots drawn on paper, has important conceptual differences. The image that the user sees actually provides a bidirectional communication media. By "pointing" to an element of the displayed image, the user can indicate where he wants an action to be applied. He can even show what action is desired by the use of a "pointing" device. The effectiveness of this concept is demonstrated by the commercially available interactive graphics drafting systems.

Response Time.   There are two other interactive graphics concepts that are of interest. The first is the response time of the system.   One definition of interactivity is related to whether or not each response of the system to the user is less than a certain time limit; as an example, 15 milleseconds.   A preferred definition is: does the system respond within a time acceptable to the user?   When it is desired that a note on the screen be moved in the manner described above, the modification of the position of the note should be very quick. The user will

become impatient if he must wait for this trivial result. However, the user should realize that the system's response to the command for a new mass haul diagram resulting from a significant change in basic roadway data takes a substantial amount of time. Therefore, response times are an important aspect to be considered in the system's design.

This response time requirement is one area where the proposed system differs from the NCHRP 20-8 proposed system and other systems currently being proposed or under development. It is felt and was confirmed by user committees (to be discussed in the next section) that while quick response is expected when performing such design functions as geometric calculations; calculation of earthwork design cross-sections with its longer calculation time, can be based upon a batch system concept as long as the input is performed interactively. For example, the calculation of the coordinate of the intersection of two lines is a simple function performed by many hand-held programmable calculators; therefore, the response to the command should be rapid. However, the combining of all the parameters of proposed templates to compute the three dimensional shape of a stretch of highway requires a relatively large computer resource and more time than a user would normally want to spend at a terminal waiting for a response. This difference is the basis for the formula used by the project staff in defining what functions should be "interactive", that is having the computer respond immediately, and those functions which can be performed while the user is performing other tasks.

Communication with the Computer.   The last concept of interest is that the communication between the computer and the user must be carried to the smallest step of the operation. The "pointing" at a line or symbol to identify the element for action should result in a recognition signal by the computer, such as the blinking of the line, to assure the user that a proper understanding was achieved. Guides to the next user step should also be displayed where possible.   This recognition signal and response provide the interaction desired by allowing the user to perform most of the editing of a problem as he proceeds instead of having to develop all of the input to a problem, input it into the computer and then have to analyze all the input errors at one time. It also allows the user to try several solutions to a design problem and select the best solution more rapidly.

Simply stated, interactive graphics provides the user with interaction with the computer for calculation purposes and with the graphic communication medium he is used to using in the form of work rolls, etc.

Interactive Graphics Benefits

The following discussion is presented to answer the question of what benefits an interactive graphics system can provide.

1. Engineering personnel typically use three forms of information in the design process:

    a. Input for calculations, whether it is design notes or computer program input.

    b. Results of the calculations either in design notes or computer program output.

    c. Graphical representation of the design and survey information either manually drawn or digitally plotted by a computer.

The existing Texas Roadway and Automated Mapping Systems each provide these three functions but with some limitations. For example, the Roadway Design System (RDS) prints both a list of the input and the results of the calculations. In addition, the system has extensive digital plotting capabilities. In general, the use of RDS plots for computer drafting is limited because of the lack of interaction between the user and the system. For instance, in the case of geometry, the user requires a work sketch to relate the index numbers of data he has entered into the system to the points and curves to which they refer. It would be very desirable to instead have these points and curves displayed on a graphics device as they are entered into the system and have the system maintain the index.

The Texas Automated Mapping System (TEAMS) prints a list of its input and the results of the calculations it performs. In addition, it produces plots of greater detail than is normally obtained by conventional surveys and manual drafting. See Figure 1 for an example of a design map produced by the system. It provides the basic working drawings as well as the representation required to document the existing conditions of the construction area for the contract plans. However, there is no direct link between the TEAMS data base or graphics and RDS. All extraction of basic input for RDS from TEAMS is manual. It would be beneficial to the design engineer if the TEAMS data base was available to him for direct input into RDS and he could generate an RDS computer plot that included the geographic data from a TEAMS data base and also be able to display the same data on a graphics terminal. The development of interactive graphics capabilities for RDS is intended to minimize these limitations.

2. An interactive system should provide the user "immediate" response from his input to the computer allowing rapid iteration of design problems. Now he uses a batch system such as RDS because it allows input of all calculations and processes all the input at one time. But there are many instances where a user needs the results of a series of calculations to make design decisions before proceeding. At the present time he must input the problem and wait for the results, analyze them and then make another computer run to make needed revisions. In an interactive system he receives the results as he proceeds through the problem allowing him to make the design decisions required. He will be able to make design decisions with minimal disruption of his thought process. It also allows the trials of various options to be processed more rapidly while he is trying to optimize a design.

3. An interactive graphics system edits the input, which minimizes rerunning a problem to correct errors, and allows the user to perform self checking of his calculations reducing the need for an independent review of the calculations.

4. An interactive graphics system not only provides the user with interactive alphanumeric input but it also provides him with a graphic representation of the input and output. This differs from batch systems where the graphics are a by product of the calculations and do not aid in input. With current graphics equipment technology, a user can "point" at the screen to provide input to the computer system. Interactive graphics also allows the user to have his required work drawings readily available on the screen for reference. In addition, since the work drawings will be developed as he computes the required dimensions and will be accurately filed, a draftsman can start with the results of the design in a computer medium to develop the required plan sheets. The basic work drawing at the beginning of the design process will be the photogrammetric design map. Interactive graphics also provides a ready means for the user to visually edit his input in such functions as describing the shape of his roadway template. The input is basically slopes and distances for each segment of the template. An interactive graphics system would "immediately" display graphically the result of his input for verification.

5. There are other reasons why interactive graphics is considered a justifiable capability. These come primarily from the experience obtained by the Department and other users of engineering systems in implementing systems like RDS and training personnel using them. For example, computer prompted input mimimizes the training of design personnel in the use of an interactive program. It also makes program enhancements available to the designer in a minimum of time and with reduced additional training.

    The transformation of the design of a modern highway to right-of-way descriptions, and construction plans and specifications is only one task in the process of taking a planned project to actual use by the public. Although they are an extremely important function in obtaining an optimal facility for the tax dollars spent, less time is spent on the actual calculations than is required to obtain public involvement in the planning process and to satisfy local and federal requirements. This usually means that the engineering personnel responsible for the calculations required to document the design, in many instances, do not use the computer programs with enough frequency to maintain

proficiency in their use. The very nature of the myriad of functions involved in highway design calculations requires large, complex computer systems and this intermittent use means the designer must "retrain" himself in the use of the systems. An interactive graphics system will minimize this retraining.

6. Computer systems must be dynamic to be viable tools. As technology and design requirements change, the systems have to be updated creating additional problems in maintaining user documentation and training of part time users. It is felt that the training would be reduced with the proposed interactive graphics system because its prompted input guides the user through the calculation process. The process is one in which the system interprets the answers given by the user to questions (prompts) displayed by the system and then branches to the needed calculation and allows entry of the required input. The input is then edited to inform the user of any detected errors. Provision for the more experienced user to bypass many of higher level prompts should also be provided. The system should be somewhat self instructional and any enhancements made to it would be available to the user on the screen as they are made along with any needed instructions on how to use them.

This introduction has attempted to answer many of the broad questions that have been posed in discussions about the proposed development. The following sections will be more specific in the discussion of the proposed Interactive Graphics Aided Design System capabilities.

II. System Objectives

General Objectives

Some of the objectives of this development effort were implied in the introduction to the report as well as discussed in Departmental Research Reports 520-1 and 2. A concise statement of the project objectives would be: To link together the basic components of highway design-surveying, calculations, and drafting-in order to minimize the manual intervention currently required to pass data from one function to another by:

1. Enhancing the existing batch computer system, Roadway Design System (RDS), through the addition of interactive graphics input-output capabilities.

2. Providing a direct interface with a geographic data base (survey) and a commercial Interactive Graphics Drafting System.

The interactive graphics enhancements are to provide (1) the designer with more direct interaction with the computer processes and his required graphics and (2) the capability for the graphics resulting from the design process to be available to the draftsman in a computer medium for development of the required construction plans. One overall goal to be followed in the development is to retain the flexibility adopted in the development of RDS. Since potential users of IGADS do not have identical highway design and plan sheet standards, every attempt is to be made to keep the system general. For example, the information to be passed from one highway design function to another will be selectable instead of establishing preset formulas, and no attempt will be made to establish preset template shapes, but

to keep the flexible input used by RDS.

Since this is an interactive graphics development effort, emphasis will be placed on improving the graphics capabilities to the designer. This objective will be met (with some of the development already accomplished) in the following ways:

1. Defining of a common graphics record format (previously accomplished and called the Graphics Interface Format (GIF)) which allows all graphics output to be combined into a common display. Provision for translation of graphics files into a common coordinate system, such as sheet coordinates is provided.

2. Defining of a geographic data base using the common graphics record format of Item 1 which will allow an engineering survey to be transformed into a computer medium regardless of origin (manual or photogrammetric survey). Photogrammetric surveys may be input using the Texas Automated Mapping System (TEAMS) and manual surveys may be input using batch or interactive RDS, or the Interactive Graphics Drafting System. (Translation from the drafting system to the GIF file will be required.)

3. Modifying batch RDS to output its graphics (plots) in the common graphics interface format.

4. Developing a General Plotting System (GPS) to plot any graphics in the common graphics interface format. GPS will have the capability of using different character fonts (such as Leroy and gothic), symbols (such as sign posts and traffic signals) and line patterns (such as dash, curb, railroad and guardrail). The user will have the ability to define the type of fonts, symbols and line patterns to be used when the graphic data is plotted and change them for subsequent plots. Output from GPS is to have various plotting devices (such as drum and flat bed plotters).

5. Providing graphics display software to function with the Interactive Graphics Roadway Design System to display the graphics generated during the design input process and to obtain input requested by the user from the graphics display. This function will be accomplished by linking the Interactive Graphics Roadway Design System to an Interactive Graphics Drafting System.

6. Developing a means to convert the common graphics interface format records into the format of commercial Interactive Graphics Drafting Systems. This will allow

the graphics results of the design process to be passed to a draftsman for preparing the construction plan sheets using the drafting systems. This capability has been developed for the commercial interactive drafting system used by the Department.

User Committees

To obtain user input into the system development to meet the objectives, two committees were formed to work with the engineering personnel of the project team. The make up of the two committees are as follows:

1. The Roadway Design Committee consisted of six registered professional engineers and three engineering technicians with varying degrees of experience and responsibility. Most have extensive experience with the use of RDS and other automated techniques. Personnel not familiar with RDS were included to obtain input not influenced by current RDS capabilities.

2. The Structural Design Committee consisted of three registered professional engineers and two graduate engineers. Some have experience with RDS Bridge Geometry and all have experience with various structural programs used by Texas DHT.

The committees met several times and defined the components of the highway design process from inception of a highway project to final preparation of contract plans. Each component was discussed and potential interactive graphics capabilities were identified. A priority for development of the capabilities was also established to guide the project team. The results of this effort will be documented in a later section of this report.

The work of the Structural Design Committee will be discussed in this report; however, due to the unfortunate delay in the project, it is not considered practical to develop any of the interactive graphics structural design capabilities in the

current project. The RDS Bridge Geometry functions, however, will be included.

System Design Philosophy

Before discussing the requirements of the system, several ideas should be discussed which outline the philosophy of the project team in the design of the system. The first point to clarify is the relative importance of graphics. While graphics in the form of such tools as work rolls, right-of-way maps, and construction plans are an integral part of the engineering process from project concept to construction, the numbers displayed on the graphical representation or in accompanying documents define the actions to be taken in construction and not the graphics. Only in rare instances are the graphics used for more than a method of clearly conveying the meaning of the numbers. This is an important concept to acknowledge. The change in a graphical representation is the result of the change in a dimension (for example, the width of pavement), and not the result of changing the location of the edge of pavement graphically and then determining the resulting dimension. One example where this might not be the case is a right-of-way line that is made to coincide with an existing property line; but, even in this example, the change in graphical representation is based upon a fixed dimension and not arbitrarily. Even in the situation where a designer using an interactive graphics design system would "point" to a position on the graphics display screen to be the location of the point of intersection of two roadway tangents, he

is not abandoning the concept of the numbers being more important than the graphics, but merely saying that the location of the point of intersection is not more critical than can be determined by "pointing" at the screen. Once the location is identified on the screen, the numerical value of the point becomes absolute as if it had been entered through the keyboard. The opposite is true during drafting, since the function is to complete the basic drawing developed during the design process. The placement of north arrows, annotation, and dimension lines is more a function of aesthetics than the precise placement required to accurately convey the required construction or right-of-way purchase.

The second point to consider is that highway design is an iterative process and the integration of several separate processes. It begins with a concept, for example, the need to construct a facility from point A to point B, and proceeds through the design process, being refined at each step until a set of construction plans is prepared and the facility constructed. If a microscopic view of the process is considered, earthwork design for example, we find the same process involved. A designer rarely determines the final configuration of the vertical profiles and ditch shapes the first time he goes through the earthwork design process either manually or using a computer. There are almost always refinements required, for example, to make the earth moving more balanced between cut and fill or to revise a ditch grade or shape to accommodate drainage. This same refinement process is true between the different design functions

such as right-of-way purchase and geometric design. Preliminary design of the facility will determine the right-of-way requirements, and the property takings can be computed; however, during the right-of-way process, economical revisions to the taking lines may be determined which then must be conveyed to a geometric designer (if the tasks are being performed by different persons). The revisions may then allow or dictate revisions to geometric and/or earthwork design. The same refinement process can also occur the other way, that is, more detailed design may dictate revisions in the taking lines and, therefore, property takings. This process is one of interaction but is not the interaction implied in the term "interactive" graphics.

This interaction between functions, however, brings up a third point to consider. The requirement to pass information between teams performing different design functions, such as between roadway and bridge and/or hydraulics designers, implies that, to eliminate errors in transferring data, all personnel must work with a common data base. While this sounds good in theory and is a valid procedure in management systems, it requires very sophisticated programs and controls. It is not considered justified in an engineering environment. Since some tasks go on simultaneously, such as right-of-way taking calculations and detail geometric design, it would require strict controls to ensure one team did not invalidate another's work. The amount of data to be shared is also usually small compared to all that goes into obtaining it. Geometric designers are interested only in the

location of the right-of-way lines and not all of the calculations necessary to purchase the takings. Therefore, transfer of data should be selective and not burden the computer systems and designers with the necessity of sifting through unnecessary data. Graphical representation of the design, however, should be transferred as a file to eliminate the necessity of redrafting a drawing to display it at a different scale and/or with a different amount of detail.   The discussion on graphics manipulation capabilities will provide information on systems which will provide this transfer of graphics data.

III. <u>System Requirements</u>

<u>Interactive Graphics Work Station</u>

The understanding of the man-machine interface of an interactive graphics design system is important to the user and can be best explained through a discussion of the proposed interactive graphics design system work station. Therefore, the following discussion will attempt to describe in general the interaction of the user with the work station and computer programs that would make up a typical interactive graphics design system.

All computer systems require a method for the user to communicate with the computer. This can be through the use of data forms and keypunched cards or through some device connected directly to the computer to allow more "interaction" between the user and the computer. That is, the user or roadway designer, in this case, would input a command to the computer and receive an immediate response. Based on that response the designer would enter another command. This would continue until the user completed his design or had to stop to obtain more information. The work station of the Interactive Graphics Design System would be similiar to the terminals of commercial interactive graphics drafting systems since the functions performed closely parallel that used by a highway designer in geometry calculations. These stations typically consist of the following equipment:

1. One (or two in some systems) Graphics Display Tube(s)

2. Alphanumeric keyboard

3. Graphic input device (usually a Data Tablet)

4. Optionally a screen copy device

An example station is shown in Figure 2. The Graphics displays can range in size from 11 inch to 25 inch measured diagonally across the display screen. They can also utilize refresh or storage tube type of display. A refresh type of display is like a television tube, that is the image on the screen is redrawn approximately 60 times a second. Refresh displays have the advantage that since the image is being constantly redrawn, any revision of the image being displayed is immediately visible. On storage displays the image is drawn one time and remains "etched" on the screen until it is erased by command. To delete an item from the screen or to change the view displayed, the complete screen is erased and redrawn. The time to redraw the image is dependent upon the complexity of the image. The amount of information and the detail that can be displayed on a graphics display are dependent on the resolution of the screen, that is the number of individual drawing elements that are used to draw the image. Graphics displays can be a photogrammetric design map to the detail that would be shown on a drafted version. (See Figure 3 for an example.) Commercial interactive graphics drafting systems use both refresh and storage displays; and, since the system to be developed under this project will use drafting systems for its graphics display, the system will be capable of using either type of display. The graphics display(s) will be used to display any graphics developed by the designer during a design session. It is
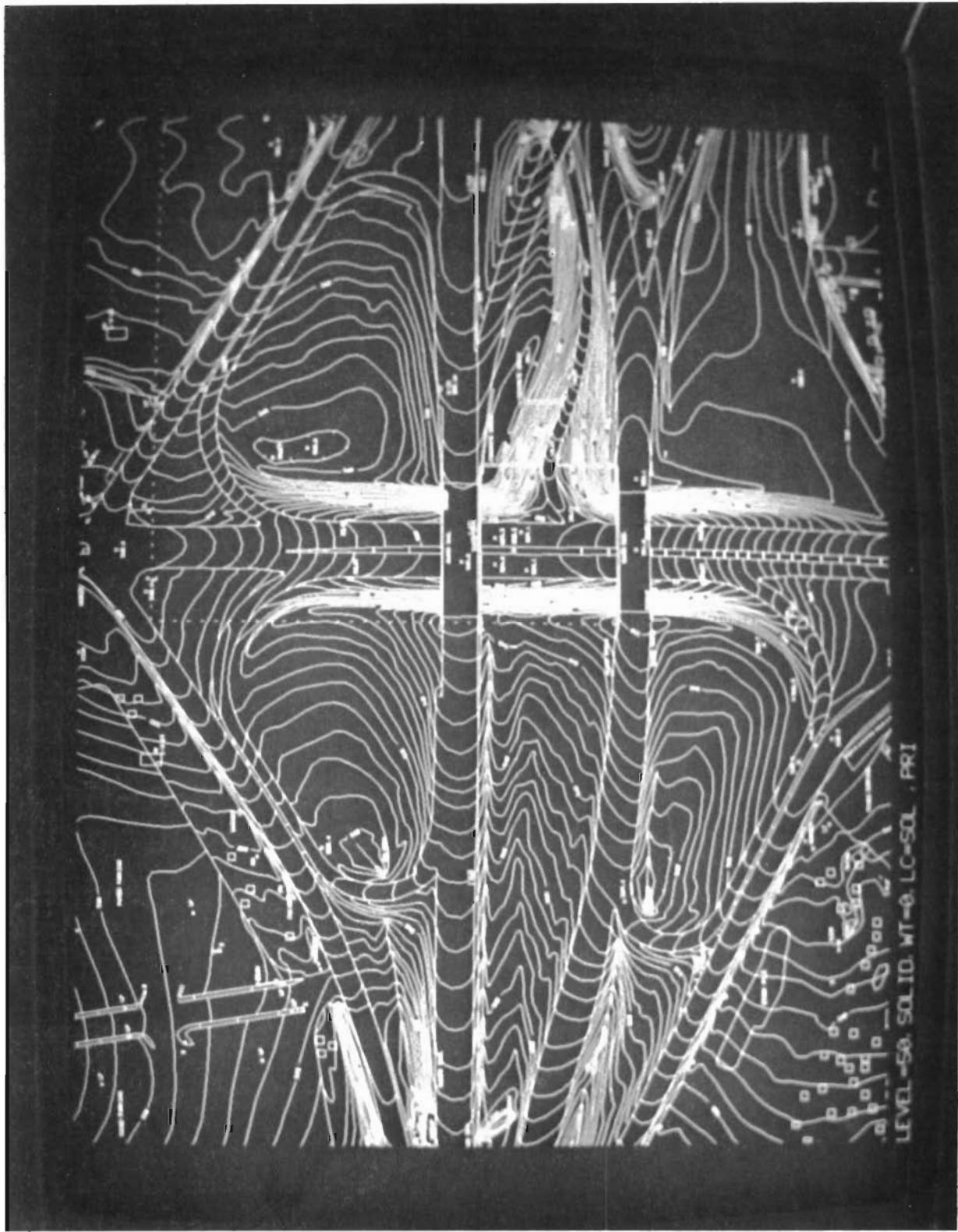
Figure 3. Example of Photogrammetric Map on Graphics CRT

considered beneficial to have two graphic screens for use by the designer in a design session. Two graphic screens provide the ability to display simultaneously:

1. Two separate views (scales) of the same graphic file.
2. Two unrelated graphic files.

This two graphic screen concept provides the user with a method for maintaining orientation when viewing a window of a complex drawing and the ability to look at both a plan and profile view of a section of highway at the same time. Some drafting systems provide the functions mentioned above on one screen; however, the two screens are considered desirable.

Another display device not listed above for the Interactive Graphics Drafting System that may be necessary for the design system is an Alphanumeric Display CRT. An Alphanumeris Display CRT is a refresh type of device that is specifically designed for alphanumeric data display. In a design system, the user can have considerable amounts of alphanumeric data displayed. This consists of prompting information and responses to his input. It is not considered desirable to take up a large portion of the graphics display area for the alphanumeric displays.

The alphanumeric keyboard is an input device to allow the user to key in any alphanumeric data that the computer system requires including commands and data such as coordinates. The keyboard is much like the keyboard of a typewriter and replaces the coding of data forms and keypunching of data cards. The advantages of keyboard entered data include:

1. The system can display the data as it is keyed-in, giving the user a visual verification of the entered data.

2. The system can edit the data for validity and inform the user of any errors so they can be corrected before proceding further with the calculation.

3. Corrections can be made immediately by the user by keying over the erroneous data.

Although each interactive graphics drafting system uses different methods for providing the functions performed by a data tablet, the data tablet will be described to outline this user interface with the systems. The data tablet is an input device used for digitizing a grid position. It has an internal wire grid and uses a hand-held control device, referred to as the cursor, to sense grid positions. The cursor usually is a free moving device that may be positioned anywhere on the data tablet. A locating device is provided on the cursor to give the user a visual means of positioning the cursor on the data tablet. As the cursor is moved about the data tablet, the system displays a graphic symbol on the screen in the corresponding coordinate location. This symbol is referred to as the graphic cursor and has a point of origin for positioning on the screen. The data tablet is used by moving the cursor or the graphics cursor to a desired position and depressing one of the buttons on the cursor. The digitized grid position is then input to the system to be used for various functions. The functions the data tablet serves for the drafting systems are discussed below for a better understanding of its use:

1. Command Selection - One function of the data tablet is for command selection. In this case, the cursor is used to point to a desired command on a command menu (Figure 4). This menu is overlayed on the data tablet or could be displayed on the screen. A menu consists of a series of areas associated with a specific command function. The command associated with an area is normally easily identified by name or graphic representation. A command may be selected from the data tablet overlay by placing the cursor within the boundaries of the appropriate area and depressing the command button (one of the buttons on the cursor). A command could be similarly selected from the screen by placing the graphic cursor within the boundaries of the appropriate displayed area and again depressing the command button. The system then makes an appropriate response for the selected command such as enter particular data or identify an element on the graphics screen.

2. Graphic Data Definition - The systems provide the user with the ability to define certain types of data parameters graphically instead of keying in data values. In this case, a point(s) is digitized with the data tablet to represent the required data. This type of data consists of coordinates, bearings, distances, and radii. This allows the user to digitize data from a working drawing on the data tablet by moving the cursor to the desired location(s). He also has the ability to digitize points on the graphics screen by positioning the graphic cursor on the identifiable screen location. After the required points are digitized, the system scales, translates, and rotates the coordinates to the user's coordinate system and displays any appropriate graphic response.

3. Graphic Identification of Previously Stored Data Elements - When a displayed graphic element needs to be identified for use as part of a subsequent command, the user can identify the element by pointing to it on the screen. That is, the graphic cursor is placed over the desired element and the data button on the cursor depressed. The system responds by determining which graphic element is nearest to the digitized point and then redraws the element in the display for the users visual verification. This type of graphic identification would be useful in an Interactive Graphics Design System for identification of elements to be used in calculations. For example, in geometry calculations the user must identify the element that a new element is to be parallel to. This could be conveniently done by pointing to the required element on the graphics screen.
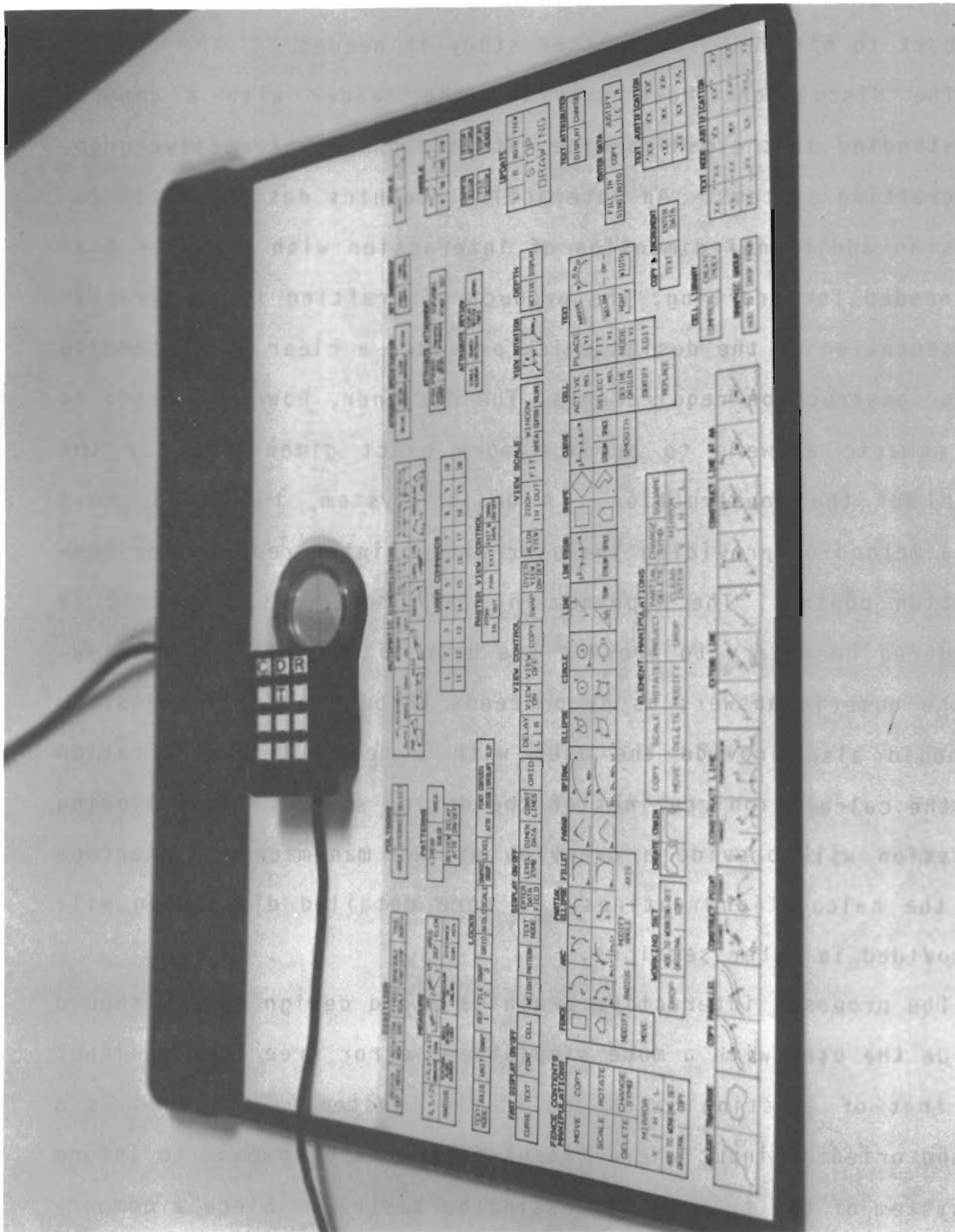
Figure 4. Example of Command Menu

The hard copy device provides the ability to make copies of the display on the graphic screen(s). The user can make a copy to take back to his desk for further study if needed.

The discussion above provides the reader with a general understanding of the man-machine interaction of interactive graphics drafting systems. An interactive graphics design system requires an additional dimension of interaction with the user over that needed for drafting. The product of drafting is the graphic representation of the design which provides a clear understanding of the construction requirements. The designer, however, needs to have numeric answers to provide more exact dimensions for the control of the construction. A design system, therefore, must have a method of providing the user with printed reports for construction control. The Alphanumeric CRT previously discussed is considered necessary to provide the user with a means of reviewing the numeric answers as he proceeds through a design session. It should also provide the user with a means of communication with the calculation routines of the design system. The following discussion will provide a overview of the man-machine interface with the calculation routines. A more detailed discussion will be provided in later sections.

The proposed interactive graphics aided design system should provide the user with a more simplified, error free form of input than that of existing batch application systems. Proposed is a command oriented input where the user selects a command to inform the system of the type of processing he desires. Since a commer-

cial interactive graphics drafting system will be used for the graphics manipulation, the graphics commands provided by the drafting system will be available to the designer by whatever input device(s) is provided by the system. The application program commands could be input using the keyboard of the alpha-numeric CRT or by having the commands on the menu. When a command is selected by the user, the design system will respond by displaying a reflection of the selected command for the user's verification.

In most cases, graphic displays will occupy the graphics screen simultaneously with a formatted display of the command. This will provide the ability to make use of existing graphics, such as maps, horizontal alignments and geometrics as graphic input to the command. Simultaneous display of the input data and graphics will also allow the user to verify the input data by analyzing the graphic representation of it.

After a command is entered, the system will begin displaying messages informing the user of the required input. The displayed messages will ask the user for the data in a more specific form than used on the general purpose geometry input forms used with RDS where the columns are used for different input data depending upon the command being used. The following shows an example of the type of messages that would be displayed for the Bearing-Distance option of the 'TRVS' command:

IDENTIFY PREVIOUSLY STORED POINT

ENTER BEARING

ENTER DISTANCE

These messages will be displayed one at a time. As soon as a data entry is completed the next message will be displayed. Most data, when keyed in, will immediately undergo an edit check. This would check for things such as (1) format errors, (2) insufficient data, (3) improper range, and (4) reference to data that is not stored.

If any edit error occurs, the system will display an error message indicating the type of error. The error then will have to be corrected before continuing. Many types of data will have a graphic input method. As previously discussed, two functions of the data tablet are to: (1) digitize a point(s) that graphically defines the data value, and (2) digitize a point on a displayed data element to identify the element. When one of these options is applicable, the user will perform the input function graphically instead of keying in a data value. For either option, the system will instruct the user to digitize a point(s). For example, if X-Y coordinates are required, the system would instruct the user to digitize the coordinate values. (The coordinate values could optionally be keyed in.) The system would then respond by displaying the coordinates for the user's verification. Another example would be when a previously stored curve number is required. In this case the system would instruct the user to digitize a point on the curve. The system would respond by displaying the storage number of the curve for the user's verification. In either of these cases, the system will

display the data value for the user's verification. If the user is not satisfied with the value he may repeat the process or key in a data value.

This brief discussion of the input/output techniques will be expanded in later sections of this report. The description should, however, give the reader an indication of the philosophy of interactive graphics design implied during the discussion of Interactive Graphics Potential In the Highway Design Process.

IV. Interactive Graphics Potential
In the Highway Design Process

Introduction

The discussion in this chapter is intended to provide a con-
cept of the functions that interactive graphics could provide in
the complete process of designing a highway from location studies
to construction. It is based upon an outline developed by user
committees and will include the priority they gave for the need
for each of the functions. The priorities are based upon a rank-
ing of from 1 to 10 with 1 being the highest priority.

Route Studies

The first step in the design of a highway on a new location
is the study of the various potential routes to identify the
corridor through which the highway is to be designed and
constructed. The determination of this final corridor location
may involve the analysis of several alternative routes and
include the calculation of approximate costs for the various
alternatives. While this study is always required on new loca-
tions, it may also be required for major reconstruction of exist-
ing highways since the analysis of the social, economic, and
environmental effects of a highway location may dictate that an
alternate route be established.

For interactive graphics to be of benefit in the route study
phase of a highway project, it would be necessary to have avail-
able in a geographic data base the tools used by the planning

engineer in his route determination. These include land use, U.S. Coast and Geodetic Survey Quadrangle Maps, environmental factors (i.e. the habitat of endangered species), existing highway locations, and their current and projected traffic. Since these pieces of information are normally contained on maps of differing scales, the inclusion of the information in a geographic data base viewable on a graphics display screen in selectable combinations would provide the planning engineer with a valuable tool for route analysis. The information would, of course, have to be kept reasonably up-to-date and could be supplemented with more recent information obtained through aerial photogrammetry. The justification of maintaining this type of geographic data base would need to be explored; however, the ability to display information contained in a geographic data base such as this is currently available. Implementation of the necessary computer equipment for an interactive graphics design system would provide the planning engineer with the capability of viewing any data contained in the geographic data base. The inclusion of this information and, in particular, the highway locations contained on the county maps would allow the automatic development of route maps depicting the corridor locations of the alternate routes. This capability would be a natural extension of the Texas Automated Mapping System.

The determination of costs for the alternative routes is similiar to that utilized in the preliminary design for schematic preparation discussed later; however, the accuracy of the basic

input is less than required for schematics. RDS has the basic tools required to quickly perform the basic design of a highway facility to obtain estimated costs. Some enhancements which have been identified to aid in the process are as follows:

1. The digital terrain model utilized by RDS is the Numerical Ground Image System and it should be enhanced to allow partial scan profile input and an easier method for defining discontinuity lines. (These recommendations and a description of the Numerical Ground Image System are contained in Departmental Research Report THD 1-19-71-186-2F entitled, "Numerical Ground Image System.") (Ref. 6) (Other digital terrain models are available and would need to be studied before any work enhancements were performed).

2. The ability to obtain cross-sections from contour maps such as U. S. Coast and Geodetic Survey Quadrangle Sheets is needed. See discussion on schematics for a more detailed definition of this requirement.

3. More automatic input of design parameters such as degree of curve, vertical curve lengths, superelevation rates and transition lengths, and typical sections is needed in RDS.

4. One of the several available vertical alignment optimization routines may need to be implemented to allow quicker design of preliminary vertical profiles.

The Roadway Design User Committee assigned a Level 7 priority to the development of interactive graphics capabilities for the route study function of highway design. The ability to develop route study maps will be available through the development of the Texas Automated Mapping System and subject only to the constraint that the data be contained in the geographic data base.

Project Survey

To perform any design of a transportation facility, a survey

of the corridor is required to provide the designer with both horizontal and vertical dimensions of the existing features through which the facility is to be constructed. A survey is required regardless of the complexity of the design to be performed. Obviously, the accuracy of the survey and the detail of the information required to develop costs for alternate loca-tions during the route study phase is less than required for detailed construction plan preparation. For example, contours from a U. S. Coast and Geodetic Quadrangle sheet may be suf-ficient to develop cross-sections for route studies while a con-trolled photogrammetric survey may be required for detail design.

Automated techniques are currently available to perform many of the surveys required for detail design and right-of-way acquistion with the output in a computer medium for ready access to engineering design programs. The following is a discussion of the various survey tasks and their relation to interactive graphics.

Survey Control. Any survey, whether done manually or photo-grammetrically, requires both horizontal and vertical control lines. The horizontal control for either type of survey may be a random traverse or a baseline. A random traverse is a meandered line of control points with azimuth and distances measured bet-ween each of the control points. The position of the points is established to take advantage of natural openings in vegetation and/or vertical relief on the project location to minimize brush

clearing or measurement over rough terrain. The line is generally somewhere near the center of the proposed construction corridor. A project baseline is generally the control line for the construction project and requires that the exact location of the project be determined prior to the survey in order that the baseline can be computed and staked. This requires that any obstructions to the line of sight be cleared in the case of vegetation or traversed over in the case of uneven terrain. A baseline is normally computed and surveyed when manual cross-sections are to be obtained so that the zero reference on the cross-sections can be the center of construction and that the direction of cross-section alignments will be perpendicular to the construction centerline. Random traverses are generally used for photogrammetric surveys which permit the project baseline to be established and computed after the control survey is performed; and, since the cross-sections are obtained photogrammetrically, the baseline does not have to be staked until near the time of construction or when right-of-way lines must be established for fence construction.

Vertical control for a manual survey consists of a line of benchmarks or control points with established elevations. For photogrammetric surveys, the vertical control consists of two or three sets of panels (depending on the corridor width) encompassing the corridor location. These are used for leveling the photogrammetric stereoplotters.

Baseline surveys for manual surveys are generally to a third order survey accuracy while photogrammetric baseline surveys are

established at second order accuracy. Third order accuracies are obtained with the photogrammetric equipment. In Texas, these second order surveys are always closed surveys between monuments of known geographic position or as closed loops and are surveyed using electronic distance measurement equipment, theodolites, self-leveling levels and photogrammetric stereotriangulation equipment. The Roadway Design System has the necessary traverse adjustment and aerial triangulation computation routines to support the survey function. These capabilities and the potential use of interactive graphics are discussed below.

The RDS Geodetic Control routines include (1) electronic distance measurment reduction, (2) theodolite data reduction, and (3) geodetic traverse calculations along with supplemental routines. Input to processes 1 and 2 are coded in the field during the survey process. This lends itself to the standard card input currently used and batch processing of the calculations. The Geodetic Traverse adjustment could be interactively input (no interactive graphics functions involved) with the processing probably remaining as a batch process. The ability to review the output of the calculation process and interactively make corrections and/or revisions to the input would be beneficial. The existing card update process would need to be retained. Output from the processes would be the current printed reports and review could be on an alphanumeric terminal. Display of the traverse plot on a graphics display screen would provide quick visual review of the output. The RDS User Committee assigned a

priority 8 to this development effort since the time consumed in the process is not extensive due to its limited requirements.

The RDS Three Wire Leveling routines provide the capability to reduce vertical survey notes taken in the field using the three-wire leveling technique. This technique consists of running three separate self-checking vertical surveys simultaneously in order to minimize surveying errors. Input to the program is again field coded input forms and, therefore, like the Geodetic Control function oriented toward card input and batch processing. Like Geodetic Control, review of the output on the alphanumeric CRT and interactive update of the input would be beneficial. There are no graphics output from the system. The printed reports would still be required as in most processes for record purposes. No priority ranking was established for this capability.

The RDS Aerotriangulation routines adjust the supplemental photogrammetric control points. These supplemental control points are obtained with precise photogrammetric equipment and reduce the amount of ground survey points required to control the accuracy of the photogrammetric mapping process by approximately 80 percent. Both horizontal and vertical supplemental control are obtained using the aerotriangulation process. Accurate coordinates of physical features can be measured with the equipment. They can be visible features such as the intersection of property fences or features located by paneling prior to the aerial flight. In Texas, the equipment used in this process has encoders and keypunches to provide direct input for the aerotri-

angulation routines.   The output from the aerotrigulation
routines include listings and RDS Geometry cards for plotting the
manuscripts used in the aerial mapping process. This manuscript
should be viewable on the graphics display screen for preview
prior to plotting.   The coordinates of these control points can
be placed in an RDS project file for use by the roadway design-
ers, if desired.   Since most of the points used for supplemental
control are not physical features on the ground, the passing of a
file to the designer is probably not justified; however, the cap-
ability is available.   The card output from the aerotriangulation
process is also used as input to the Texas Automated Mapping
System for plotting the control on the maps and for adjusting the
digitized geographic data from the stereoplotters to minimize the
leveling required when the data acquisition is performed.   No
priority was developed for interactive graphics enhancements to
this process by the Roadway Design User Committee since they are
not normally involved in the process.

   Photogrammetric Surveying. The planimetric surveys required
for designing a highway facility can be obtained through conven-
tional methods or through the use of photogrammetric techniques.
Photogrammetric mapping is used in Texas to obtain most of the
design survey data.   In areas of high vegetation, aerial pho-
tography is scheduled in the winter months when vegetation is at
a minimum.   Photogrammetric mapping is performed at a scale of 1
inch = 40 feet with an accuracy specification of plus or minus
one foot.   That is, all physical features will be located at

their true geographic position to an accuracy of plus or minus one foot. When compared to conventional surveys, the photogrammetric map generally has much more detail and, typically, physical features are oriented more accurately in relation to the proposed roadway. Engineering measurements can be obtained from the map with sufficient accuracy for most design and right-of-way determination and calculations. Supplemental information can be determined by conventional survey methods if critical measurements are needed or where physical features are not visible in the photography. In Texas, the photogrammetric stereoplotters are equipped with X-Y digitizing arms and encoders to obtain the planimetric data, and the Texas Automated Mapping System (TEAMS) converts the photogrammetry imagery directly into a digital data base displayable on a graphics display screen or plotted by a digital plotter. For a discussion of the mapping system, the reader is referred to Departmental Research Report DHT1-19-75-520-1, "Conceptual Design of an Interactive Graphics Aided Design System". The designer using an interactive graphics design system can use the geographic data base from TEAMS for input for some of the design calculations. The only requirement is that the data base be displayed on a graphics display screen by the same system providing the graphics display and manipulation for the design system. It should be noted that the geographic data base could be obtained by conventional surveys and input into the interactive graphics drafting system, or any other method available could be used to convert the survey notes to a geographic data

base format. TEAMS also has the ability to store maps that use
different symbologies than that used for design maps, such as
county and city maps, which could be used for title sheet pre-
paration. Any of the maps contained in the TEAMS geographic data
base can be displayed on the graphics display screens of an
interactive graphics drafting system. Any supplemental data
needed to be added to the geographic data base by the designer
such as street names and utility locations can be input using the
drafting system. Since the designer using an interactive graphics
design system would have the geographic data base available to
him in a displayable form on the graphics display screen, the
need to produce hard copy maps for his use by a photogrammetric
unit will be minimized. The user would have the ability to pro-
duce the hard copy plots needed. To maintain the integrity of a
master geograhic data base the user could be provided a copy of
his project file.

The contours produced using TEAMS are currently contained in
the geographic data base as planimetric features. That is the
elevation associated with the contour is not accessible for
design purposes. A digital terrain model such as the Numerical
Ground Image could possibly be used to produce the contours;
however, in Texas the justification of obtaining the base model
with sufficient accuracy to produce contours and cross-sections
over retaking the cross-sections photogrammetrically has not been
analyzed. Digital terrain models are used by some transportation
organizations. In Texas, cross-section data is obtained by pho-

trogrammetric techniques in a card format usable by RDS.

The RDS User Committee assigned a Priority 3 to this development since they are not directly involved in the process; however, the development of TEAMS is required by Texas for automating the photogrammetric operation. This development, therefore, is being performed by the Department as a parallel development effort to this contract and Version 1.0 of the system has been made available to FHWA under the contract. Therefore, the priority is the Department's and not that of the contract effort.

Project Baseline

The reference line for constructing a transportation facility is normally a baseline consisting of tangents and horizontal curves and is generally located close to the center of the facility. Most or all of the required construction features are referenced to the baseline, and the terrain and design cross-sections have it as a zero reference. The Roadway Design System utilizes the baseline as the reference for its design calculations. While projects normally have only one baseline, interchanges between crossing roadways may require multiple baselines for design and construction purposes. Terrain cross-sections are always assumed perpendicular to the baseline in RDS earthwork calculations; therefore, in an interchange area where connecting roadways may become too skewed to a single project baseline, it is necessary to establish baselines for the connecting roadways for earthwork design. Needed enhancements in RDS for interchange

design would minimize this requirement.

Baselines are computed using the Roadway Design System's horizontal alignment and command geometry capabilities. Survey information comes from the photogrammetric maps, geodetic control and supplemental field surveys as required. The techniques in establishing a project baseline differ with the type of project. The techniques and potential utilization of interactive graphics for some of the types of projects are discussed below.

For projects on new location (projects that do not follow an existing facility), the process consists primarily of establishing an alignment following the terrain in the project corridor, missing as many physical features as possible and minimizing disruption of properties, in order to provide a facility at the most economical cost. In a manual survey, the baseline is normally established by the surveyor in conjunction with the designer during the route selection and is "surveyed in" on the ground with the necessary curve calculations performed during the survey effort. Initial determination of the location is made by study of photographs and property ownership maps if available. Also used are maps such as the U.S. Coast and Geodetic Quadrangle sheets. Once established and surveyed, modifications of the alignment require a re-survey of the modified area. An interactive graphics design system could only be used to input a manually surveyed alignment and to review the resultant plot on the graphics display screen.

The development of a baseline alignment on a new location

using photogrammetric mapping has somewhat more freedom in that a corridor of approximately 1200 feet of mapping is available with one flight line at 1 inch = 40 foot scale. The corridor flown for production of the photogrammetric maps has to be established to include the potential project baselines, but there is freedom to move the baseline within the corridor constraints without a re-survey being required. The designer establishes the P.I. locations by visual inspection of the maps developed from the aerial survey and the aerial photographs. The baseline is then computed using RDS and plotted (at least at critical points) to determine if the baseline is located in the desired position. Adjustments to the baseline can be made as required to relocate it and the baseline recomputed. Once the baseline has been established, its relationship to the control traverse is computed using RDS for subsequent "surveying in" on the ground when required. Using an interactive graphics design system, the designer would design the alignment at the graphics station by establishing the baseline's P.I. locations through visual inspection of the map displayed on the graphics display screen, inputting the coordinates into the design system, computing the baseline and having the computed alignment graphically displayed on the screen for visual inspection. Using the graphics display capabilities of the design system, the designer would be able to view the P.I. locations at an enlarged scale to provide sufficient accuracy to determine if the baseline is in the desired location. If geometric calculations were required to establish the alignment and/or determine the

location of the baseline in relation to a physical feature, the capability would be available to perform the calculations on-line at the terminal.

Projects that follow an existing roadway require the reestablishment of the baseline of the alignment of the existing roadway and paralleling it if the roadway is to be moved off the existing location such as a divided highway; or establishing it along the existing centerline if it is a reconstruction project. On a manual survey, it is a matter of locating control points such as right-of-way markers, centers of bridges and control monuments to reestablish the existing centerline tangents, intersecting them for the P.I. locations and resurveying the baseline. Again, under the current process the established baseline is input into RDS for graphical display as required.

Using photogrammetric maps to establish baselines on projects that follow an existing facility is similiar to the manual survey process except that the survey is performed in the office on the maps instead of in the field. Critical points are located on the map, coordinate values scaled, and mathematical tangent lines meaned through the various points of a tangent establishing a best fit alignment through the points much as is performed by a survey party using a survey instrument. The tangents are intersected mathematically and the resultant coordinate used as a P.I. coordinate for calculating the horizontal alignment. Using an interactive graphics design system, the process would be similiar but faster. With the map displayed on the graphics CRT, the

designer would establish his control points much more quickly and they could be input directly into the alignment calculation routine to mean the lines to establish the tangents. The designer would have the ability to perform the calculations and have the resultant baseline displayed on the graphics CRT for evaluation and adjusting as he sat at the terminal. The relationship between the baseline and the control line could be computed using the system for subsequent "surveying in" on the ground.

The establishment of baselines for interchanges is basically that of designing the roadway alignments, since the intent of the baselines in an interchange other than the project baseline is to eliminate excessive skew of the cross-sections across connecting roadways. The process will be discussed further under the development of horizontal alignments for roadways. Because of the iterative process required for this baseline design, the User Committee indicated that it should be an on-line calculation with immediate graphic response. Provision for updating and recalculation for subsequent iterations was also indicated. The graphic representation of the baseline will be discussed under terrain cross-sections as the control line for the stereoplotters.

The user committee established the baseline process as priority 2.

Terrain Cross-sections

The data obtained from either manual or photogrammetrically surveyed cross-sections must be converted into elevations and offset distances from a baseline for use in a design system such

as RDS. The process to convert raw survey data into elevations and offset dimensions is available in the Roadway Design System with the resultant information available for storage in the project file and plotting on a digital plotter. While the user should have the ability to input cross-section information over the design terminal of an interactive graphics design system for adding limited data, it is not considered justifiable to input all of the cross-section information of a project over the terminal since the data cards are developed automatically from the photogrammetric stereoplotters; or, if the data is recorded in field books, it can be punched on cards efficiently. An interactive graphics design system should provide the ability to display a graphical representation of the original cross-sections after they have been placed in the project file. The user committee identified this development as a priority 4 and stated that the calculations should remain as a batch process.

Cross-Section Adjustment

There are several cross-section adjustment capabilities in RDS which should be available in an interactive graphics design system. These include the ability to (1) add supplemental cross-sections or points to the existing cross-sections, for example, on photogrammetric cross-sectioning where the original data was unobtainable due to vegetation, (2) adjust the original cross-sections to delete areas of existing base materials which are to be salvaged prior to the earth moving operation so that the earthwork quantities reflect only the earth moving process, (3)

shift the baseline for minor adjustments and (4) add or subtract a constant reading from all elevations over a given range of cross-sections. While some of the adjustment capabilities should be on-line for small tasks, most of the adjustments performed are over a range of cross-sections and are best performed in a batch type of calculation.

Input of the adjustment criteria at an interactive graphics design system station should be provided as well as the current ability to input cards in a batch run. The graphic display of the results of this adjustment should be available to the user at the graphic design station just as the original cross-sections discussed above. Since the adjustment is to the original cross-sections and the user may need to return them to their original state for some calculations, retainage of the original information is required. The user committee established a priority 4 for this development effort. In addition, they identified several needed enhancements to the existing adjustment capabilities, such as the ability to reference adjustment criteria input to individual roadways rather than the construction baseline. These tasks were incorporated into the existing Roadway Design System prior to the development of this report.

Supplementing Field Original Profiles

The original ground profiles used for the design of the vertical alignment with the Roadway Design System are computed from the original cross-sections along the alignment defined in RDS. In some instances, these original profiles must be supplemented

with field information. For example, profiles along the pavement or a curb and gutter may need to be established with more precision than normally used for elevations of natural ground. These are normally taken by conventional survey methods and manually plotted on the original ground profile plot from RDS. Since the design of vertical alignments would be performed in an interactive graphics design system, by viewing the original ground profile on the graphics CRT screen, it would be necessary to supplement the graphics display with the additional information. Input should be by elevation and station rather than by a drafting technique and should be by cards and/or at the interactive graphics design station. The ability to input supplemental profile information should allow both the supplement of an existing profile or the input of a completely new profile for design purposes. This would provide a capability for inputting a profile along a right-of-way line for design of frontage road curb and gutters which was identified by the user committee as being required. The user committee established a priority 6 for this development effort.

Schematics

One step in the highway design process not required for all projects but important for many is the development of a preliminary design for display and presentation to the public and other review agencies. The process for any preliminary design is similiar to that described for route studies and for development of the construction plans. However, it is not as refined. For ex-

ample, the slope and ditch designs are not refined to that required for the complete construction process. Also ramp transitions are usally not completed and the location of the bridge headers are only approximate. The terrain cross-sections obtained for the schematic preliminary design are not normally as accurate as those used for the final design, although they could be the same terrain cross-sections used in the final design and contractor pay determination.

Cross-sections for schematic development could be taken from contour maps such U.S. Coast and Geodetic Survey Quadrangle maps. This is currently accomplished by plotting the proposed baseline and cross-section lines on the contour map and manually scaling and recording the offset and elevation of the contour points. These are input into the Roadway Design System as cross-section data for subsequent design processes. This same task could be performed on an interactive graphics design station if the contour map was in the geographic data base. The measurements would be performed with the graphics cursor and elevation input on the keyboard. The justification for developing this capability would require analyzing.

The use of a digital terrain model is another method for obtaining cross-sections for preliminary design as previously indicated. A method of more automatically scanning the terrain and establishing the required input to the terrain model would enhance this capability.

Departmental Research Report THD-1-19-70-171-2, "Extensions

of the Roadway Design System - Preliminary Location and Design Studies" (Ref 10) documents and demonstrates the use of the Roadway Design System for preliminary design and also includes (1) a discussion of the enhancements made to the system to assist in the preliminary design process and (2) proposals for additional enhancements. These enhancements will be discussed in individual sections; however, no direct reference will be made to the report. Most of the enhancements proposed in the report have either been included in the Roadway Design System or were proposed by the User Committee. The report gives an example problem illustrating the use of RDS for preliminary design and may be of benefit to the reader not familiar with the capabilities of the system for earthwork design.

To discuss the capabilities of the Roadway Design System for schematic preparation, the various tasks involved in developing a design will be discussed along with their potential interactive graphics application.

Preliminary Horizontal Alignment. This task involves the definition of a reference line for construction of the individual roadways and is performed utilizing the horizontal alignment and coordinate geometry functions of the Roadway Design System. The reference lines or centerlines, as they are usually called, define the horizontal location of the roadways. On a single roadway project, the centerline normally corresponds to the project baseline; however, in an interchange there may be numerous centerlines defining the various ramps and connecting roadway

alignments. In the earthwork process, the roadway shape, slopes, and ditches are referenced to the alignments; and, although the Roadway Design System provides for 26 individual alignments to be stored on the project file for calculation purposes, only 6 of these may be utilized for earthwork calculations. While this may be a limitation on some rare projects, it can be handled through multiple design calculations for the project by reusing the alignment designation. This limitation could cause some inconvenience in an interactive graphics design system but should not be any more problem than in RDS.

Input to the RDS horizontal alignment process consists of P.I. coordinates and radius or degree of curve for each change in alignment. RDS also has provision for inclusion of station equations and spiral transitions. The P.I. coordinates are obtained through geometric calculations and/or scaling from photogrammetric maps as described earlier under Project Baseline; however, in the case of alignments such as ramp alignments, the process is more one of geometric calculations to define the location of the ramp in relation to the main lane and frontage road alignments than one of scaling positions of the P.I.'s. Both ramp and connecting roadway alignment determinations require close coordination with the vertical alignment design so as to eliminate ramp entrances hidden by vertical profile changes. In interchange areas, connecting roadways which go over or under another roadway also require close coordination with the vertical profiles to maintain vertical clearances. This involvement of both the

horizontal and vertical positions in the process makes it essential that both the vertical and horizontal alignments be viewable simultaneously during a design using an interactive graphics design system. The process of designing horizontal alignments is one of iterative calculations and, therefore, the ability to perform the function at an interactive design station with immediate graphical display of the results of the calculation would provide the designer with a valuable tool to more quickly establish the alignments. If a project involves an existing highway location and the original design of the highway was performed using interactive graphics, the construction plans would be available for display on the graphics display screen for determining the original design parameters without having to refer to the hard copy plans and inputting the information into the system for the design of the new alignments. The original plan sheets could also be utilized as background information on the schematic drawings if photogrammetric maps were not available. One requirement to allow efficient use of old construction plans is that consistent control be established and utilized for a given section of highway. For example, if the current project covered a section of highway that was constructed in more than one project and different coordinate systems were used for each construction project, the plans could not be displayed together and used for the schematics unless the coordinate systems could be translated and rotated into the same system. In Texas, projects surveyed using photogrammetric techniques normally have the same coordinate

system since they are compiled on the State Plane Coordinate system.

An important by-product of the ability to have construction plans available in a geographic data base and displayable on a graphics display screen is their ready accessibility for such tasks as development of traffic signal plans and review by maintenance and planning engineers during the life of the highway. Development of the plans on an interactive graphics design system would also allow the updating of the construction plans to reflect the actual construction performed.

For later earthwork calculations, the relationship between the alignment and baseline is computed at each terrain cross-section station. While the input request for this alignment relation calculation should be provided on the interactive graphics design system, the calculations should probably still be performed in a batch mode. The alignment calculations would need to be interactive to provide the graphics display response required. The user committee assigned a priority 2 for this development effort.

Terrain Profiles. Prior to the design of preliminary vertical alignments, it is necessary to obtain a graphical representation of the original ground profile along the alignment. The location of the vertical profile normally coincides with the horizontal alignment; however, they can be offset to the alignment, for example, in the design of curb and gutter sections or when superelevation control is to be on the edge of a roadway

rather than along the centerline. As discussed under Field Original Profiles, RDS develops original ground profiles from the terrain cross-sections and produces a graphical display. Up to six original profiles may be displayed simultaneously on one plot with different line symbologies identifying the various profiles. In an interactive graphics design system, the request for the development of the original profile(s) should be provided at the design station; however, the computations could be performed in a batch mode. The graphical representation then could be displayed on the graphics display screen for design of the vertical align- ment. The user committee assigned a priority 2 to this develop- ment effort.

Preliminary Vertical Alignments. The original ground profi- les discussed above are utilized to design the vertical alignment of the individual roadways. Design of the vertical alignment in- volves the consideration of both passing and stopping sight dis- tance, location of turning roadways such as ramps, and vertical clearance in the case of underpasses. The current Roadway Design System provides the ability to define a vertical alignment. In- put is the station number of each vertical P.I., the elevation of the P.I. and the vertical curve length. In an interactive grap- hics design system, the same input would be required; however, the location and elevation of the vertical P.I. could optionally be established with the use of the graphics cursor by "pointing" to the position of the V.P.I. on the screen. Since the horizon- tal and vertical alignments must be looked at simultaneously for

proper design, an interactive graphics design system should pro-
vide the ability to display together both a plan and profile view
on the graphics display screen. The user committee requested
that RDS be enhanced to provide for a table lookup of design
standards, thus allowing the input of the design speed required,
and the system then determining an initial vertical curve length
from the grades of the tangents. The designer would have the
ability to accept or override the computer generated length. To
be effective, vertical alignment design must be an on-line calcu-
lation and display capability since the process is iterative like
the horizontal alignment design with the designer entering a
trial alignment and viewing and adjusting as required. To
further aid in this design process the user committee requested a
vertical geometry capability similiar to horizontal geometry.
The vertical geometry would allow calculation of tangents to
parabolas, passing of parabolas through critical points and tra-
versing along a profile tangent for example. The user committee
identified vertical alignments as a priority 2 development
effort.

Preliminary Roadway Templates. The input of roadway templa-
tes and the overriding parameters of superelevation and widening
is used to define to RDS the shape of the subgrade, base courses
or pavement surface. The input required is the slope and width
of each segment and the location of the centerline and profile
line in relation to the segments. The template defined is assum-
ed by the system to be perpendicular to the centerline of the

roadway or to the baseline depending on the calculation the template is subsequently used for. The significance of this distinction of definition will be discussed later. The template is input for a specific roadway station but RDS provides the ability to identify the shape for recall at another location without having to input all of the parameters again. RDS also provides the ability to input the roadway surface and parameters for the system to develop the subgrade template. This option has some limitations which the User Committee requested revised. The requested enhancement consisted of providing a table look-up of the superelevation values by the system given the degree of curve and design speed. Of more significance was a request to allow the input of the shape of the complete typical section including subgrade, base courses and pavement shape for use in calculations. The complete section then would be available for plotting and computing earthwork volumes, construction staking and roadway elevations of each layer if required. One additional beneficial capability would be to allow each office or user to develop a table of typical sections which could be recalled for different computer runs and modified as required. In an interactive graphics design system, the user could recall a typical section from a master file, revise the dimensions as required, and store the section for the design run being worked on. The User Committee placed a priority of 3 on the development of an interactive graphics method of inputting the roadway templates.

Preliminary Side Slopes and Medians. The input of the side

slope and median parameters develops tables of typical fill and cut slopes and median configurations for the definition of ditches, benching, cut and fill slopes to connect to natural ground, and medians between roadways. The tables are referred to in the earthwork design process along with the roadway templates to complete the three dimensional shape of the proposed construction. The input consists of slopes and distances along with a selected option to be used to develop the section. RDS also allows the input of ditch grades to override the ditch elevations computed from the table values. RDS assumes that the slopes and distances input are along a line perpendicular to the baseline and it does not correct for any skew of the roadway to the baseline. This causes some input problems in interchange areas. One method proposed to aid in the design of interchanges is the use of contours. The roadway portion of the interchange can be contoured and, if these contours were displayed along with the natural ground contours on the graphics display screen, the remaining portion of the interchange could be designed by contouring. This method is used to some degree now but is a tedious job. With the capabilities of an interactive graphics drafting system, the process could be speeded up considerably. The user committee requested an enhancement which would further aid in the contouring of the interchange area. That is the ability to input ditch location by some method similar to alignments and to define the profile of the ditch like roadway profiles. With the ditches defined in this manner, it would be possible to contour them as

an aid in the contouring of the slopes. The procedure of obtaining the design cross-sections from the contoured design will be discussed in the next section. One method used at present with RDS to design interchange areas is to take original cross-sections about each roadway centerline and design each roadway separately as if the other roadways were not present and to connect the individual designs at a match line. If RDS considered the skew of the roadways during the design process, many of the interchanges could be designed directly. The User Committee requested also that RDS be enhanced to transition side slopes like roadway templates are transitioned. The user committee established that the input and updates for this process in an interactive graphics design system should be performed on-line, with the resulting data stored for further processing. They also stated that a graphic representation of the shapes input should be displayed for visual editing as they are entered. The priority established for this process was 4.

Preliminary Design Cross-Sections. To instruct the system on how to combine the typical side slope patterns, median shapes and roadway templates to form the design cross-sections, the user must input the station limits where they are to apply. To perform this task the user must have the alignments and profiles of the roadways available to define the station limits and know the identification codes of the shapes. To perform the task with an interactive graphics design system, the alignments and profiles could be displayed along with the graphic representation of the

particular shape being input (i.e. roadway template) and allow the user to graphically "point" at the stations and shape desired. It should be noted that the station numbers are not required to be input exactly since the design cross-sections would be developed where original cross-sections have been input; therefore, graphic identification of the station would be accurate enough. Both original input and updates could be performed in this manner. It should be noted that this task is only to prepare the data for a later run to develop the design cross-sections. An edit routine should be developed to perform some checking of the data and to allow correcting prior to the processing of the earthwork design calculations.

It was the opinion of the user committee that the design calculations should not be performed in an interactive mode but should be requested to be run by the user in the same manner as the current version of RDS. The graphics produced by RDS such as Haul, Station File and Cross-section plots should be viewable on the graphics display screen for editing of the data along with the design reports to allow determination of any revisions necessary such as balancing the earth moving.

The procedure for developing design cross-sections from a contoured design, discussed in the previous section, should be similiar to that discussed under the section on Schematics. The result would be a cross-section much like a final cross-section and earthwork volumes could be computed. More study is required to determine how construction staking information could be ob-

tained. The procedure would allow the development of design sections in interchange areas which would take into account the skew between roadways.

The user committee developed a priority of 4 for development of interactive graphics capabilities for preliminary design cross-sections.

Preliminary Earthwork Quantities. Once the design cross-sections are computed, the user instructs the system to compute the amount of earthwork movement required to construct the proposed highway configuration and the amount of hauling of material required. The earthwork quantities calculation is performed using RDS by the average end area method between the original and design cross-sections. RDS provides the user the ability to input design exceptions such as bridge locations and any added quantities that are not reflected in the design cross-section such as material placed upon the base slope. The results of the calculations are listings of the volume of cut and fill at each original cross-section station and, if requested, plots of the original and design cross-sections and haul plots. The user committee defined that the input for this function should be interactive in an interactive graphics design system (no graphics are involved in the input) and the processing should be in a batch mode. The resulting graphics would be viewable on the graphics display screen.

The user can review the results of an earthwork design performed using RDS at any stage of the process of designing the

roadway and make adjustments and reprocess the design. Reasons for adjusting the design include: (1) revisions of the ditch grades for drainage, balancing the earth movement to balance the cut and fill quantities to minimize haul, or (2) adjust the profile of a roadway to provide for a drainage structure. There are other reasons why a designer would adjust the design of the roadway; however, the point to consider is that the user has the freedom with RDS to modify the design until he is satisfied with the results. This ease of designing a roadway is why the preliminary earthwork design is included in the description of the schematic phase of a project. By performing a preliminary design, the designer has better information to prepare the schematic for presentation to the reviewing agencies and to the public, and the need for revisions during the plan preparation phase are minimized. This also provides better information to begin the next phase, right-of-way determination, after approval of the project is received. For example, if the information used to prepare the schematics is not based upon a preliminary design, the chances for revisions of the design profile during the plan preparation phase are increased. A 5 foot change in the profile can require 15 feet more right-of-way if the slope of a fill is 3:1. If the schematic has been presented to the public the only solution is the steepening of the slope or possibly having a supplemental hearing. The priority established for this function was 6.

Establish Right-of-Way Lines. Once the designer is satis-

fied with the preliminary design, the next step is to determine the amount of right-of-way required to build the highway. With the preliminary design cross-sections available, RDS has the ability to produce a plot of the plan view of the design. The plot can include the roadway alignments, crown lines, ditch locations and cut and fill slope catch points (location of the extremes of earth moving). Using an interactive graphics design system, this plot could be displayed along with the photogrammetric survey map on the graphics display screen. In addition, if a property map was available in the geographic data base, it could also be displayed. With this information the designer could establish the preliminary right-of-way lines for display on the schematics. One enhancement requested by the user committee was the modification of RDS to provide a string geometry element. The string element would be a string of lines and arcs related by the system so they could be defined and used as one entity. One method of defining a string would be to define it to be parallel to an alignment and offset by a defined distance. Since much of the right-of-way of a highway facility is essentially parallel to the alignments or baseline, this capability would provide the user an efficient method to accomplish this task. It should be noted that the system must also allow a string input as parallel to an alignment to be modified at user selected locations to correctly define the right-of-way line where it deviates from parallel to the alignment. Once the right-of-way lines are established, the user must have the ability to delete any of the displayed data

such as catch points or property lines from the display and/or resulting graphics file for passing to later stages such as drafting the schematics. The user committee established a priority of 4 for development of this function.

Draft Schematics. This function is the preparation of the actual map to be reviewed by the appropriate agencies and the public. The basic information for development of the schematic would be available from the previous steps in a graphics file for the draftsman to complete if the procedures outlined above were used. This drafting function is one of adding information such as title blocks, annotation, borders, structures and control of access lines, if applicable. The graphics file could be accessed using a commercial interactive graphics drafting system and the drafting performed. If a profile was required on the schematics, the draftsman would access the profile developed during the preliminary earthwork phase and merge it with the plan view information to prepare the schematic. The result of this drafting function would be a graphics file of the schematic which could be displayed on the graphics display screen and/or plotted on digital plotters including a high quality flat bed plotter. The user committee established a priority of 4 for this development.

Other Public Hearing Displays. Any other graphic displays needed for presentation at the public hearing could be developed using an interactive graphics drafting system. One special display which is available in RDS is perspective plots of the roadway design. This is a three-dimensional view of the roadway

at user specified locations and has proven effective in conveying to the public how the completed road will appear. RDS has no provision to add structures and/or signs to the perspective and an interactive graphics drafting system could be employed to add these design features. Once the perspective is developed, a photomontage can be developed which is the overlaying of the perspective over a corresponding photograph. Photomontages make it easier for the public to visualize the proposed construction. A series of perspectives can also be developed at a defined spacing and photographed or plotted using a COM microfilm plotter. These can be run as a movie to give the impression to the viewers that they are in an automobile driving down the new highway. No priority was established for this function.

Right-of-Way

This phase of the highway design process involves the acquisition of the necessary property for the facility to occupy, along with related functions such as the adjustment of utilities which interfere with the proposed construction. Obviously not all projects require additional right-of-way and, in some instances, the acquistion is performed by other agencies and the property transferred to the transportation organization. The process consists of establishing the final taking lines, determining ownership of the parcels, computing the takings, drafting right-of-way plans (or strip maps), preparing the deeds and drafting parcel sketches where required. In Texas, the various tasks are performed in different offices depending upon the or-

ganization of the District which is responsible for the right-of-way acquisition. Sometimes it is performed by the design office which will prepare the construction plans, and other times the function or specific tasks are performed by a right-of-way office specializing in right-of-way acquistion. Regardless of what office performs the function, the base information should be the preliminary design performed for the schematics if public hearings where required or a preliminary design specifically performed to determine the right-of-way needed. Typically, the right-of-way function and the final design, including preparation of the construction plans, are performed concurrently and it is essential that the personnel performing the tasks keep each other up to date on changes. As was discussed earlier, an interactive graphics design system should have the facilities to transfer selected graphics information between offices; however, they should not use a common data base. The final right-of-way information should be electronically transferred to the draftsman preparing the construction plans to minimize redrafting the same data and to minimize errors. The transfer should be as a graphics file with the necessary dimensions annotated for the designer to use in his geometric calculations or in the reverse if the designer has progressed ahead of the right-of-way taking calculations. To state the process of transfer simply, the tasks go "hand in hand" and an interactive graphics design system (which would be used for both functions) must have the capability for the transfer of graphics files between offices as needed. The

data to be transferred must be user selectable.

The following is a discussion of each of the tasks of the right-of-way function that could be enhanced by an interactive graphics design system.

Deed Research. Before the necessary property takings can be determined it is, of course, necessary to determine the ownership of all parcels of land the proposed highway facility will traverse. This is usually accomplished by searching the property ownership records for the last deed of record and is performed by both title companies and right of way personnel depending on the project and the policies of the organization acquiring the right-of-way. The result is a complete record of the property ownership of the area so that separate deeds can be prepared for each parcel to be acquired. One point about this deed research process, that is outside of the development of an interactive graphics design system but related to it, is that, if the deed records where stored in a graphics file, the determination of the property ownership could be automated. This is a goal of the CAMRAS project sponsored by the American Public Works Association. If the graphics files of an interactive graphics design system and the deed records were compatible and an automatic search was not practical, the ownership map could be displayed with the schematic for visual identification of the properties affected. A property ownership map usually is not of sufficient accuracy for calculation purposes but is sufficient for ownership determination. The user committee placed a priority of 10 on the

task.

Property Ownership Map Preparation. Regardless of whether or not there was a property ownership map available as discussed above, it is necessary to reconcile differences between the bearings and distances contained in the existing deeds and the survey performed for the right-of-way acquistion. The term "property ownership map" in this context is meant to describe a schematic type of work sheet drawn by some designers or right-of-way personnel to aid in determining the ownership of the property affected by the proposed right-of-way acquistion, reconcile differences in deed records of adjoining parcels, locate vacancies and overlaps and to identify property lines that were obtained during the survey of the project. There are differences normally between deeds of adjacent properties for common property lines and reconciliation of the differences is like solving a jig saw puzzle and is usually the most time consuming process of the right-of-way calculation process. The type of survey, manual or photogrammetric; the location, urban or rural; and the type of land use, farming or ranching, determines the procedure followed to develop the property ownership map. However, if an interactive graphics design system is to be used for the calculations, the existing property lines must be established in the same coordinate system used for the survey even if it is an assumed system. There are a number of methods used to accomplish this task and all will not be discussed here. The following is a discussion of one method that is used in rural areas and the pro-

cedure will be contrasted with a similiar method using interactive graphics. The method involves drafting or plotting the individual parcels, including ties to witness marks, to a small scale such as 1"=400' and then matching the drawings together like a jig saw puzzle, matching up known common points such as witness marks or common property corners. It is possible to compute the bearings and distances of the parcels in relation to the coordinate system of the project since the project survey normally includes the locations of identifiable property lines and corners, particularly when the property lines are marked by fence lines or monuments, and distances and bearings to the back corners of the properties for calculating the property left after acquistion of the right-of-way for determining damages. If the project survey is a photogrammetric map with a third order survey accuracy as used in Texas, much of the required information can be obtained by scaling from the map. Using an interactive graphics design system, the user would have the survey displayed on the graphics screen from the schematic phase. Any known property corners or witness marks which were obtained from supplemental surveys could be input and the location displayed. Since as stated above, the bearings of the deeds usually do not agree nor do they normally agree with the survey (normally the distances are in close agreement), the user's problem is to translate the parcel to fit the suvey. A suggested method for accomplishing this would be to select a coordinate for the beginning point of the deed metes and bounds description such that when the deed is

entered the image will be displayed close to the actual location of the parcel but outside of the area where other images are displayed. The parcel would then be entered using the bearings and distances of the deed. The result would be as if the parcel had been drafted individually but it would be in the same coordinate system of the project survey. The next step would be to use the facilities of the drafting system to rotate the entire parcel sketch to make one of the property lines parallel to a corresponding property line of the project survey. Then again using the facilities of the system, the entire parcel image could be moved in the file so that a common point such as a property corner coincides with the point on the survey. The result is the plot of the parcel rotated and translated into the coordinate system of the project. This may sound like a lot of trouble to a reader not familiar with the capabilities of commercial interactive graphics drafting systems, but the whole process can be accomplished in much less time than it would take a draftsman to manually plot the parcel. The final step would be to use an interactive graphics design system to perform any calculations to adjust the dimenisions of the parcel to match the survey. The property lines would be stored as geometric elements of the design system for use in subsequent right-of-way calculations. It should be noted that this could be performed during the route location phase or at any time in the design process to minimize the cutting up of properties and the resulting damages. The user committee assigned a priority of 5 to this development. The user

committee also determined that the calculations of this phase should be performed on-line as it is a trial and error process and any delay would be detrimental.

Finalize Right-of-Way Takings. If the procedures discussed above were followed, the preliminary right-of-way lines would have been determined during the schematic phase (if the step was required) and this phase involves finalizing the right-of-way requirements for the highway facility in coordination with the designer. The right-of-way lines could be input using RDS or an interactive graphics design system. If schematics were prepared, the process would be one of modifying the preliminary takings. The process usually is a continuing process during the entire right-of-way and design phases as the design of the facility is optimized. Using an interactive graphics design system, the schematics would be displayed on the graphics CRT and the right-of-way lines would be input using geometry commands. In many instances this is done at the same time as the next step, right-of-way calculations. The user committee placed a priority of 6 on this step

Right-of-Way Calculations. This phase involves taking the results of the property ownership determination and finalization of the right-of-way takings phases, and computing the metes and bounds descriptions of the required parcels, and preparing the deeds for acquistion of the property. Using an interactive graphics design system, the property and right-of-way lines would be displayed and the process would be one of computing the dimen-

sions of each of the parcels. RDS provides and, therefore, an interactive graphics design system should provide the calculation capabilities required, including a command to compute the area of the parcels. The resulting dimensions would be available for placing on the display using an interactive graphics drafting system. Consideration should be given to displaying the AREA command output on the graphics display of an interactive graphics design system so that the dimensions could be "moved" into the proper position using a drafting system without having to reenter the data. The user committee placed a priority of 5 on this development and specified that the calculations should be performed on-line with input edits to speed the process.

Preparation of the Deeds. The next phase is the conversion of the calculations into metes and bounds descriptions and adding the text required to develop the legal documents. Much of the text is repetitious and the user committee requested a method of automating the preparation of the deed documents; however, this capability can be provided by many of the commercial word processing systems and is not a function which interactive graphics would provide benefits. Preparation of any required parcel sketches would be easier using an interactive graphics drafting system since the basic graphics would be available in the graphics data base. The user committee placed a priority of 8 on this development.

Drafting of the Right-of-Way Plans. In Texas, a detailed map is required to document the right-of-way acquisition which is

usually prepared as a set of right-of-way plans. The map inclu-
des the survey of the facility to document the area prior to
acquisition including any existing improvements, the dimension
of the parcels, sketches of the parcels showing the remaining
land, a schematic sketch of the proposed facility, and control of
access lines, if applicable. This is primarily a drafting func-
tion of pulling together previously developed information. The
basic information would be available from previously developed
data in graphic format from an interactive graphics design system
under the development proposed in this report and could be
enhanced with an interactive graphics drafting system and plotted
as a finished product without having to redraft the same infor-
mation that was previously developed such as the schematics.
Required supplemental sheets such as a title page, which would
not be part of the calculation process, could be drafted using
the drafting system. If maps showing the project area such as
county maps were contained in the geographic data base, they
could be transferred into the drafting system to minimize the
drafting required. The user committee placed a priority of 6 on
interactive graphics development for this phase.

Draft Parcel Sketches. Parcel sketches are scaled drawings
of the individual parcels which are used as attachments to the
deeds. As discussed above, these sketches could be extracted from
the graphics file of the right-of-way maps or plans using an
interactive graphics drafting system and could be rapidly
produced; and, subject to legal restraints, could replace the

verbal metes and bounds descriptions contained in the deeds which would speed the development of the deed documents. No priority was placed on this phase.

P.S. & E. Preparation

This phase is the preparation of the detailed construction plans, engineering estimates and specifications for a highway facility for letting the construction project. The development of the final design of the facility should begin with the recall of the preliminary design and adjusting it to add the needed detail required for construction. The process is iterative with each step further optimizing the design. The same basic functions are involved that were described in the schematic phase with such details as ramp mergers and intersection designs added which are not usually required for the schematics. If the preliminary earthwork design for the schematics was performed using preliminary terrain cross-sections, these would be replaced with more accurate cross-sections for the final design. The steps required to develop the P. S. & E. varies depending upon the type of project. What is required for a facility to be constructed on a new location is different than a widening project. The following discussion will cover the steps required for major construction and not all steps would be required for all projects. Different steps of the design are usually performed by different personnel, depending upon the expertise and experience needed, and much of the design is performed concurrently. To maximize the use of the on-line files of an interactive graphics design system, most of

the design functions for a project should be performed by the same individual; however, the on-line capabilities of the proposed system should allow the designer to perform the work with more efficiency than in the past. Functions such as structure design and hydraulics have their own files and could be performed by different personnel than those performing geometrics and earthwork. The graphic results of the design process should be available in a file(s) for finalization into the construction plans without redrafting. The following is a discussion of steps involved in P. S. & E. development including potential interactive graphics enhancements.

Soil Classification. Soil borings and profiles are needed to design pavement structures and bridge foundations; however, the amount of testing required varies depending upon the type of project and the soil structure on the project. There is little interactive graphics design that could be applied to this function. An interactive graphics drafting system could, however, be used to draft the information for the construction plans. Standard symbols for the various soil classifications could be developed and stored in the system to aid in the drafting process which would make the plans uniform in appearance. The user committee placed a priority of 10 on development of interactive graphics development for this function.

Pavement Design. This phase is the designing of the pavement structure to support the projected traffic and is based upon the support characteristics of the soil, traffic and available

materials. The type of pavement required can be rigid or flexible or a combination of the two. There are design systems available to design both types; however, rigid pavements are usually designed by the use of charts or nomographs. The user committee placed a priority of 10 for interactive graphics development for this phase. The results of the pavement design, template shape, and depth are required for subsequent design functions, such as vertical profiles and roadway templates; and the required data could be efficiently input into an interactive graphics design system without requiring linking the pavement design systems with the interactive graphics design system.

Horizontal Alignments. This phase consists of designing or, more correctly, computing the horizontal control lines of each of the roadways of the proposed highway facility. If the automated process defined in this section was used, this phase would involve refining the preliminary horizontal alignments developed in the schematic or right-of-way phases. Any supplemental align-ments for ramps and crossroads that were not designed in the schematic phase would be designed at this time. The design of the horizontal alignments in many cases must be coordinated with the design of the vertical alignments, and the two design functions would be performed together although they will be discussed separately. In an interactive graphics design system the design-er should have both the horizontal and vertical alignments avail-able for review together when required. The designer would recall the required graphics files to begin the design process if using

an interactive graphics design system. These graphics would in-
clude the survey map, schematic, and right-of-way lines (parti-
cularly if frontage roads were involved). The design procedure
then would be similiar to that discussed under schematics but
would be more one of revising previously designed alignments than
designing new ones. The P.I. Coordinates would be input, computed
using geometry commands or 'scaled' as required. Several enhan-
cements that would improve the current capabilities of RDS and
therefore, an interactive graphics design system are discussed
below:

1. The table look-up of the degree of curve required for a
    given deflection angle and design speed discussed under
    preliminary horizontal alignments would be useful.

2. Sometimes the designer uses horizontal alignments to
    "fool" RDS for the design of special cases such as
    pavement widening projects and ditches where the hori-
    zontal position must be controlled differently than can
    be accomplished with side slopes. It would be benefi-
    cial if these parameters could be defined without the
    use of horizontal alignments normally used as roadway
    alignments.

3. RDS currently requires that the alignments defining
    ramps be continuous thoughout the project for earthwork
    design (design and quantities are handled by design
    exceptions). The system needs to be modified to allow
    the definition of intermittent alignments or the
    acknowledgement of the design exceptions by the align-
    ment. This would eliminate the display of the "bogus"
    sections of an alignment on the graphics display screen
    of an interactive graphics design system.

4. There are a number of geometric functions involving a
    series of individual commands that are repetitive, and
    the development of a single command that would perform
    the functions of the series of commands would improve
    the user's efficiency. An example is the definition of
    three centered curves.

5. The existing spiral transition limitations of RDS need
    to be eliminated.

6. Most construction dimensions are referenced to horizontal alignments and the dimensions are shown on the construction plans. An interactive graphics design system needs the capability to optionally place the computed stations and offsets on the graphics display (and in the graphics data base) for ease in detailing the construction plans. An interactive graphics design system should not be burdened with determining whether the annotation overlaps other graphic elements since the user could move the annotation as required using an interactive graphics drafting system once it was displayed.

The user committee placed a priority of 1 on the development of interactive graphics design capabilities for horizontal alignments.

Geometrics. This phase of the design process involves the use of command geometry to calculate all of the required geometric features such as ramp transitions, intersections, turn-outs, and turning roadways (for defining alignments). The function is the same as used for right-of-way calculations although used to compute different geometric features. An interactive graphics design system should provide on-line calculations (except possibly for some of the commands which produce tabular listings such as RDWY) and immediate graphic display of the results of the calculations. The user should also have the ability to graphically define input as required, such as identifying previously stored geometric elements, and digitizing coordinate positions. The geometry commands should provide detailing capabilities as discussed under horizontal alignments. Making the geometric calculations interactive would, as discussed earlier, be more responsive to the user's needs. An interactive graphics

design system should also provide system editing of each command as it is executed (minimizing reruns), visual edit of the results by the user on the graphics display screen and automatic book-keeping by the system of the required line and point I.D.'s. The user committee placed a priority of 1 on developing interactive graphics capabilities for the geometric function.

Vertical Alignments. This phase of the design process is the design of the vertical profiles of the roadways and, like the horizontal alignment discussed above, should be the refinement of previously designed vertical alignments developed during the schematic stage. The profiles of ramps and supplemental roadways such as cross-roads are designed at this time. An interactive graphics design system should provide interactive execution of the vertical alignment input and immediate graphic display so that the multiple trials prevalent in the design of profiles can be accomplished efficiently. A special purpose vertical align-ment is provided by RDS and should be available in an interactive graphics design system for use in designing roadway widening projects. A design profile can be defined to follow the natural ground at the profile location if the existing roadway is not to be rebuilt. RDS is also used to design and compute quantities for asphaltic concrete overlay projects; however, some enhan-cements are needed to make the process more automatic. The user committee placed a priority of 1 on development of interactive graphics design capabilities for vertical alignments.

Roadway Templates. This phase of design consists of defin-

ing the roadway shapes including superelevation and widening transitions. Again the process should be one of refining the preliminary design templates developed during the schematic phase and defining any needed supplemental templates such as for ramps. The process is basically the same as discussed under preliminary roadway template design. The widening function of RDS needs to be enhanced to provide curved transitions for defining ramp mergers. The capability should also be available in an interactive graphics design system. The superelevation rate should come from a table based on the design speed and degree of curve with a user override capability provided. The user committee placed a priority of 2 on development of interactive graphics design capabilities for roadway template definition.

Side Slopes and Medians. This process is the same as described under preliminary side slope and median definition; however for P. S. & E. it should be more a process of refinement of input developed during earlier stages. The discussion of interchange design under schematics takes on more significance for the P. S. & E. phase. Investigation into developing a true interchange design capability for RDS should be made. The user committee placed a priority of 2 on the development of interactive graphics definition capabilities for side slopes and medians.

Design Cross-Sections. This phase is one of defining the manner in which the various design parameters will be combined to define the three-dimensional shape of the roadway to be built.

The process is the same as discussed under preliminary design cross-section definition; however, unlike the previous P. S. & E. processes, the user would normally not review and modify the previous input, but instead develop new input.

One enhancement requested by the user committee to aid in adjusting the design cross-sections developed by RDS and, therefore, for an interactive graphics design system was a procedure to modify the design cross-sections. The procedure was available in the past as a batch process under the previous earthwork system used by the Department and was called Design Point Modification. Under an interactive graphics design system, design point modification would consist of the user displaying a design cross-section and indicating a segment of the section to be modified by "pointing" to the end point of the segment and indicating the modification to be applied. The resulting design section would not represent the basic design parameters such as templates or grades, and any revision of these parameters and reprocessing of the earthwork design would make the design point modifications applied in the areas redesigned void and they would have to be reinput. If the procedure was used after "automatic" design was completed to "fine tune" the design cross-sections for construction staking purposes, the procedure has benefit.

The user committee placed a priority of 3 on the development of interactive graphics capabilities for design cross-sections.

Earthwork Quantities. This function is the definition of additional parameters required by RDS for the calculation of

earthwork quantities, the initiation of the design process to develop the three-dimensional representation of the proposed roadway defined by the parameters discussed above, and the input of the plot requests such as original and design cross-sections and haul plots. The additional parameters include compaction factors, and design exceptions. With RDS, the user can request the design to be computed and earthwork quantities developed at any time in the design process to determine, for example, stage construction quantities and/or trial designs to determine the need for refinements to provide better earthwork balance or cost/benefit comparisons. The user has full control of the sequencing of the design calculations and quantity determination with the only restriction being that sufficient parameters have been input for the design to be developed. As discussed under schematic development, this process in an interactive graphics design system should provide for interactive input but the design calculations should probably be performed in a batch environment. The user committee placed a priority of 7 on the development of interactive graphics for earthwork quantity calculation.

Hydraulics. This phase of the P. S. & E. development is the design of hydraulic structures such as culverts, bridges and ditches to carry the storm run-off in and across the highway facility without undue flooding of adjacent property and the highway facility. The following discussion provides an overview of the interactive graphics design capabilities that could be provided for hydraulic design. This Department uses an intergrated

hydraulic design and analysis system called the Texas Hydraulic System (THYSYS). The reader is directed to the first report for this project (520-1) for a description of the capabilities of THYSYS; however, the following discussion is directed at describing potential interactive graphics functions for THYSYS.

1. Drainage Areas. To design or analyze any hydraulic structure or ditch it is necessary to determine the area of terrain that contributes run-off to be handled by the feature. This is determined by surveys and/or the examination of contour maps. If the contour map was stored in the graphics data base of an interactive graphics design system or one of the commercial interactive graphics drafting systems, the limits of the drainage area and the path length of the run-off could be measured on the graphics display screen. Since the interactive graphics design system being proposed in this section would use a commercial drafting system, this function would be available assuming that the contour maps such as U.S.C. & G.S. topographic maps or maps from the automated mapping system were available in the graphics data base. The user committee place a priority of 5 on development in this area.

2. Hydrology. This involves the determination of the amount of storm water which can be expected at a given point for a given frequency flood. There are several methods used to compute the flood run-off depending on the size of the drainage area and other factors. THYSYS has several methods of run-off methods included. There is little graphics involved in the input determination except for the drainage area discussed above. The ability to input the parameters in an interactive mode and having the calculations performed on-line would be of benefit since the results are passed to subsequent functions. The user committee placed a priority of 5 on development in this area.

3. Hydraulics. This is the determination of the carrying capacity of an open channel. There are several methods of computing the capacity of a channel like there are for hydrology calculations depending upon the size of the channel (i.e. river or ditch). All of the methods of calculating the carrying capacity of a channel require cross-sections of the channel. Interactive graphics could be of benefit in viewing the cross-section(s) input graphically along with the water surface computed both in cross-section and profile. The procedures discussed previously for developing terrain

cross-sections from contours would be of benefit for this function also. Since it is also necessary to determine the carrying capacity of proposed drainage ditches within the highway facility, it would be beneficial to have the ability to develop cross-sections of the ditches from the design cross-sections developed with RDS or an interactive graphics design system and pass them to the hydraulic system. The input for the hydraulic function should be interactive and the calculations on-line since the results are needed in subsequent calculations. The user committee placed a priority of 5 on development in this area.

4. Culvert and Bridge Hydraulic Design. To pass storm runoff from one side of the highway facility to another or within the facility requires a hydraulic structure capable of supporting traffic and of sufficient size to pass the run-off without undue flooding. THYSYS has capabilities to analyze existing or to design new drainage structures of both span and culvert type. The determination of the most economical structure to handle the run-off is somewhat of a trial and error process since several structures can be capable of performing the function. THYSYS produces several trial sizes; and optionally, a cost estimate for each trial. To aid in this trial and error process, an interactive graphics design system should provide interactive input with editing and on-line calculations. The graphics display could be the basic configuration of the structure along with the cross-section at the structure for culverts and profiles for bridges. An interface with the terrain and design cross-sections of the roadway design system would provide much of the input required. The user committee placed a priority of 5 on development in this area.

5. Storm Sewer. On many highway projects (particularly urban projects), the drainage must be carried below the surface in a network of pipes or box type structures called a storm sewer. The water enters the storm sewer through inlets placed at strategic locations such as at low points of the roadway. Design of the storm sewer requires the determination of the location and size of the inlets and the amount of run-off to be handled to minimize flooding the roadway or to prevent run-off from slopes from getting to the roadway; and the location, depth, slope and size of the pipe network to handle the run off. THYSYS provides calculation tools to aid the designer in all of the functions of storm sewer design. One of the most beneficial aids that could be developed for the storm sewer designer using an interactive design system would be a digital terrain model of the design and terrain in the area of the

storm sewer which also contained the three dimensional location of underground obstructions such as culverts and utilities. The digital terrain model would need to be capable of contouring the surface and developing profiles of storm sewer lines with the optional capability of adding the position (both top and bottom) of underground features crossed by the line. An interactive graphics design system would need the capability of displaying any of the graphics displays developed in the design process and storing the data in the geographic data base. The profiles would need to be accessible to THYSYS for the calculation of excavation quantities (routines would have to be developed for THYSYS). With the design contours superimposed over a plan layout of the roadways and existing features from the Automated Mapping System, the designer could locate the inlets, determine the contributing drainage areas and, using THYSYS, size the inlets. The input and calculations for this process would need to be interactive as it is a trial and error process.

With the inlets located and sized, the designer then defines the pipe network to carry the run-off, that is, lays out the network between inlets (or manholes if required) to gather the run-off and carry it to the outfall. The length of each pipe run must also be determined for later use in determining the size of pipe(s) required. The designer must also determine the location and depth of any obstructions such as utilities, footings and depressed roadways to allow the pipe to be located horizontally and vertically to miss the obstructions. As discussed above, providing a digital terrain model which included the location of the obstructions and provided an interface with the geometric calculation functions of an interactive graphics design system would ease this process since a profile could be developed for each pipe run and the length computed using geometry. Since the program can not lay a pipe profile to miss obstructions, THYSYS requires the designer to input the soffit elevation of each pipe run whether the system is analyzing or designing a sewer network. The system will then determine the size of pipe required to handle the run-off for the slope input when design is specified. The process is still a trial and error solution for the designer. The process is speeded using the capabilities of THYSYS; however, many designers prefer to tentatively design each run manually and then use THYSYS to analyze the network to verify the design. An interactive graphics design system should provide for interactive design of each run to match the process currently used. A final analysis could then be made of the entire network for documentation purposes.

THYSYS provides graphic output of the profile of each pipe run showing (1) the flow line and soffit line of the inside of the barrel, (2) the calculated uniform (normal) depth of flow in the barrel, (3) the calculated hydraulic gradient line and (4) the tailwater elevation. This graphic output should be displayable on the graphics display screen of an interactive graphics design system along with the natural ground profile for visual verification of the design.

The Roadway Design User Committee placed a priority of 4 on development of interactive graphics design capabilities for storm sewer design.

6. Pump Installations. In instances where the pipe network of a storm sewer system can not be designed to match an existing outfall elevation; or, in some instances in underpass construction, it is necessary to provide a pump installation to pump the water to a higher elevation. THYSYS provides calculation capabilities to analyze or design a pump installation and provides graphic output of the conveyance curves of the pump. The user committee did not address interactive graphics design needs for pump installations; however, the ability to interactively input the data and get a graphics display of the plots would be beneficial enhancements. Since this is a little used capability because most organizations avoid installing pumps if at all possible, the priority of development in this area would be low.

Structure Design. This area of P.S.&E. development involves the design and/or analysis of highway appurtenances such as span bridges, culverts, retaining walls, sign support trusses and high mast lighting towers. The functions of the structural engineer are also involved in analyzing existing structures for structural integrity. A full description of interactive graphic design capabilities for structure design could entail a report as large as this one; and, since this project will not address any development in the structural area except for the bridge geometrics available in RDS, only brief comments will be included in this

section. The Structural User Committee addressed some of the requirements for development in the area of bridge design; however, the work was not as complete as the Roadway Design User Committee's and will not be documented. Should the results of NCHRP Project 12-18 or other development produce an integrated structural design system, it is recommended that a separate project be instituted to develop interactive graphics design capabilities for structural engineers along the lines that are proposed for roadway designers in this report.

In Texas, structural and roadway design are generally performed by different personnel. This is especially true if a special design is required for the structure. If a standard detail will accomplish the function, the roadway designer will include it in the plans. Since the design is normally handled by different personnel, the work is usually performed concurrently. Once the roadway designer has determined the detailed design of the roadways at the structure, the data is passed to the structural engineer. In Texas, this consists primarily of a partial bridge layout sheet providing such information as roadway widths, span lengths, and skew. The structural designer then completes the details and returns it to the roadway designer for inclusion in the construction plans. In some instances, the preliminary details supplied by the roadway designer must be modified in consultation with the structure designers. The detail sheets should be developed using an interactive graphics drafting system proposed to be part of the interactive graphics design system out-

lined in this section and the information transmitted between the designers electronically. Having the detail sheets in the drafting system file also allows the designers to view the same information while discussing any questions on the phone if they are located in distant offices as they are in Texas. The roadway details, such as horizontal and vertical profiles, and pavement cross-slopes and widths, could also be developed by the roadway designer using an interactive graphics design system and passed to the structural designer as a computer file to minimize input errors. Since the structural designer would use the interactive graphics design system's bridge geometry for calculation of the bridge framing, the basic input data would be available to him along with graphic displays of the profiles and alignments.

Two features that should be available in an interactive graphics structural design system are member section calculation capabilities and a master data base of the basic parameters of the structure. The work data base would contain any trial designs desired to be temporarily maintained by the designer with the final design placed in a permanent data base for later use in structural analysis of the structure for such functions as widening and overload permits.

No priority was defined for the development of an interactive graphics structural design capability; however, it is felt that sufficient justification exists for funding a project to develop the system.

Miscellaneous Design Functions. There are other miscella-

neous design functions that may be involved in a highway project. These include illumination systems, irrigation, signing, and traffic signals that could be included in an interactive graphics design system. Some of the functions would benefit more than others from interactive graphics; however, most would benefit from the availability of interactive input capabilities if computer design capabilities are used. One design function that would definitely benefit from interactive graphics is the design of large sign panels commonly called interstate signs. While there is little graphics input involved in the program, the result is a scaled plot of the sign. With interactive input and calculation capabilities and interactive graphics manipulation of the graphics output, the user could quickly make several trials of the various signs and then arrange the output on sheets using an interactive graphics drafting system. The user committee provided no indication as to the priority for development of interactive graphics capabilities for these miscellaneous design functions; however the functions are diverse in application and use and, therefore, should be analyzed individually for the benefits to be derived.

Drafting. Graphic presentations in the form of construction plans, right-of-way plans, schematics, and maps are the primary method used by the engineer to convey the results of his design to the public, contractors and other interested individuals. Many of the design computer programs discussed above produce graphic output which can be used for the presentation of the design;

however, very few produce a product that can be used without add-
itional drafting being required. The interactive graphics design
systems proposed use of the graphic manipulation capabilities of
a commercial drafting system, with the documented improvements in
productivity provided by the drafting systems, makes the use of
the drafting system's capabilities for the design system most
beneficial. The capabilities of drafting systems needed for
graphics manipulation for an interactive graphics design system
will be discussed in a later section; however, for the purpose of
this discussion the reader should understand that the general
purpose interactive graphics drafting systems available today can
be used to produce almost any type of drawing, including three
dimensional representations, with productivity improvements over
conventional techniques of 3:1 up to 10:1. The productivity
increase depends upon the sheet being produced and whether the
graphics are input totally using the drafting system or some of
the graphics come from another source such as an application
program like RDS. The drafting of some sheets that have repeti-
tive details, such as bridge structural detail sheets, increases
in productivity because the details are input once and stored to
be recalled to draft subsequent sheets. Discussion of the many
varied types of drafting involved in roadway design would require
a large document; therefore, only some of the basic sheets will
be discussed in general in this document to provide the reader
with a basic understanding of the concept of automated drafting
in conjunction with an interactive graphics design system. One

basic concept needs to be discussed before proceeding with any detail of individual sheets. This concept is that any graphics produced by an application program such as RDS, Texas Automated Mapping System, or Interstate Sign Sizing must be produced in a form that can be transferred to an interactive graphics drafting system to minimize the redrafting of data currently required. There are several techniques that could be used to accomplish this conversion including the transfer of the plot records produced to drive the digital plotters used with the application programs. The method chosen by the project team and used by the Texas Automated Mapping System is the production of generalized graphics records by the application program which can be converted to the format of the Interactive Graphics Drafting System (or plotted by the General Plotting System developed by the Department). The generalized graphics records, called Graphics Interface Format (GIF) records, not only pass the necessary information for plotting or displaying; but, they can also pass identification information concerning the record. Examples of the identification information of the record (or group of records) are railroads in the mapping system or bridge bent lines in RDS.

The following is a discussion of some of the more common plan sheets produced by highway designers with an indication of where the basic graphics could be obtained for producing the sheet without requiring all of the input to be entered using the Interactive Graphics Drafting System. The discussion will follow

generally the practices of this Department and, while probably not the same as all highway organizations, the concepts should be similiar. The reader should also keep in mind that any reference to the capabilities of RDS should also be applicable to an interactive graphics design system.

Title Sheet. The purpose of the title sheet is to provide the general location of the project to be constructed along with identifying information and an index of the remaining sheets of the plans. The layout of the location of the project varies with its length; that is, if a project covers several miles of rural construction, the location is normally shown on a portion of a planning survey county map and the project would be depicted as a heavy line on the map. For an urban freeway, the project would normally be shown on a portion of a city map with all the roadways and ramps shown on the layout. The maps could be obtained from a file if they were developed and maintained using the drafting system or an automated mapping system. The project layout could be obtained from an RDS alignment file. Since interactive graphics drafting systems have the capability to store repetitive information such as the sheet border and the sheet index and combine the different elements into one graphic representation, the basic information required to produce the title sheet would be available and only minimal finalizing would be required to produce the final sheet.

Typical Sections. This sheet is used to convey typical roadway configurations for the contractors' reference. The basic information could come from the design cross-section file of RDS and the sheet layout from the drafting system.

Plan-Profile Sheets. These sheets provide a detailed graphic representation of the proposed construction including the location and width of roadways, storm sewers, culverts and bridges. Detail sheets are also produced for many of the items to provide more detail; however, the basic data would come from the same sources and be used as required and presented at the scale required for the purpose and with the detail needed. The background information showing the existing condition of the project location could come from the automated mapping system file developed for the survey of the project. The roadway layouts and profiles could come from RDS files and the sheet layout from the drafting system. If an interactive graphics hydraulic system was developed, as discussed above, the layout of the storm sewer could be available from it.

Estimate and Quantity Sheets. The purpose of these
sheets is to provide the contractor with the construction
items and their estimated quantities. This Department's
Contract Information System produces these sheets from the
engineer's plans estimate input and the graphics output
could be transferred to the drafting system for review and
finalization. Since the plans estimate is used to produce
the bid proposal and contract letting file, any revisions of
the estimate would have to be made using the Contract Infor-
mation System and the drafting system's copy updated.
However, the graphic representation would be available for
review by the different review offices using the drafting
system even if they were located in different cities.

Specification Data and General Notes. These sheets
also provide the contractor information on contract specifi-
cations that apply for this contract that are different than
the general specifications of the Department. The Contract
Information System provides the capability to produce the
sheets and the discussion under Estimate and Quantity Sheets
would apply for these sheets.

The list of sheets presented above is not intended to cover

all possibilities, but only to present the concept of the

transfer of graphics information from design systems to an auto-

mated drafting system to minimize the redrafting of data pre-

viously developed for design or other purposes.

An advantage of performing drafting with an interactive

graphics drafting system is the capture of the construction plans

(as well as other graphics such as schematics and right-of-way

maps) in a computer medium so that the data can be transferred

between offices without the delay of mail service. In a decen-

tralized organization such as Texas, this allows the design of a

facility to be reviewed during the design process and transmittal

of the final design to the headquarters by file transfer. It also

allows interactive revision of the plans by the headquarters

staff, if required, and the design office that developed the

plans. Any changes can be reviewed before they are finalized and advertised for letting without having District personnel travel to the headquarters office. Plotting of the final plan sheets could be delayed until just before the time to release them to the contractors for bid preparation.

In addition, with the design plans in a computer medium, the as built plans could be developed quickly and stored in a electronic form. The plans could then be recalled for development of plans for reconstruction of the facility without having to photographically reproduce them.

The user committee placed a priority of 3 on the development of interactive drafting capabilities for some of the sheets, such as plan-profile down to a priority of 5 for the title sheet drafting.

Construction

Once a project is let to contract, the construction inspection personnel need, in many cases, to calculate dimensions and elevations for layout of the construction for the contractor. The Roadway Design System provides several specialized capabilities for the construction personnel. These include using the general geometric capabilities for calculation of dimensions and elevations including bridge grades. An interactive graphics design capability for highway design should provide these specialized construction calculation functions. The user committee placed priorities of 5-8 on development of interactive graphics design capabilities for construction; however, many of the functions

would need to be addressed for use by the designer and therefore by available for use by construction personnel.

Final Quantities

The Roadway Design System provides capabilities for computing final earthwork pay quantities. The user committee placed a priority of 5 on development of interactive graphics capabilities for this function. The only development proposed by the committee was the interactive input of the data for defining any adjustments required to the final cross-sections and the request for the calculation of the final quantities along with interactive update of the data if subsequent runs were required. Also requested was the graphics display of the cross-section and haul plots produced for review.

Summary

This discussion of the system requirements for an interactive graphics design system which would cover all of the requirements of a highway designer to move a project from concept to final pay is by no means complete and is only intended to provide the user with a general concept and to document the work of the user committees that provided the basic outline used to develop the discussion. It should, however, provide a long range goal for providing the highway designer with interactive graphics design capabilities that are enjoyed by other disciplines. Subsequent sections of this report will discuss the capabilities to be provided under this project.

V. General User Design

Introduction

The preceding sections of this report have discussed in general terms the concepts of the project, provided definitions of terms, and outlined the concept of a total interactive graphics design system for many of the functions of highway design from project inception to construction completion and storage of the final plans. This and the following section will discuss in detail (although still in general terms) the user interface for the interactive graphics capabilities to be developed under this contract. The purpose is to outline to the system designers the functions to be provided and the needed user interaction with them. The capabilities to be defined in this section are those of the Interactive Graphics Roadway Design System (IGRDS) intended to provide the user with interactive graphics input/output functions for the Roadway Design System (RDS).

Interactive Graphics Aided Design System

Before defining IGRDS, a brief description of the the total concept of the Interactive Graphics Aided Design System (IGADS) development under this contract will provide the reader with an understanding of the interaction of the various systems making up IGADS. No detailed description of the minor modifications that will be made to the other batch systems will be provided as this report is intended to define the development of IGRDS. The other systems are existing and should be familiar to the reader. The systems which make up IGADS in conjunction with IGRDS are:

1.   Roadway Design System (RDS)

2.   Texas Automated Mapping System (TEAMS)

3.   Interactive Graphics Drafting System (IGDS)

4.   General Plotting System (GPS)

IGDS is a proprietary system and the rest were developed by the Department. Development on these systems under the contract will consist only of enhancements to support the needs of IGRDS. The interface between the systems will be through data files which allow each system involved to complete or add to the processing performed by another and produce updated data files, printed reports and hard copy plots. These systems and files are depicted in Figure 5 and discussed below.

Graphic Data File. The graphic data file is the common interface between all of the systems. The file supplements the existing plot file which has been the output medium for creating hard copy plots. All of the programs will output graphic data in the form of graphic elements. These graphic elements will be stored in a data file in the Graphics Interface Format (GIF) which was developed as a generalized graphic data base. GIF will provide a method of transferring RDS and/or TEAMS graphics to IGRDS and/or IGDS for review, use in design, or drafting. This will also allow the merging of RDS, TEAMS, and IGRDS graphics files for plotting by the General Plotting System and the transferring of the composite graphics data to IGDS for finalizing as plan sheets or other graphic output formats. The data could be transferred back to GPS for hard copy plotting of the plan sheets or plotted directly from the IGDS data base.

INTERACTIVE PROCESSING

INTERACTIVE GRAPHICS DRAFTING SYSTEM (IGDS)

+ GRAPHICS DISPLAY

+ INPUT/OUTPUT CONTROL

+ DRAFTING

+ GRAPHICS FILE
  MANAGEMENT

+

INTERACTIVE GRAPHICS ROADWAY DESIGN SYSTEM (IGRDS)

1. HORIZONTAL
   ALIGNMENT

2. VERTICAL
   ALIGNMENT

3. GEOMETRY

4. -

IGDS GRAPHICS FILE

+ IGRDS DEVELOPED

+ IGDS DEVELOPED

+ MAP FILE (SURVEY)

IGRDS PROJECT FILE

1. POINT/CURVE

2. DESIGN DATA

3. -

TEXAS AUTOMATED MAPPING SYSTEM (TEAMS)

(INPUT)

GENERAL PLOTTING SYSTEM

GRAPHICS INTERFACE FILE (GEOGRAPHIC DATA BASE)

(INPUT)

ROADWAY DESIGN SYSTEM (RDS)

RDS PROJECT FILE

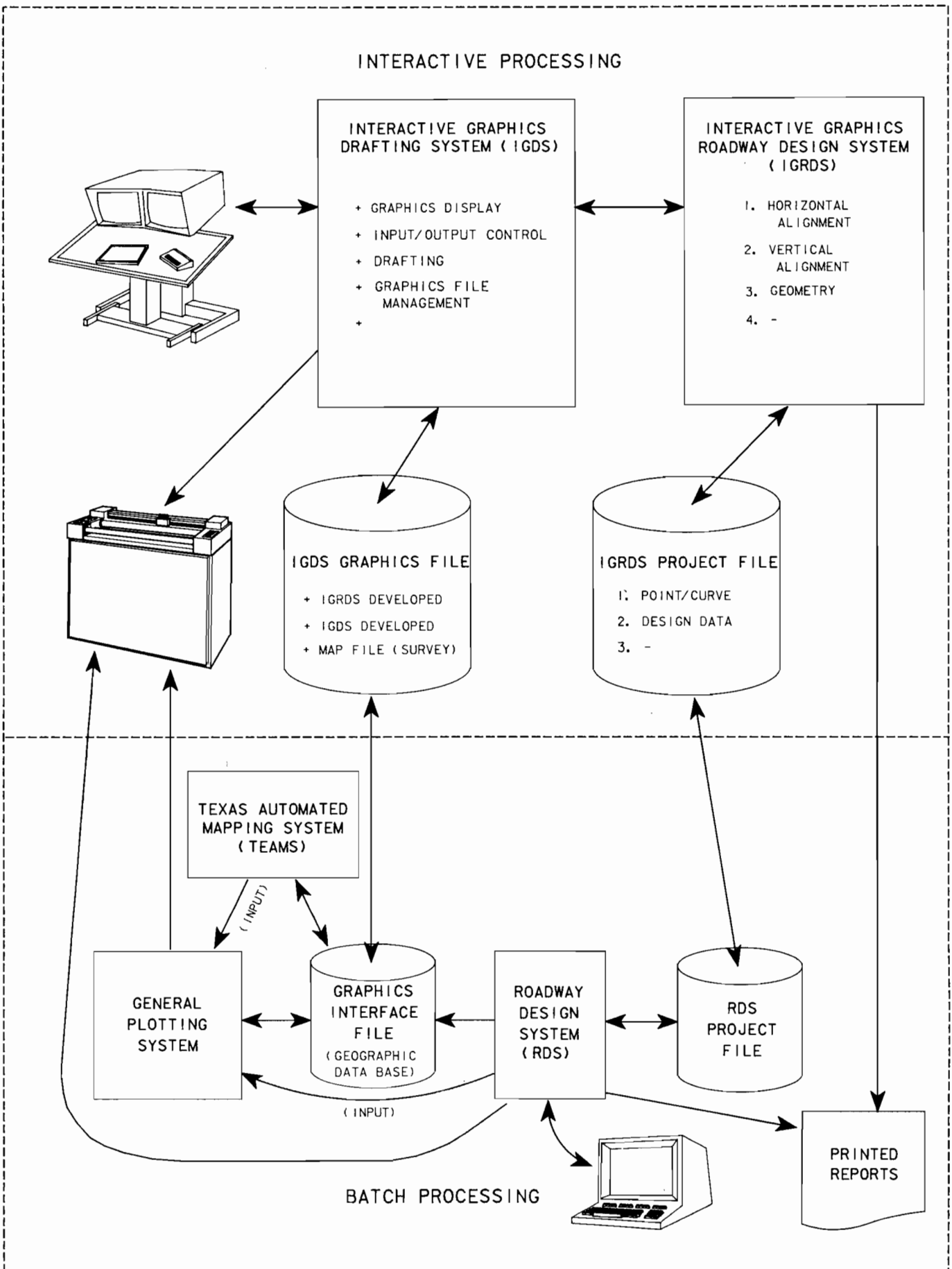### PRINTED REPORTS

BATCH PROCESSING

FIGURE 5.   INTERACTIVE GRAPHICS AIDED DESIGN SYSTEM

V-3

The ability to selectively extract data from a GIF file by numeric key will be available. Each GIF record is indexed by codes relating the graphic data to its specific application in the source program. In the case of RDS, the codes relate to features such as roadway, structure and span. This will allow specific parts of the graphic data file to be plotted independently of the remainder of the file or to be transferred to IGRDS for use in a design process thereby minimizing the amount of graphics data the user must have displayed on the graphics station during the design session.

RDS Project File. The RDS project file will be used by both RDS and IGRDS. This will allow the project file to be updated during IGRDS processing and transferred to RDS to complete the remainder of the project file update for those functions of RDS that will not be included in IGRDS (functions not related to graphics). The reverse procedure could also be used in the case of projects that were started using RDS where additional design was to be performed using IGRDS.

Roadway Design System. The Roadway Design System will continue to process in a batch mode either on a main-frame computer or on a mini-computer used by IGRDS in a background mode similar to now with the following exceptions:

1. Project File. The project file will stay basically unchanged; however, it may be transferred between RDS and IGRDS always reflecting the updates by either system. The graphics data base may also be added to the project file for storing with the computation data.

2. Graphic Output. All graphic output, which previously consisted of only a series of digital plotter instructions, will now additionally consist of a series of graphic elements (lines, areas, characters, etc.). The

user will have the option of producing both. These graphic element records will be in the GIF format. This will allow the updating of the graphic data file using both RDS and IGRDS. The plotting of the graphics records will be performed using the General Plotting System (discussed below).

Texas Automated Mapping System. TEAMS also outputs graphic data in the GIF format to the graphic data file. This allows map data to be transferred to IGRDS for use as background survey information. The graphic display of map data will allow the map data to be used as graphic input while designing. The common graphic format of map and RDS plan view graphics will also allow the two to be plotted together, using the General Plotting System, for the development of plan sheets and/or transferred to IGDS for finalization.

Interactive Graphics Drafting System. IGDS referred to in this report would be one of the commercially available systems. As stated earlier, the design station to be used in the development of IGRDS will consist of the same equipment that composes an IGDS drafting station with the possible addition of an alphanumeric CRT for IGRDS input/output. IGDS will also perform all of IGRDS's graphic manipulation functions. IGDS creates a graphic data base similar in format to the GIF format and can be converted to the GIF format and visa versa. This allows graphic data from sources such as RDS, TEAMS and IGRDS to be transferred to IGDS for further processing. IGDS functions such as adding elements, deleting elements, revising elements, windowing, rotating, and annotating provide the user with a method of interactively modifying the graphics from these other sources. This is espe-

cially useful in the creation of plan sheets such as plan pro-file, bridge layout, and right of way. The modified graphics file may then be transferred to the General Plotting System for hard copy plotting. Note: IGDS could be used to develop the background survey map file like that produced by TEAMS if the using organization did not implement TEAMS.

General Plotting System. GPS will take GIF data from any source to create hard copy plots on several different digital plotters both drum and flat-bed. The system allows the user to plot graphic data at the scale, rotation and window defined by the source program or to modify these parameters (scale, rotation or window) and plot the data. GPS will be discussed under "Graphics Manipulation".

Interactive Graphics Roadway Design System

The functions that will be provided in IGRDS are selected RDS functions with the enhancements of interactive graphic input/output, data editing and on-line processing of some of the RDS calculations. The criteria used to define the two methods of processing input in IGRDS is defined below. The definition of a set of data is a corresponding line of RDS input on a coding form:

1. On-Line Design Computations. If the design function of a set of data requires relatively few computations, the computations will be performed on-line. Examples include individual geometry commands and horizontal alignments.

2. Input Creation. During the discussion to follow on the user design of IGRDS, the text has been prepared to indicate that for some processes an input capability will be developed which is nothing more than the input of card images in a key to disk mode for background processing. However, there are systems available that

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provide this function; therefore, during the system design stage it may be determined that it would be sufficient to utilize these available systems and only to develop the input capabilities needed for the on-line computations discussed in number 1 above. This would not modify the user interaction with IGRDS except that he would be executing another program to perform the input and editing instead of IGRDS.

The design processes available in RDS that will also be provided in IGRDS are listed below with a brief description of each of the functions.

1. Command Geometry. This process provides routines for general coordinate geometry calculations including specialized routines for bridge geometric calculations. The process provides for use of horizontal alignments in the calculation process and the calculation of elevations in many of the commands.

2. Design Data. This process provides routines to allow the entry of the three dimensional description of the various components of the roadway shape for calculation of the design cross-sections and earthwork quantities. It also allows entry of terrain functions such as Partial Cross-section Adjustment and Earthwork.

3. Plot Requests. This process will be an enhanced plot request capability including the definition of requests for plots from either the graphics or station files.

Project Initialization

This function is the process that will be used to start a design session and it can not be defined in detail until the system design is completed. The exact method required will depend upon the method used to interface IGRDS with the Interactive Graphics Drafting System, the drafting system the using organization selects to utilize with IGRDS, and the particular computer utilized. In general, however, the user will enter a command such as 'RUN IGRDS' and the system will then prompt him to provide the required information such as the files (graphic and

project) that will be used in the design session, to indicate whether he wants to reinitialize the files (if they exist) or update them, and to identify project information such as control and section. Once the initializiation process is completed, the system will provide the user a means of inputting a command to begin the design session.

Command Geometry

The Command Geometry Process will provide the user with the ability to perform all of the calculation functions provided by the Command Geometry portion of RDS. The process will provide the user with the ability to define, and delete geometry data elements. Most of the RDS geometry commands including roadway and bridge geometry will be available to the user in this process. The difference in the command set in IGRDS from the existing Roadway Design System will be that there will be commands for all functions but the options now used for some of the commands will be deleted. In addition, line and circle elements now defined without limit will be revised to include limits for display purposes. This will not affect the calculations as now performed by RDS; except for such cases as a user intersecting two lines that do not intersect in the display, then the calculated and displayed point will not be on the lines. There will be provisions to modify the limits of the geometric elements to represent the feature correctly. In addition, string elements will be added. These will be similar to the PSLB elements used in bridge geometry. These string elements could be used to repre-

sent right-of-way lines or edge of pavements, and calculations such as intersection of the string elements will be available. Some RDS geometry commands, such as RDWY, which generate tabular output may not be included in IGRDS.

The following discussion outlines the user interaction with the interactive graphics command geometry.

Graphic Display. When a geometry command is entered the system will automatically retrieve the graphics file. The complete graphic control command set provided by the drafting system will be available throughout the command geometry process for initiating or changing the viewing window and for controlling the features to be displayed. (Refer to the "Graphics Manipulation" section for a discussion of the capabilities that might be available.)

General Geometry Input. Immediately following the initial graphics display, the system will respond with a prompt for the user to input data for the geometry command entered. If required, the user may input HELP and the system will display the geometry commands available with their corresponding command code. An update command will be used to revise or delete an existing geometric element and a review command will be used to review existing stored data. When processing of a command is complete, the user will have the ability to proceed to another command directly from the input display of the command used.

Geometry Data Input. The system will issue prompts for each of the applicable data required for each command. All data may be

keyed in; however, the system will provide the user with optional interactive graphic input methods for certain types of data as described below:

1. Element Identification. Currently in RDS geometry, storage numbers are input when existing geometry elements (points, curves, bents, etc.) are being referenced and when a number is being assigned to a newly defined element. However, in IGRDS, when an existing element needs to be retrieved for use in a command, the user will graphically identify it on the screen.

2. X-Y Coordinates. X-Y coordinates may be defined by digitizing a point on the screen or keying in the value. If digitized, the system will compute X-Y coordinates from the digitized point. If the coordinate desired is on an existing element and the drafting system being used for graphics manipulation has the capability, the system would compute a coordinate on the element opposite the point digitized if the digitized point lies within a given tolerance. Whether the coordinate returned to IGRDS is to be on an element or at the position digitized will be at the user's option.

3. Station. A station may be defined by digitizing the station location on the screen or keyed in. The system will compute a station from the digitized point.

4. Distance. A distance may be graphically defined by digitizing two points or the distance may be keyed in.

5. Horizontal Alignment Letter. When a horizontal alignment letter is required, the horizontal alignment may be graphically identified on the screen. The system will then retrieve the alignment letter or the alignment letter may be keyed in.

6. Bearing or Azimuth. A bearing or azimuth may be defined by graphically identifying an element on the screen or the data may be keyed in.

7. Radius. A radius may be defined by keying in the radius or degree of curve, or graphically by one of the following options:

    a. Digitize two points representing the length of the radius.

    b. Digitize three points on the circumference of an arc if it is not known if the arc was defined by a radius as may be the case of a displayed arc from a mapping system.

c. Digitize a point on the circumference of a circle known to have been defined by a radius (or degree of curve) such as from IGRDS or RDS.

When one of the graphic input options is used to define data, the system will display the results in the data field for the user's acceptance or revision before entering the data into the record.

Editing and Processing. When the data entry is complete for a geometry command, the system will edit the input data. If no editing errors occur, the geometry command will be processed as described below:

1. Retrieve the required data from the project file.

2. Make the necessary computations.

3. Display the results of the computations.

4. Display the graphic representation of the computed element. General geometry lines and circles will be displayed in accordance with the limits of the element input. Note: If the element does not fall within the screen display, the user may modify the viewing window to review the element. (Refer to the "Graphics Manipulation" section.)

Data Storage. When the above processing is complete, the system will perform the following steps:

1. Add the computed geometry element(s) to the geometry files.

2. Add the graphic record(s) to the graphic file and project file.

Delete Geometry Instruction. The following steps describe the process for deleting an existing geometry element:

1. Retrieve Element. The element to be deleted will be graphically identified on the screen.

2. Delete Stored Data. After the element is identified, the user will enter the "Delete" command to delete the data. The following file updates will then occur:

a. The geometry elements will be deleted from the geometry files.

b. The graphic record(s) will be deleted from the graphic file. (Existing graphic elements may remain on the display until the screen is updated.)

Printed Reports. IGRDS will produce output reports of the geometry commands as they are input and processed. To print the output file the user will use the "Print" command.

Design Data

The user will have the ability to define and store the various types of RDS design data and the ability to update any existing design data in a project file. To enter Design Data, the user will enter one of the Design Data commands listed below:

+ INIT - Initialize design data files

+ HALG - Horizontal Alignment

+ VALG - Vertical Alignment

+ TSTA - Roadway Template Stations

+ TEMP - Template Table

+ SUPR - Superelevation

+ WIDN - Widening

+ SSTA - Side Slope Stations

+ SLOP - Side Slope Tables (Cut/Fill Tables)

+ MSTA - Median Stations

+ MEDN - Median Tables

+ DGRD - Ditch Grades

+ EXCP - Design Exceptions

+ RWMX - ROW / Maximum Slope

+ CFAC - Compaction Factors

+ ADDQ - Added Quantities

+ FBAL - Forced Balance

+ OFFS - Offset Data

+ EQAT - Equation Data

+ MODX - Original and Final Cross-Section Modification

+ ERWK - Earthwork Request

If the user is not sure of the design data command he needs, a HELP command will provide him with a list of the available commands.

The following discussion outlines the user interaction for each of the design data commands.

INIT. This command provides the user with the capability of instructing the system to initialize all of the design data on the project file. Each of the other design data commands will provide an option to initialize that particular type of data.

HALG. This command instructs the system to start the horizontal alignment process which will provide the user with the ability to define and store horizontal alignments or to update existing horizontal alignments. This process will allow the input of P. I. data and then allow the user to visually review the defined or revised horizontal alignment graphically on the display screen.

1. Graphic Display. When the HALG command is entered, the system will instruct the user to enter the horizontal alignment letter for the roadway desired (see "Roadway Identification"). The complete graphic control command set provided by the drafting system will be available throughout the horizontal alignment process for initiation or changing the viewing window and for controlling the features to be displayed. (Refer to the Graphics Manipulation" section for a discussion of the capabilities that might be available.)

   The user might at this point or at any time during the horizontal alignment process use the capabilities of IGDS to "sketch" his proposed horizontal alignment.

This would place a representation of the horizontal alignment (although it would not be stationed) on the display screen for use in defining it to IGRDS. Using the interactive graphics capabilities of IGDS, alternative horizontal alignments could be "drafted" before using IGRDS to input the alignment.

2. Roadway Identification. Before defining a new alignment, the user must first determine whether there is existing data for the roadway. The user will enter the desired roadway -letter and the system will determine whether horizontal alignment data exists for that roadway. If data does exist, the user will have the option to delete the existing data and define a new horizontal alignment for the roadway.

When the status of the horizontal alignment data has been established, the user may then start defining P. I. data. The system will automatically retrieve the graphic file if one exists.

3. New Horizontal Alignment. The following steps describe the user interface for defining a new horizontal alignment.

    a. Enter P.I. Data. The system will first prompt the user to enter the data for the initial P.I. and then to enter the data for each subsequent P.I. For each P.I. defined, the system will display messages instructing the user to enter data for the various P.I. parameters. All data parameters may be keyed in; however, the following P.I. data will have the optional input methods described below:

        (1) P.I. Number. If left blank, the system will assign the P.I. number and insert it in the data field.

        (2) Radius. The radius may be optionally defined using the procedures described under Command Geometry data input.

        (3) P.I. Coordinates. The P.I. coordinates may be optionally defined by either digitizing a point or retrieving an existing element from the display.

    b. Data Edit. When the data entry is completed for a P.I., the system will edit the input data. If no editing errors occur, the system will display a symbol representing the defined P.I.; then it will prompt the user to enter data for the next P.I.

4. Existing Horizontal Alignment. The following steps describe the user interface for this process:

a. <u>Horizontal Alignment Update Commands</u>. When updating a horizontal alignment, the user will be able to add, revise or delete P.I.'s. A command will be provided for each of these functions. The user will select one of these commands prior to entering data for each addition, revision or deletion.

b. <u>Enter Data</u>. After the update command is entered, the system will prompt the user to enter data for the selected command. The four update commands are:

(1) <u>Add P.I.</u> When a P.I. is to be added to the end of a horizontal alignment, the data entry will be the same as that when defining P.I.'s for a new horizontal alignment.

(2) <u>Insert P.I.</u> When a P.I. is to be added between two existing P.I.'s, the first of the two P.I.'s must be identified. The P.I. number may be keyed in or graphically identified. If the P.I. is to be added ahead of the first P.I., then a P.I. number of "0" must be entered.

(3) <u>Revise P.I.</u> When a P.I. is to be revised, the user will first be required to retrieve the P.I. data by graphically identifying the P.I.

For the update options above, the system will respond by displaying the retrieved P.I. data and by flashing the existing P.I. symbol on the display. The system will then display messages prompting the user to enter new data parameters. The user will enter only data to be revised. Data may be keyed in or the optional input methods described under "New Horizontal Alignment" may be used.

(4) <u>Delete P.I.</u> When a P.I. is to be deleted, the user must first retrieve the P.I. as discussed under "Revise P.I." After the P.I. is retrieved, the user will then instruct the system to delete the P.I.

c. <u>Data Edit</u>. When data entry is completed for an addition, revision or deletion, the system will edit the input data. In the case of an addition or revision if no editing errors occur, the system will display a symbol representing the new P.I. The system will then instruct the user to input another command.

5. <u>Horizontal Alignment Calculation Command</u>. At any time during the definition or update of a horizontal align-

ment, the user will have the option to enter the horizontal alignment calculation command. When entered, the system will use all currently defined P.I.'s, make all horizontal alignment computations, check for curve overlaps, and produce a horizontal alignment plot on the display screen.

6. Horizontal Alignment Annotate Command. After horizontal alignment calculations have been performed, the user may enter the "Annotate" command to annotate the displayed alignment. -Commands will be provided to suppress or add the various alignment labels such as bearing, radius, and equation. Commands will also be provided to define or modify parameters such as tic interval, station label interval and character size. The user will have the option to enter all of the parameters or use system defaults.

7. Store Command. When the user is ready to store the resulting horizontal alignment P.I. and graphic data, he will request this storage by selecting the "Store" command. When "store" is selected, the system will first check for curve overlaps. If no overlaps occur, the system will update the project file by replacing the previous horizontal alignment data (for update) with the currently defined data. The existing graphic data will also be replaced.

VALG - This command instructs the system to start the vertical alignment process which will provide the user with the ability to define and store new vertical alignments or to update existing vertical alignments. This process will also allow the user to input vertical P.I. data with a set of vertical geometry commands, or use default parameters from stored design tables. As in the horizontal alignment process, the user will be able to graphically review the defined or revised vertical alignment on the display screen.

1. Graphic Display. When the VALG Command is entered, the system will prompt the user to enter the horizontal alignment letter for the roadway desired (see Roadway Identification). The complete graphic control command set provided by the drafting system will be available throughout the vertical alignment process for initiating or changing the viewing window and for controlling the features to be displayed. (Refer to the "Graphics

Manipulation" section for a discussion of the capabilities that might be available.)

2. Roadway Identification. Before defining a new vertical alignment, the user must first determine whether there is existing data for the roadway. The user will enter the roadway letter and the system will determine whether the vertical alignment data exists for that roadway. If data does exist, the user will have the option to delete the existing data and define new vertical alignment data for the roadway.

When the status of the vertical alignment has been established, the user may then start defining V.P.I. data. The system will automatically retrieve the graphics file if one exists.

3. New Vertical Alignment. The following steps describe the process for defining a new vertical alignment.

    a. Design Speed. The user will first be prompted to enter the design speed. The system will then display the maximum grades for various terrain conditions and types of highways for the input design speed. The user will then enter the appropriate maximum grade.

        NOTE: The maximum grade input will not have to correspond to those listed in the display.

    b. Enter V.P.I. Data. The user will next be prompted to enter the data for the initial V.P.I. and then data for each subsequent V.P.I. For each V.P.I. defined, the system will display messages prompting the user to enter data for the various V.P.I. parameters. All data parameters may be keyed in; however, the following V.P.I. data will have the optional input methods described below.

        (1) V.P.I. Number. If left blank, the system will assign the V.P.I. number and insert the number in the appropriate data field.

        (2) V.P.I. Station and Elevation. The V.P.I. station and elevation may be optionally defined by digitizing a point on the screen, identifying a vertical geometry point on the screen, or keying in the data.

        (3) Vertical Curve Lengths. A vertical length may be optionally defined by one of the following methods:

        (a) If left blank, the system will assign the curve length based on K factor and grade differential. This will not be assigned until the next V.P.I. is defined.

        (b) A curve length may be keyed in.

c.   Data Edit. When the data entry is completed for a V.P.I., the system will edit the input data. If no editing errors occur, the system will display a symbol representing the defined V.P.I., then instruct the user to enter data for the next V.P.I.

4. Existing Vertical Alignment. The following steps describe the user interface for updating an existing vertical alignment:

a. Design Speed. The user will first be asked if the design speed needs to be revised. If so, the procedure discussed under "New Vertical Alignment" is used.

b. Vertical Alignment Update Command. When updating a vertical alignment, the user will be able to add, revise or delete V.P.I.'s. Commands will be provided for each of these functions. The user will enter one of the commands prior to entering data for each addition, revision or deletion.

c. Enter Data. After the update command is entered, the system will prompt the user to enter data for the selected option command. The four update commands are discussed below.

      (1) Add V.P.I. When a V.P.I. is to be added to the end of a vertical alignment, the data entry will be the same as that when defining V.P.I.'s for a new vertical alignment.

      (2) Insert V.P.I. When a V.P.I. is added between two existing V.P.I.'s, the first of the two V.P.I.'s must be identified. The V.P.I. number may be keyed-in or graphically identified on the screen. If the V.P.I. is to be added ahead of the first V.P.I. on the vertical alignment, then a V.P.I. number of "0" must be entered.

      (3) Revise V.P.I. When a V.P.I. is to be revised, the user will first be required to retrieve the V.P.I. data by graphically identifying the V.P.I.

    For the update options above, the system will respond by displaying the retrieved V.P.I. data and

by flashing the existing V.P.I. symbol on the display. The system will then display messages prompting the user to enter new data parameters. The user will then enter only the data parameters to be revised. Data may be keyed in or the optional data input methods described under "New Vertical Alignment" may be used.

    (4) <u>Delete V.P.I.</u> When a V.P.I. is to be deleted, the user must first retrieve the V.P.I. as discussed with "Revise V.P.I." After the desired V.P.I. is retrieved, the user will then instruct the system to delete the V.P.I.

  d. <u>Data Edit.</u> When data entry is completed for an addition, revision or deletion, the system will edit the input data. In the case of an addition or revision, if no editing errors occur, the system will display a symbol representing the new V.P.I. The system will then prompt the user to enter another command.

5. <u>Vertical Alignment Calculation.</u> At any time during the definition or update of V.P.I.'s, the user will have the option to enter the vertical alignment calculation command. When entered, the system will use all currently defined V.P.I.'s, make all vertical alignment computations, check for curve overlaps, and produce a vertical alignment plot on the display screen.

When the vertical alignment calculations are performed a V.P.I. Summary List will be displayed. The following will be included for each V.P.I.:

a. V.P.I. Number

b. Station

c. Elevation

d. Vertical Curve Length(s)

e. Back Tangent Grade

f. Design Speed

g. Truck speed reduction for back tangent

h. Error Conditions

    (1) If back tangent grade exceeds maximum grade

    (2) If curve overlaps occur.

6. <u>Vertical Alignment Annotate Command</u>. After vertical alignment calculations have been performed, the user may enter the "Annotate" command to annotate the displayed vertical alignment. Commands will be provided to suppress or add the various labels such as grade and V.P.C. Commands will also be provided for defining certain annotation parameters such as character size. The user will have the option to enter all of the parameters or use system defaults.

7. <u>Vertical Geometry</u>. The system will provide the user with vertical geometry commands that may be used to compute V.P.I.'s. These commands will allow the user to perform the functions listed below:

    a. Store and display critical grade points.

    b. Store and display tangents.

    c. Store and display parabolic curves.

    d. Compute tangents and store points for recall as V.P.I.'s.

    e. Fit curves to critical points.

    The user may enter any of the vertical geometry commands at any time during the process of defining or updating a vertical alignment. This will allow the user to temporarily exit the input of V.P.I. data and then return after the vertical geometry computations are completed.

8. <u>Store Command</u>. When the user has completed V.P.I. data entry, he will instruct the system to store the data. A "Store" command will be entered to accomplish this. When this command is entered, the system will update the project file by replacing the previous vertical alignment data (for update) with the currently defined data. The existing graphic data will also be replaced.

    NOTE: The system will not store the data if curve overlaps occur.

<u>Other Design Data Commands</u>. The remaining types of design data processes will have an input process for storing and updating the particular type of design data. These input processes will be based upon a forms type of input with all data keyed in

and with no graphic input options available. However, the user will have the ability to display any graphics file that has previously been developed and that may aid in determining the input data. An example would be the horizontal alignments for the project. The remaining design data processes are listed below:

+ TSTA - Roadway Template Stations
+ TEMP - Template Table
+ SUPR - Superelevation
+ WIDN - Widening
+ SSTA - Side Slope Tables (Cut/Fill Tables)
+ MSTA - Median Stations
+ MEDN - Median Tables
+ DGRD - Ditch Grades
+ EXCP - Design Exceptions
+ RMAX - ROW / Maximum Slope
+ CFAC - Compaction Factors
+ ADDQ - Added Quantities
+ FBAL - Forced Balance
+ OFFS - Offset Data
+ EQAT - Equation Data
+ MODX - Original and Final Cross-Section Modification
+ ERWK - Earthwork Request

Entry of any of the above commands will instruct the system to start the applicable design data input process. Once the data entry is complete, the system will edit the data and, if no errors occur, store the data in the project file.

The Design Data commands may be used as required to enter the needed design data for the earthwork design or to modify an existing set of design data to obtain a different earthwork design. Once the design data process is complete and the data is stored, it will be available for subsequent processing using RDS as is currently performed. NOTE: While the entry of the other Design Data is proposed to be by a forms type input for the system developed under the contract, some design of interactive graphics input procedures for the data was performed and is included in the Appendix to document the work performed.

Plot Requests

The Plot Request process will provide the user with commands for initiating requests from the Graphics or Project File for (1) plotting using the General Plotting System (refer to "Graphics Manipulation" section for a discussion of capabilities), or (2) transferring files to the Interactive Graphics Drafting System for viewing on the graphics display or having enhancements drafted prior to plotting. Cross-section plots are an example of the type of plot that would be requested from the project file. As previously discussed, the user will have the ability to store horizontal and vertical alignments in the graphics file in the design data process.

When this process has been selected, the system will instruct the user to enter the command for the type of plot needed. A detailed description of the process or all of the commands will not be provided in this report; however, when the user enters the

plot request command, the system will prompt the user to enter the data for the plot.

When the user enters the command to produce a plot from the graphic file, the system will request input required by the General Plotting System. The reader is directed to the "Graphics Manipulation" section for a discussion of the plot parameters available. In general, the user will input parameters defining the graphics files to be plotted (RDS plan, TEAMS plan, and RDS profile for example), the scale (horizontal and vertical), file rotation, features to be plotted (such as horizontal alignment and right-of-way lines), the limits of the plot (window), and orientation. The user will also define the symbology tables and sheet type to be used (if applicable).

Summary

The discussion in this section, General User Design, is intended to provide the reader with an understanding of the user interface proposed for the Interactive Graphics Roadway Design System and the capabilities to be provided. The user will have the ability to transfer between the Design Data functions of IGRDS as needed to prepare the data needed for processing using RDS. Once all of the input is prepared, the user will exit and utilize the capabilities available to him to batch process the data. Depending upon the mini-computer used by the drafting system, he may have to transmit the data and project files to a main-frame computer for processing; or, if the mini-computer is large enough, he may submit the data for processing on the mini-

computer.   Since the results of an IGRDS Design Data Process are card images and the project file, the subsequent processing is flexible.   It should be noted that several of the functions of IGRDS such as Command Geometry and Horizontal and Vertical Alignments will process data as it is input.   The subsequent processing of the data is at the user's option and he can make the decision depending upon his needs.

VI. Graphics Manipulation

Introduction

The purpose of this section is to describe the two graphics display methods to be available with the Interactive Graphics Aided Design System (IGADS). The first portion of the section will outline the basic functions needed in the Interactive Graphics Drafting System (IGDS) for graphics display when used with the Interactive Graphics Roadway Design System (IGRDS). The second section will describe the capabilities of the General Plotting System (GPS) for generating digital plots from Graphics Interface Format (GIF) files.

Interactive Graphics Drafting System (IGDS)

This section will not attempt to describe the functions needed for drafting, since the individual user agencies of IGADS will have to obtain the system which meets their specific drafting needs. The description will outline the basic functions needed by the drafting system to provide the graphics display functions for IGRDS. The description is not intended to serve as system specifications and should not be used by an agency to purchase a drafting system in anticipation of implementing IGRDS when it becomes available. The documentation of IGRDS will contain the specifications required by the display system used with IGRDS.

Program Interface. IGDS must have a means for the system to be linked with IGRDS. The interface will require that IGDS accept commands passed from an external application program (IGRDS in

this case), allow the user to perform graphics functions such as digitizing coordinates when control has been passed to IGDS, and return the value(s) requested by an application program when the user completes the graphic command functions. The system will also have to accept commands from an application program, perform the tasks, and return any requested data back to the application program without the user having to issue any commands using the input devices provided by IGDS.

Graphic File(s). The system must be capable of accepting a graphics file generated by an application program such as RDS and store the file in a graphic data base. IGDS must also provide the user with the ability to develop (draft) a graphics file with a graphics command set provided by the system. The user must have the ability to establish a new file, recall an existing file or utilize a file currently being displayed as described below:

1. Establish a New Graphic File. When the user needs a new graphics file established to accept graphics data from IGRDS for example, the system should allow him to enter a file name, check if a file exists by that name and, if so, require the user to verify the file name before deleting an existing file. The system should allow the user to establish the following parameters for a new file:

    a. Linear unit precision (i.e. .01)

    b. Linear unit name (i.e. feet)

    c. Angular unit precision (i.e. 1)

    d. Angular unit name (i.e. degrees, minutes and seconds)

    e. Text height

    f. Symbol scale

    g. Relative origin of file

The user must also have the ability to define pattern, symbol and font tables to be used in displaying the graphics generated. The user should be provided default tables and be able to define specific tables for his purposes. The tables would establish the symbology used to display text, lines and points. These tables and parameters should not have to be redefined when the file is recalled with subsequent processes.

2. Recalling an Existing Graphic File. The user must have the ability to recall an existing graphic file by name and have the file available for display.

3. Currently Displayed Graphic File. IGDS must allow the application program to access an active graphic file regardless of whether or not the user has changed processes in the application program.

Display Control Commands. IGDS must provide the user with the ability to establish the initial appearance of the graphic display of a graphics file and to modify it at his option. A set of display control commands need to be provided for performing such functions as defining the viewing window origin and orientation, zooming, and controlling the features to be included in the display. The user must have the ability to select these commands at any time during an IGRDS design process and then continue his operation at the point where he left off. The commands may be entered by keyboard or data tablet command with a combination of both methods being preferred. The needed display control commands are discussed below:

1. Display. After a graphic file has been established or recalled, the user should be able to request an initial display using a single command. This command should have the default values listed below for the window origin, scale and orientation.

    a. New Graphic File (no data).

        (1) Window Origin - The screen origin should be set equal to the origin of the graphic file.

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> (2) Window Scale - Both the X and Y scales should
> be set equal to one screen unit per graphic
> file linear unit.
>
> (3) Window Orientation - The window orientation
> should be set equal to zero degrees (due east).

> b. Existing Graphic File - An existing graphic file
> should be displayed using the window origin, scale
> and orientation from the last time the file was
> displayed. If the file was created from an applica-
> tion program, the following should be used.
>
> (1) Window Origin - The window origin should be
> calculated by centering the graphic data on the
> screen.
>
> (2) Window Scale - The window scale should be cal-
> culated by filling the screen with the graphic
> data.
>
> (3) Window Orientation - The window orientation
> should be set equal to zero degrees (due east).

2. <u>Zoom In</u>. A command should be provided to produce a new display in which the current viewing window is magnified by a factor. The zoom command should allow the user an option to select a point on the screen that would be the center of the new viewing window.

3. <u>Zoom Out</u>. This command should produce a new display in which the current viewing window is reduced by the factor mentioned above.

4. <u>Window Area</u>. This command should allow the user to modify the viewing area. One method of instructing the system of the area to be displayed is for the user to select two points on the screen which would be the diagonal of the next viewing window. The system should create a new display using the maximum magnification that will allow the graphic data within the window to fit on the screen.

5. <u>Window Center</u>. This command should allow the user to select a point on the screen which is the center of the next viewing window. The system should then create a new display centered about the selected point using the current magnification.

6. <u>Window Origin</u>. This command should allow the user to enter the origin of the next viewing window. The system would then create a new display using the current magnification and the input origin.

7. <u>Fit</u>. This command would produce a new display using the maximum magnification that would allow all of the elements in the graphic file to fit on the screen.

8. <u>Delay</u>. If the IGDS being used by an agency uses storage tubes for graphics display, the system should provide a command that would "delay" updating the screen until the user specifically requested a screen update by command. This command would stop the system from deleting the existing graphic representation on the screen when deleting an element. When this command was active, the system should delete the graphic data from the graphic file as directed by the user or IGRDS, but the screen would not be updated. The system should display a symbol on the existing element to indicate that it has been deleted from the graphic file.

9. <u>Update</u>. If the delay command is used, this command would be used to erase and redraw the screen while the system was in the delay mode.

10. <u>Data Level</u>. The system should provide the user with the ability to select the graphic elements that are to be displayed on the screen either by providing data levels to separate different types of graphic elements, or commands that will include or exclude graphic elements by type. The identification of the graphic elements should be by the graphic data's function in the application program that created it. The identification or key should be used to group the data into hierarchical levels. A method should be provided to allow the user to identify the data levels or types to appear in the graphic display. The following options should be provided for selecting the elements to be displayed:

    a. Display all data.

    b. Delete all data from the display.

    c. Display a particular group(s) of data.

    d. Delete a particular group(s) of data.

    e. Display a sequence of data groups.

    f. Delete a sequence of data groups from the display.

11. <u>Grid On</u>. This command would allow the user to display a reference grid of the coordinate system. The grid should be displayed by a symbol spaced at intervals defined by the user. The grid display should also allow the display of grid labels spaced at intervals defined by the user. The system should allow the user to define different "scales" in the X and Y directions.

12. <u>Grid Off.</u> This command should allow the user to delete the grid display.

13. <u>Grid Interval.</u> This command should allow the user to define the following grid intervals:

    a. X-axis grid interval

    b. Y-axis grid interval

    c. X-axis tick interval

    d. Y-axis tick interval

    e. X-axis label interval

    f. Y-axis label interval

14. <u>Line Pattern.</u> This command should allow the user to define an active line pattern (display symbol). The user would enter a code indicating the line pattern from the Pattern Table to be used. Once a pattern is defined, all subsequent graphic elements defined should be stored and displayed with that line pattern until another is specified. The basic line pattern should be a solid line.

15. <u>Line Weight.</u> This command should allow the user to define an active line weight. Once a line weight is defined, all subsequent graphic elements should be stored and displayed with that line weight until another is specified.

16. <u>Font.</u> This command should allow the user to define the active character font. The user would enter a code indicating the font in the Font Table. Once a font is defined, all subsequent graphic characters defined should be stored and displayed with that font type until another is specified.

17. <u>Character Height.</u> This command should allow the user to define the active character height. Once defined, all subsequent defined graphic characters should be stored and displayed with the input character height until another is specified.

18. <u>Symbol.</u> This command should allow the user to define the active symbol type and size. The user would input a code indicating the symbol to be used from the Symbol Table and the symbol size. All subsequent defined points should be stored and displayed with the active symbol type and size until another is specified.

19. <u>X-Y.</u> This command should allow the user to key in coordinates as input to a graphic command.

20. <u>Digitize</u>. IGRDS will provide the user the option of defining certain types of data parameters graphically. In this case, a point(s) will be digitized using IGDS to represent data such as coordinates, bearings, distances, stations and radii. When the user chooses the optional graphic input while using IGRDS, IGRDS will pass a command to IGDS as to the type of data the user is to define. IGDS must accept the command and instruct the user to enter the data required, and pass the requested data back to IGRDS for processing. IGDS should provide the user with the abililty to digitize points from the screen by positioning a graphic cursor ("cross-hair") at the proper position on the screen. The movement of the graphic cursor should be by a method such as a free floating cursor on a data tablet.

Also, IGDS should provide a method for the user to indicate that the point desired is on a displayed graphic element and then to compute the coordinates of a point on the graphic element opposite the point digitized, thus not requiring the user to position the "cross-hair" exactly on the element.

21. <u>Identify</u>. IGDS should provide a means of maintaining identification data with the graphic element in the graphic file. This command should allow the user to graphically identify a graphic element and obtain the I.D. of the element. IGRDS should be able to invoke this command as discussed under Digitize above and IGDS pass the I.D. to IGRDS. When this command is used, the system should provide the user with a means of verifying that the system has identified the correct graphic element. One method of accomplishing this is for the system to redraw the element for the user's acceptance.

<u>Creating and Displaying Graphic Elements</u>. The drafting system must provide a means for IGRDS to pass graphic records generated in a design process and IGDS display and store the records. The records should be displayed and stored using the currently active symbology (line pattern, line weight, font, character size, symbol, symbol size, etc.) window scale and window orientation. The graphic records created by IGRDS will include the I.D. of the element(s) and the I.D. should be stored by IGDS.

This description of the functions needed by the Interactive

Graphics Drafting System used with IGRDS is not intended to imply that all of the functions are required although some will be. There are other functions that would be desirable and many of the available drafting systems provide them. The functions described are considered basic capabilities provided by a good drafting system that would be useful in a highway engineering environment. The command names used are intended to be generic and would be called by different names in the various systems. The functions described for the commands should be considered the important part of the description and not the name.

General Plotting System (GPS)

This section will describe the capabilities to be provided by the General Plotting System (GPS) developed by the Department to produce digital plots from Graphics Interface Format files. GPS has been implemented by the Department and is being used in production to produce the plots from the Texas Automated Mapping System data base. The system may require some enhancements to provide all of the capabilities needed by IGADS. More detailed descriptions of the system are available in the user and program documentation.

Purpose. GPS was developed to provide complex plotting functions and facilities for application programs. The system:

1. Makes a wide variety of graphics devices accessible to application programs without the necessity of including the software for each device in each program.

2. Combines graphics from two or more application programs on a common set of axes or on related axes (i.e. one at the top of the page and another at the bottom).

3. Selects graphic elements from graphic files by type and produces a new file which may be plotted or transferred

to another program such as a commercial Interactive Graphics Drafting System.

4. Provides windowing, scaling, rotation and translation of graphics data produced by an application program without the necessity of including these functions in the individual programs.

5. Allows special symbols, patterns, character fonts, sheets and standard details stored on tables to be inserted into generated plots.

6. Provides both quick edit plots with simple patterns and symbologies and plan-quality plots with complex patterns from the same data.

7. Permits plots of different parameters to be produced from one set of graphics files, generated with one run of the application programs.

Data Flow. GPS can plot data generated in a general graphics format defined for the system called GIF. The application systems create graphics data files and a plot request file. GPS plots the data as directed by the plot request. A single application program may generate more than one graphics file and graphics files from more than one application program may be accessed for a single plot. The user requests a plot of a graphics file or files by identifying (1) the input file(s), (2) the plot request file, and (3) the output graphics device(s). The plot request file may also contain selection criteria to plot or exclude graphic elements by key. The data flow through the three main stages from creation to plot is as follows:

1. Data is stored in a GIF graphics data base file by an application program.

2. A plot request is written on a plot request file by an application program.

3. Data in the GIF data base is plotted by GPS according to the plot request.

Each of these stages is described below:

1. <u>Graphics Interface Format (GIF) Files.</u> GIF files form the interface between the application programs and GPS. By generating files structured in GIF, application programs create the data base to be plotted by GPS. Files created by several application programs or one program (such as right-of-way, general geometrics, horizontal alignments, vertical alignments and survey maps) and stored on one or more GIF files may be merged by GPS to produce end product graphics representations (such as plan-profile sheets).

   In the GIF files, data is stored in the form of graphic elements such as lines, arcs, and character strings. These data elements are grouped together as graphic entities. The entities are indexed by numeric keys and data identification codes which relate them to their specific application. For example, for the Texas Automated Mapping System the keys would include group, model, and item; and, the data identifiers are the plotting code. In RDS the keys would include roadway, span and structure.

   These keys are used to select or exclude graphic elements from a plot or subsequent graphic file.

2. <u>Plot Request.</u> The following is a sample of some of the plot parameters included in a plot request:

   a. Output Device - Any device included in GPS and available at the user's installation may be specified as an output device. This includes a storage device to store the resulting file which would be in the Graphics Interface Format.

   b. Selection - Selection criteria to include or exclude any graphic entity by its key.

   c. Scale - The scale factor in linear units per plot unit (normally ft/in). The horizontal and vertical scales are assumed to be equal unless a vertical scale is entered.

   d. Vertical Scale - The vertical scale factor in linear units per plot units (normally ft/in). It is set equal to "Scale" if left blank.

   e. Rotation Angle - The rotation angle is defined by one of the following options:

      (1) Bearing, azimuth, or angle counterclockwise from the positive X-axis

      (2) Two points with coordinates in graphics file linear units

(3) Automatic orientation

(4) As defined by a window.

f. Window - The boundaries of the plot window may be defined by one of the following options:

(1) Window vertices (graphics file linear units)

(2) Window origin (graphics file linear units) and page length and width (plot units)

(3) Window center (graphics file linear units) and page length and width (plot units).

g. Window Offset - The window offset defines (in plotter units from the lower lefthand corner of the plot page) the X and Y locations on the page of the window center. This enables the user to plot multiple graphics files at the same plot page origin. Using a single window offset the user may overlay plots such as TEAMS and RDS geometrics. Adjusting the Y-axis of the window offset permits the production of parallel plots of vertical profiles to produce plan-profile sheets.

h. Sheet Type - This identifies the style of sheet to be plotted; for example, a plan-profile sheet with a half-inch profile grid. The sheet description is stored in one of the auxiliary tables discussed below.

i. Grid Increments - If grid ticks are included on the plot, the user may define the increment between ticks in graphics file linear units. The system then determines which ticks fit the plot window.

j. Grid Labels - The user may define the increment between grid tick labels in graphics file linear units.

k. Scaling Factors - The user may enter scaling factors for symbols, characters, etc. This allows the specified elements to be scaled independently of the scale of the plot. For example, the symbol scaling factor allows symbols to be plotted the same size on a 1"=80' map as on a 1"=40' map although other features are only half the size. The character scaling factor permits characters to be plotted at standard sizes regardless of the plot scale.

l. Item Numbers - Numbers identifying the items may be included on the plot.

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m. Auxiliary Tables - The user may specify to the plotting system the auxiliary tables to be used to generate a plot. These tables may define patterns, symbols, fonts, sheets or standard details. The tables may be user defined.

3. <u>General Plotting System</u>. GPS plots the GIF file(s) according to the plot parameters and auxiliary tables specified by the plot request. GPS sequentially retrieves the GIF records and inserts data from the auxiliary tables as specified by the individual GIF records. It then calls routines to bias, rotate, scale, clip, and plot the data. The interface between GPS and an application program is device independent, but GPS includes lower-level device dependent routines that generate data required by each graphics device.

    GPS may also be directed to create a GIF file such as a plan-sheet file which has the same structure as a GIF data base but which is already biased, rotated, scaled and clipped. This new file may include data from several GIF data bases and may have selected data from each of the files. GPS also generates a plot request file for the newly arranged data. The new file can again be plotted by the system, specifying a new set of auxiliary tables or a different plot device.

<u>Structure of the General Plotting System</u>. GPS includes a driver, Graphics Compatibility System (GCS), and device-dependent subsystems. These are described below:

1. <u>GPS Driver Subsystem</u>. The GPS driver reads plot requests from the plot request file. As directed by the plot requests, the driver reads one or more GIF files and generates calls to the GCS subsystem (See description below) to plot the data on those files.

2. <u>GCS Subsystem</u>. GPS contains routines from GCS developed by the U.S. Military Academy and obtained from the U.S. Corps of Engineers, Waterways Experiment Station in Vicksburg, Mississippi. GCS is a Fortran-based batch mode computer graphics system designed for use with a wide variety of graphics devices.

    Included in the version of GCS obtained from the Corps of Engineers are device dependent routines for devices such as Calcomp drum plotters, interactive alphanumeric terminals, ARDS Storage Tube Terminals, Computex 400/15 Storage Tube Terminals, Datapoint 3300 Refresh Alphanumeric CRT Terminals, Gould 4800 Dot-Matrix Printers, IMLAC PDS-ID and PDS-4 Terminals, Alphanumeric Line Printers, Textronix 4010 series Storage Tube Terminals, Terminet 300 and Remote Batch Alphanumeric Terminals.

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All of the device dependent routines included in GCS are not currently used by GPS. Only those written for the Calcomp drum plotters were utilized. The other device dependent routines can be inserted into the system if the corresponding devices are used by an agency using GPS. In addition to the Calcomp drum plotter routines, device dependent routines for the Kongsberg and Houston Instruments Plotters were added. Other routines contained in the original GCS package of routines have been replaced or modified to provide the ability to utilize the auxiliary tables discussed above.

The coordinate system options of GCS were designed to enable the user to work in whatever coordinate system is most natural and convenient. When the user coordinates are entered into GCS, they are transformed by the program to basic (internal) coordinates. This basic coordinate system is a simple Cartesian (rectangular) X-Y coordinate system. Axes are orthogonal to the screen or plot bed, and the system origin is the lower lefthand corner of the screen or plotbed. Coordinates are in basic units and are absolute (with respect to the origin), not incremental (with respect to the previous point). The display or plot is clipped by the GCS routines to fit the screen or plotbed. The user coordinate system may be one of the following:

a. Cartesian (rectangular)

b. Log-log or semi-logarithmic rectangular

c. Polar.

Points or lines to be plotted may be identified either by absolute or incremental coordinate positions. The coordinate units may be user specified in abstract "virtual space" which can be projected onto the plotting device at any desired scale, or they may be directly specified in a "device space", i.e., in terms of the dimensions of the plotting device. Virtual units may be hundredths of feet, feet, miles, meters, etc.; device units may be inches, centimeters, font-units (alphanumeric character heights and widths), or percent-units. In either case, angles may be given in radians, pi radians, or degrees.

In addition to the primary or system axis used for the basic coordinate system, the user may define any number of secondary user axis systems which may be rotated, translated, and scaled differently from the system axis or relative to a previously defined user axis. This feature facilitates the definition of complex coordinate systems where, for example, it simplifies the

drawing of a curve in a basic axis system while simultaneously maintaining a secondary axis whose origin is a point on the curve which is oriented tangent to the curve at that point. The relative scaling of the two axes may be controlled independently of one another and defined either with respect to the system axes or cumulatively based on successive transformations on a series of different user axes. Since the rotations and scaling in GCS are accomplished by standard matrix transformations, one can obtain mathematically accurate visual representations of highly abstract vector spaces.

Summary

This discussion of the two graphics display components of the Interactive Graphics Aided Design System is intended to provide the reader with some understanding of the committment this development has towards utilizing graphics in roadway design. The Interactive Graphics Drafting System, when coupled with the Interactive Graphics Roadway Design System, will provide the user with graphic review functions on graphics terminals as well as a means of obtaining design input from the display in an interactive environment. The General Plotting System provides the user the ability to produce digital plots for any application program that is modified to output GIF records. IGADS will provide this facility for RDS and TEAMS.

VII. Conclusion

This development was begun in March, 1976, suspended for technical reasons in December, 1978, and reinstated in March, 1981. During this time frame many advances have been made in the state of the art of interactive graphics equipment and software. The basic concepts of the user needs and interfaces for the Interactive Graphics Aided Design System have remained the same; however, the "tools" (graphics equipment and software) available to develop the system have undergone a dramatic revolution. This revolution in the graphics industry and the interest in the engineering community for the use of interactive graphics as an aid in their work have required the project staff to reexamine the concepts to verify that they are still valid and to redefine those that were not valid with the current technological advances. This report intended to define the user interfaces for an Interactive Graphics Roadway Design System utilizing the latest technology available without compromising the requirement that the development be device independent. IGADS, however, also involves enhancements in the batch computer programs required in conjunction with IGRDS and these enhancements while not defined in detail have been discussed.

The current status of the project in general terms is outlined below:

1. The Texas Automated Mapping System has been rewritten to utilize the the Graphics Interface Format and is in production use by the Texas State Department of Highways and Public Transportation and the complete system package has been delivered to FHWA. Some enhancements are projected for the system and will be developed in

the future. These enhancements deal basically with pro-
viding capabilities to produce maps at different scales
than those used for highway engineering.

2. The General Plotting System has been developed and is
   in production to provide the plotting for TEAMS and has
   been delivered to FHWA. Some enhancements are antici-
   pated to provide the capabilities needed by IGADS.

3. The Roadway Design System has been in production use
   for several years by a number of agencies. The system
   is supported by contract for some of the users and is
   currently being revised. This new version of the
   system will be enhanced to produce the GIF records for
   use with the General Plotting System. This work will
   commence when the new version of the system is receiv-
   ed. The routines added to RDS to produce GIF records
   will be available as part of the contract deliverable
   for inclusion in other application programs to allow
   their use with the General Plotting System.

4. Development of a first version of the Interactive
   Graphics Roadway Design System has begun. It will
   include general geometry, and horizontal and vertical
   alignment capabilities.

As previously stated, the purpose of this design document is

to allow prospective users of IGADS to comment on the concepts of

the development effort; therefore comments are solicited.

Appendix: Interactive Graphics RDS Design Data

The input of certain design data is indicated to be by a forms type of input (other Design Data Commands, page V-20) for the Interactive Graphics Roadway Design System to be developed under this contract. However, the project staff developed interactive graphics input/output concepts for several of these functions but did not include them as capabilities of the proposed system due to funding and time constraints of the contract. In addition to the expansion of the design data functions, interactive graphics input/output functions for the terrain process and the earthwork process were expanded in the discussion which follows to provide documentation of the design. The following discussion would replace the section "Other Design Data Commands" (pages V-20 through V-22) if these interactive graphics functions were to be included in the system to be developed. The discussion starting below should be read as a continuation of the Design Data section with the commands MODX and ERWK (page V-13) in the list of design data commands removed. (These two commands are in the Terrain and Earthwork Request sections of this discussion.)

TSTA, SSTA and MSTA. These commands instruct the system to start the Roadway Template Stations, Side Slope Stations and Median Stations processes respectively, which will provide the user with the ability to define or update the stations where these parameters are to be applied. The input for each of these commands will be different; however, the user interface will be

similar; therefore, a general description will be provided for all three command processes in this section. For ease of reading, the discussion will be written as though the description is for one process; but the reader should keep in mind that the discussion is intended to define a user interface for each of the processes. The reader is reminded that the order of input of the commands such as TSTA presented in this report is not intended to reflect the order they would be used in a design session. For example, the station definition commands being discussed here would not be used before the template table input commands (such as TEMP) and the user may have to go back and forth between types of input during a design session if, for example, he was inputting station data and determined that he needed to define another template shape. However, he could also continue inputting station data and call for a template that was not defined and, when finished inputting the station data, revise the template table to include the needed template.

This process will allow the user to graphically review the template table and plan view graphics (horizontal alignments) on the display screen as an aid in entering the station data. Depending upon the capabilities of the drafting system being used for graphics control, both the plan view graphics and the template shapes would be viewable at the same time to aid in the input process.

    1.   Graphic Display. When the process is selected, the system will first determine if the user needs a graphics file(s) displayed and, if so, if the file is in the Interactive Graphics Drafting System. If the file(s) is not active in IGDS, the user will perform the needed functions (required by the IGDS being used)

to initiate the file(s). The complete graphic control command set provided by the drafting system will be available throughout the station definition process for initiation or changing the viewing window and for controlling the features to be displayed. (Refer to the "Graphics Manipulation" section for a discussion of the capabilities that might be available.)

2. Roadway Identification. Immediately following the initial graphic display, the system will prompt the user to enter the roadway letter for the "template" stations to be defined or revised. The user will enter the desired roadway letter and the system will determine whether data exists for that roadway. If data does exist, the user will be placed in an update mode. The user will also have the option to delete existing data and define new station data for that roadway. The user will have the option of identifying the roadway by pointing to it on the display screen.

    When the status (new or existing) of the station data has been established, the user may then start defining station data.

3. New Station Data. The following steps describe the user interface for defining new template station data:

    a. Enter Station Data. The system will first prompt the user to enter the data for the initial station and then enter data for each change in template shape. For each change in template shape defined, the system will display messages prompting the user to enter the various parameters. The user will enter data to define the template shape that will be applicable for that station and until a new station input is entered. All data may be keyed in; however, the user will have the option of defining the station number by digitizing the station location on the screen. The system will compute the station from the digitized point.

    b. Data Edit. When the data entry is completed for a station definition, the system will edit the input data. If no editing errors occur, the system will display the template identification opposite the station on the display. The system will then prompt the user to enter data for the next template change station.

4. Existing Station Data. The following steps describe the user interface for updating an existing station data file.

    a. Update Commands. When updating a station data

file, the user will be able to add, revise or delete station data. A command will be provided for each of these functions. The user will select one of these commands prior to entering data for each addition, revision or deletion.

(1) Add Command. When a station is to be added it will always be added to the end of the file and the system will sort the data into the proper sequence when the data is stored.

(2) Revise Command. When station data is to be revised, the user will first be required to retrieve the station data by one of the following methods:

+ Key in the station number.

+ Graphically identify the station number on the display as described under "New Station Data".

In either of the above cases, the system will respond by displaying the retrieved station data. The system will then display messages prompting the user to enter new data parameters. The user will only enter data to be revised. Data may be keyed in or the optional data input methods described under "New Station Data" may be used.

(3) Delete Command. When station data is to be deleted, the user must first retrieve the data as discussed with "Revise Station Data". After the desired station data is retrieved, the user will instruct the system to delete the station data.

b. Data Edit. When data entry is completed for an addition, revision or deletion, the system will edit the input data. If no editing errors occur, the system will display the template identification opposite the station in the case of an addition or revision. The system will then instruct the user to select another command.

5. Station Data Summary. Once the station data has been input, the user may request a station summary. For the system to produce this summary, the template shapes would also have to be available. The station summary would consist of a display of the stations where a change of template occurred and the template(s) in effect at that station along with the other input parameters included with the particular template being

reviewed (i.e. Roadway Template, Side Slopes or Medians).

6. Store Command. When the user is ready to store the station data, he will instruct the system to store the data by selecting the "store" command. When this command is selected, the system will store the data on the design data file. Note: The system will not store the data if errors are encountered.

TEMP, SLOP, and MEDN. These commands instruct the system to start the Roadway, Side Slope and Median Table processes respectively which will provide the user with the ability to define or update the tables which describe the template shapes to be used in earthwork design. The input for each of these commands will be different; however the user interface will be similar; therefore, a general description will be provided for the three command processes in this section. For ease of reading, the discussion will be written as though the description is for one process, but the reader should keep in mind that the discussion is intended to define the user interface for each of processes.

One difference between the processes which should be pointed out is that for the slope table process, the user will be required to develop the cut/fill tables in addition to defining the template patterns. For the cut/fill process, the user will be provided the ability to define or store slopes in the cut/fill tables or update existing tables. Slopes will be defined, revised or deleted by slope letter at user request. There will be no graphics used in the process.

This process will allow the user to graphically review the template shapes on the display screen as an aid in reviewing the template defined.

1. Graphic Display. When the process is selected, the
    system will first determine if the user needs a
    graphics file displayed and, if so, if the file is in
    the interactive graphics drafting system. If the file
    is not active in IGDS, the user will perform the needed
    functions (required by the IGDS being used) to initiate
    the file. The complete graphics control command set
    provided by the drafting system will be available
    throughout the template definition process for ini-
    tiating or changing the viewing window and for
    controlling the features to be displayed. (Refer to the
    "Graphics Manipulation" section for a discussion of the
    capabilities that might be available.)

2. Template Table Identification. When the template table
    process is selected, the system will determine if a
    table exists for the project and make it available for
    updates. If the table does not exist, a new table will
    be initiated. The user will also have the option of
    recalling a table from a master file to be used for
    this project. If data does exist or the user recalls a
    master table, the user will be placed in an update
    mode. The user will also have the option to delete
    existing data and define new data.

    When the status (new or existing) of the template data
    has been established, the user may then start defining
    template data.

3. New Template. The following steps describe the user
    interface for defining a new template:

    a. Template Number. The system will first prompt the
        user to enter a template number. The user will have
        the option to key in a number or let the system
        assign a number. When the template number has been
        established, the system will display messages
        instructing the user to enter the various parame-
        ters. The user will key in the data, and then the
        system will instruct him to select an optional
        method of input to define the template shape as
        described below:

        (1) Input Option. The user has two options for
             defining a new template. He may input all new
             data for a template or modify data of an
             existing template (in the table) to define the
             new template. The user will select the option
             needed by command prior to defining each
             template.

             + New Template Data. The user will be
                prompted to digitize a series of points on
                the screen that approximates the template

configuration. Note: For side slopes this process will not be applicable and the user will have to key in the template configuration referring to the cut/fill tables or to modify an existing template as described below.

Segment Data. The system will number the digitized points and prompt the user to enter the applicable data for the template being entered for the leftmost segment. The user will then key in the data for the first segment. This will be repeated until all the segments are defined.

Point Data. The user will be instructed (where applicable) to identify the profile grade, centerline, and pivot points. These points may be identified by keying in the point number or by graphically identifying the point on the screen.

+ Modified Template Data. The user will be prompted to enter an existing template number. The existing template will be displayed graphically. The system will then display the existing data for each segment and prompt the user to accept or modify the data. The data entry of revised data will be the same as discussed under "New Template Data".

b. Data Edit. When data entry is completed, the system will edit the the template input data. If no editing errors occur, the template may be displayed and stored.

c. Graphic Display. The system will provide the user with the ability to request a scaled and annotated graphic display of a defined template. A "template plot" command will be provided to initiate this display. When selected, the system will instruct the user to enter the template number of the template to be displayed. If no number is entered, the last template defined will be displayed. This display will be for visual editing only and will not be stored on a graphic file.

4. Revise Template. A template will be revised in the same manner as defining a new template by modifying an existing template. The data will be edited and may be displayed and stored. (Refer to "New Template".)

5. Delete Template. A template will be deleted by entering the existing number to retrieve the existing

data. The user will then instruct the system to delete the template with the "delete" subcommand.

6. Store Command. When all template data has been entered, the user will instruct the system to store the defined data. The "store" command will be selected to store the template data on the project file. Note: The system will not store the data if errors are encountered.

SUPR. This command instructs the system to start the superelevation definition process which will provide the user with the ability to define and store the superelevation rates for the project's horizontal alignments or to update existing superelevation tables. This process will allow the user to view plan view graphics (horizontal alignments) to aid in defining superelevation rates. The user will also be provided with the ability to display the roadway templates applicable for the roadway he is defining superelevation rates for.

1. Graphic Display. When the superelevation process is selected, the system will first determine if the user has the proper graphics file(s) displayed in the Interactive Graphics Drafting System. If not, the user will perform the needed functions (required by the drafting system being used) to initiate the file(s). The complete graphic control command set provided by the drafting system will be available throughout the superelevation definition process for initiating or changing the viewing window and for controlling the features to be displayed. (Refer to the "Graphics Manipulation" section for a discussion of the capabilities that might be available.)

2. Roadway Identification. Immediately following the initial graphic display, the system will prompt the user to enter the roadway letter for the superelevation stations to be defined or revised. The user will enter the desired roadway letter and the system will determine whether data exists for that roadway. If data does exist, the user will be placed in an update mode. The user will also have the option to delete existing data and define new superelevation data for that roadway. The user will have the option of identifying the roadway by pointing to it on the display screen.

When the status (new or existing) of the superelevation data has been established, the user may then start defining station data.

3. New Superelevation Data. The following steps describe the user interface for defining new superelevation data:

    a. Design Speed. The user will first be prompted to enter the design speed. The system will then display superelevation rates and transition lengths for various classes of highways and prompt the user to input the identification for the table of superelevation rates and transition lengths to be used. The user will also be provided with the capability to revise the table for use during this project.

    b. Identify Curve. The system will then prompt the user to identify the curve that superelevation will be applied to. The user will have the option of keying in the P.I. number of the curve or graphically identifying it on the display screen.

    c. Enter Superelevation Data. The system will prompt the user to enter one of the command options, key in data or system look-up from superelevation table. The two optional input methods are described below:

        (1) Key in Data. The system will prompt the user to enter the various parameters. The user will enter data for each station and have the option of graphically identifying the station number on the display screen. The system will compute the station number from the digitized point.

        (2) Automatic Superelevation Lookup. The system will look up the appropriate data from the superelevation table and display the superelevation data beginning with the beginning transition station for the user's acceptance or revision prior to entering it into the record.

    d. Data Edit. When data entry is completed for each station, the system will edit the input data. If no editing errors occur, the system will then instruct the user to enter data for the next superelevation transition.

4. Existing Superelevation Data. The following steps describe the user interface for updating existing superelevation data.

a. Design Speed. The user will first be prompted to enter the design speed. The system will then display superelevation rates and transition lengths for various classes of highways and prompt the user to input the identification for the table of superelevation rates and transition lengths to be used. The user will also be provided with the capability to revise the table for project use.

b. Identify Curve. The system will then prompt the user to identify the curve that superelevation will be applied to. The user will have the option of keying in the P.I. number of the curve or graphically identifying it on the display screen.

c. Update Commands. When updating superelevation data, the user will be able to add, revise or delete superelevation data. A command will be provided for each one of these functions. The user will select one of these commands prior to entering data for each addition, revision or deletion.

    (1) Add Command. If the add option is selected, the input will be the same as described under "New Superelevation Data".

    (2) Revise Command. If the revise option is selected, the system will display each record for the curve identified, in turn, for the user to revise the input by keying in data. The user will have the option of instructing the system to modify the data from the superelevation table and accepting or revising the resulting data before it is entered into the record.

    (3) Delete Command. If the delete option is selected, the system will delete all records for the curve selected.

d. Data Edit. When data entry is completed for an addition, revision or deletion, the system will edit the input data. If no editing errors occur, the system will prompt the user to select another command.

5. Store Command. When the user is ready to store the superelevation data, he will instruct the system to store the data. A "store" command will be provided to accomplish this. When the "store" command is selected, the system will store the data in the project file. Note: The system will not store the data if errors are encountered.

<u>WIDN</u>. This command instructs the system to start the widening definition process, which will provide the user with the ability to define or update the widening to be applied to roadway template segments. This process will allow the user to view plan view graphics (horizontal alignments) to aid in defining the widening data. The user will also be provided with the ability to display the roadway templates applicable for the roadway he is widening.

1. <u>Graphic Display</u>. When the widening process is selected, the system will first determine if the user has the proper graphics file(s) displayed on the Interactive Graphics Drafting System. If not, the user will perform the needed functions (required by the drafting system being used) to initiate the file(s). The complete graphic control command set provided by the drafting system will be available throughout the widening definition process for initiating or changing the viewing window and for controlling the features to be displayed. (Refer to the "Graphics Manipulation" section for a discussion of the capabilities that might be available.)

2. <u>Roadway Identification</u>. Immediately following the initial graphic display, the system will prompt the user to enter the roadway letter for the widening stations to be defined or revised. The user will enter the desired roadway letter, and the system will determine whether data exists for that roadway. If data does exist, the user will be placed in an update mode. The user will also have the option to delete existing data and define new widening data for that roadway. The user will have the option of identifying the roadway by pointing to it on the display screen.

    When the status (new or existing) of the widening data has been established, the user may then start defining widening data.

3. <u>New Widening Data</u>. The following steps describe the user interface defining new widening data:

    a. <u>Enter Widening Data</u>. The system will first prompt the user to enter the data for the initial station and then to enter data for each change in template width. For each change in template width defined, the system will display messages prompting the user

to enter the various parameters. The user will enter data to define the widening that will be applicable for that station. All data may be keyed in; however, the user will have the option of defining the station number by digitizing the station location on the screen. The system will compute the station from the digitized point.

b. Data Edit. When data entry is completed for a widening definition, the system will edit the input data. If no editing errors occur, the system will then prompt the user to enter data for the next widening definition.

4. Existing Widening Data. The following steps describe the user interface for updating an existing widening data file.

a. Update Commands. When updating a widening data file, the user will be able to add, revise or delete widening data. A command will be provided for each of these functions. The user will select one of these commands prior to entering data for each addition, revision or deletion.

(1) Add Command. When widening data is to be added, it will always be added to the end of the file and the system will sort the data into the proper sequence when the data is stored.

(2) Revise Command. When widening data is to be revised, the user will first be required to retrieve the widening data by one of the following methods:

+ Key in the station number.

+ Graphically identify the station number on the display as described under "New Widening Data".

In either of the above cases, the system will respond by displaying the retrieved widening data. The system will then display messages prompting the user to enter new data parameters. The user will only enter data to be revised. Data may be keyed in or the optional data input methods described under "New Widening Data" may be used.

(3) Delete Command. When widening data is to be deleted, the user must first retrieve the data as discussed with "Revise Widening Data".

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After the desired widening data is retrieved, the user will instruct the system to delete the widening data.

b. Data Edit. When data entry is completed for an addition, revision or deletion, the system will edit the input data. If no editing errors occur, the system will then instruct the user to select another input option.

5. Store Command. When the user is ready to store the widening data, he will instruct the system to store the data by selecting the "store" command. When this command is selected, the system will store the data on the design data file. Note: The system will not store the data if errors are encountered.

Other Design Data Commands. The remaining types of design data processes will have an input process for storing and updating the particular type of design data. These input processes will be based upon a forms type of input with all data keyed in and with no graphic input options available. However, the user will have the ability to display any graphics file that has previously been developed that may aid him in determining the input data. An example would be the horizontal alignments for the project.

The Ditch Grade Process (DGRD) will provide the user with the capability of displaying the ditch profile defined. The remaining design data processes are listed below:

+ DGRD - Ditch Grades

+ EXCP - Design Exceptions

+ RMAX - ROW / Maximum Slope

+ CFAC - Compaction Factors

+ ADDQ - Added Quantities

+ FBAL - Forced Balance

+ OFFS - Offset Data

+ EQAT - Equation Data

Entry of any of the above commands will instruct the system to start the applicable design data input process. Once the data entry is complete, the system will edit the data and, if no errors occur, store the data in the project file.

The Design Data commands may be used as required to enter the needed design data for the earthwork design or to modify an existing set of design data to obtain a different earthwork design. Once the design data process is complete and the data is stored, it will be available for subsequent processing using RDS as is currently performed.

Terrain

The Terrain Process will provide the user with commands for initiating the following functions:

+ SUMR - List Station File Summary

+ DISP - Graphic display of cross-section data

+ LIST - Display lists of station file data

+ NPUT - Input record creation for RDS batch processing

+ MODX - Interactive modifications of original, design and final cross-sections

+ STOR - Data Storage

The user interface for each of these functions is discussed below.

SUMR. This command provides the user with the ability to obtain a summary list of the contents of the project file. This would be similar to the tape summary report currently produced by RDS. The report summarizes the data contained in the project file

including the station limits covered (where applicable).

DISP. This command provides the user with the ability to obtain a display of cross-sections. The display may contain one or more stations and may include any combination of original, design or final cross-sections. When the command is selected, the user will be instructed to enter the desired station limits, types of sections to be included, and the ratio between the horizontal and vertical scales. The system will then create a temporary graphics file and pass the file to the Interactive Graphics Drafting System for display. The user will have the complete graphic control command set provided by the drafting system to review the cross-sections. The user will also have the following special purpose IGRDS commands available to use while viewing the cross-section display.

1. Center a given cross-section station in the viewing window.

2. Scroll new stations into the viewing window either forward or backward.

3. Scroll to a new window beginning or ending one station past the current viewing window.

4. Request point code, elevation and distance of a graphically identified cross-section point.

5. Request slope or slope ratio between two graphically identified cross-section points.

LIST. The LIST command will allow the user to display a list of the following types of station file data for a given range of baseline stations.

+ Original Cross-sections

+ Design Cross-sections

+ Final Cross-sections

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+ Horizontal Position Data

+ ROW and Maximum Slope Intercept Distance

+ Hub Data

When the LIST command is selected, the system will display messages instructing the user to enter the station range and the type of data to be listed. The system will edit the input data and produce a list of the selected data type for the initial station. The user will then be able to scroll through the remaining stations.

NPUT. This command instructs the system to start the terrain input process. When selected, the system will request the user to select the type of input desired. The types of terrain procedure inputs provided are listed below:

1. Merge original cross-sections with project file

2. Merge final cross-sections with project file

3. Original interpolation or extrapolation

4. Original extensions

5. Final extensions

6. Cross-section modifications

7. Partial vertical adjustment

8. Hub data

9. Station file print

10. Station file deletions

When selected, each of these functions will produce a forms display similar to that used in RDS. Data will be entered by keyboard for each field on the form. When the user completes an

input record (card), the system will edit the input data. The "store" command will then be selected to store the input record for future RDS batch processing. The system will automatically create RDS Terrain Header Cards and will require the user to enter the data in proper sequence.

MODX. This command will instruct the system to start the interactive cross-section modification process. When selected, the system will prompt the user to select the type of modification needed. This process will not create input records but will modify the cross-section records on the project file. The types of modifications provided are discussed below:

1. Cross-Section Extension. The extension function will provide the user the ability to add, revise or delete points from an existing original or final cross-section. When selected, the system will prompt the user to enter the following data:

   + Station

   + Cross-section type (original or final)

   + Update option (add, revise or delete)

   + Distance (plus or minus)

   + Elevation

   The user will then be instructed to enter station and cross-section type, and the system will respond with a list of data for the selected cross-section. If a graphic display has been initiated, (Refer to the "DISP" command), the system will automatically center the selected cross-section in the viewing window. The user will then be prompted to select an update option. The input for each option is discussed below:

   a. Add. The user may add a point by entering an elevation and distance. The input data will then be edited and a symbol will be displayed representing the point.

   b. Revise. When a point is to be revised, the user must identify the existing point by either keying

in the offset distance of the point or by graph-
ically identifying the point on the screen. The
system will respond with the elevation and distance
of the point and the user may enter a revised
distance and/or elevation. The input data will then
be edited and a symbol displayed representing the
revised point.

c. Delete. When a point is to be deleted, the user
must identify the point as discussed with the
revise function.. The point will then be deleted
with the next user action.

If a point to be added or revised is a terrain inter-
cept point, the user will be provided with the ability
to determine the elevation and distance of the point by
graphically identifying it. The resulting data will be
used for the data entry. The process of adding, revis-
ing or deleting points may be repeated as many times as
required to update a cross-section. The display, list
and store commands may then be used to review and store
the revised cross-section.

2. Partial Cross-Section Adjustment. The partial cross-
section adjustment function will provide the user with
the ability to raise or lower parts of an original or
final cross-section. The most common application is the
removal of existing base that is to be salvaged from
original cross-sections. When selected, the system
will prompt the user for the following data:

+ Station

+ Cross-section type (original or final)

+ Adjustment option (start, connect or follow)

+ Roadway letter (A-G)

+ Offset distance (referenced to roadway)

+ Elevation adjustment

The user will then be prompted to enter the station and
cross-section type, and the system will respond with a
list of data for the selected cross-section. If a
graphic display has been initiated, (Refer to "DISP"
command), the system will automatically center the
selected cross-section in the viewing window. The user
will next be instructed to start a partial adjustment
by selecting the "start" adjustment option and entering
a roadway letter, offset distance and elevation adjust-
ment. Data entry will be repeated in these fields
until the partial adjustment is properly defined. The

user will have the following adjustment options available to control the type of partial adjustment.

a. Start. This indicates that a partial adjustment begins at the offset distance entered and will connect to the previous point. The starting point may or may not have an elevation adjustment.

b. Connect. This forces a straight-line connection between the preceding adjusted point and the point being currently defined. Each partial adjustment set must end with a connect with a zero elevation adjustment.

c. Follow. This indicates that the elevation adjustment will parallel the cross-section between the preceding adjusted point and the point currently being defined. The elevation adjustment of the previous point will be used.

As each roadway letter, offset distance and elevation are entered, the system will edit the data and display a symbol representing the input adjustment point. When the partial adjustment is complete, the user may use the display, list and store commands to review and store the adjusted cross-section.

3. Design Point Modification. The design point modification function will provide the user with the ability to add, revise, or delete points on a design cross-section. It should be noted that the changes made with this command will have no effect on the design data parameters that generated the existing design cross-section. Also if an earthwork design is processed subsequent to the design point modification being made, the modifications are deleted and must be reentered. When the function is selected, the system will prompt the user for the following data:

+ Station (Terrain)

+ Update option (add, revise or delete)

+ Point I.D. (Roadway, Median, Ditch, or Fill)

+ Roadway (A-G)

+ Offset distance (distance referenced to roadway)

+ Elevation option (elevation, elevation correction, slope, ratio or terrain)

+ Elevation

The user will be prompted to enter a station, and the system will respond with a list of data for the design cross-section at the input station. If a graphic display has been initiated (Refer to "DISP" command), the system will center the selected design cross-section in the viewing window. The user will then be instructed to select an update option. The input for each option is discussed below:

a. Add. The user adds a point by entering a roadway letter and offset distance (may be digitized for roadway G), a point I.D., and an elevation. The elevation of the point is determined by one of the following options:

   + Elevation. The user may enter or digitize the elevation.

   + Elevation Correction. The user may graphically identify a point and then enter the difference in elevation (plus or minus).

   + Slope. The user may graphically identify a point and then enter a slope (plus or minus) or graphically identify a cross-section segment the new slope is to parallel.

   + Slope Ratio. The user may graphically identify a point and enter a slope ratio (plus or minus).

   + Terrain. The system will use an original ground elevation at the input offset distance.

   In each case above where an elevation must be computed, the system will compute the elevation. As data entry is completed for a new design point, the system will edit the input data and display a symbol representing the new point.

b. Revise. When a design point is to be revised, the user must identify the existing point by either keying in the offset distance or by graphically identifying the point on the screen. In either case, the system will display the distance and elevation for the selected point. The user may then enter revised data as discussed with adding a design point. The system will then edit the data and display the new point.

c. Delete. When a design point is to be deleted, the user must identify the point as discussed with revise. The point will be deleted with the next user action.

The process of adding, revising or deleting design points may be repeated as required to properly modify the design cross-section. The display, list and store commands may then be used to review and store the modified cross-section.

STOR. When the user is ready to store an input record or a modified cross-section, the store command must be selected. When it is selected, the system will do the following:

1. Input Record. If an input record is to be stored, it will be stored on the input file.

2. Modified Cross-Section. If a modified cross-section is to be stored, it will replace the existing data on the station file. The station will be tagged as a revision.

The data stored will then be available for later batch processing with RDS as is now currently done. No interactive processing of the data will be provided.

Earthwork Request

The Earthwork Request process will provide the user with commands for initiating the following processes:

+ HPCL - Horizontal Position Calculations

+ RWMX - Right of Way / Maximum Slope Intercept Distance Calculations

+ ERWK - Earthwork Design

+ VOLM - Volumes

+ HAUL - Overhaul

+ CNST - Constructing Staking

+ REVW - Review Data from Batch Run

All of these functions except REVW (Review Data from Batch Run) are currently input to RDS on the Earthwork Request Input Form. They will be separated into commands in IGRDS to provide the user

with more flexibility in defining the processing to be performed. The input process for each of the commands, except for REVW, will be based upon a forms type of input with all data keyed in with no graphic input options available. However, the user will have the ability to display any graphics file that has been previously developed that may aid him in determining the input data. An example would be the horizontal alignments for the project. Entry of any of the commands (except REVW) will instruct the system to start the applicable earthwork request process. Once the data entry is complete, the system will edit the data and, if no errors occur, store the data in a data file for later processing with RDS.

The REVW command will be used to recall graphic displays and to output reports that were produced by a batch run of RDS. The types of displays would include Haul and Cross-Section plots. The types of reports would include Volume and Haul reports. Input of the REVW command will instruct the system to begin the process and to prompt the user to input the type(s) of displays and/or reports to be reviewed. The user will have the ability to exit the Earthwork Request process at any time and enter any other process such as Design Data or Terrain to change data in preparation for running an alternative design.

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