1. Report No. DHT-1-19-75-520-2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INTERACTIVE GRAPHICS AIDED DESIGN SYSTEM - SUMMARY OF GENERAL SYSTEM DESIGN		5. Report Date September, 1978
		6. Performing Organization Code
7. Author(s) William L. Crawford		8. Performing Organization Report No. DHT-1-19-75-520-2
9. Performing Organization Name and Address Texas State Department of Highways and Public Transportation, Automation Division Austin, Texas 78701		10. Work Unit No.
		11. Contract or Grant No. DOT-FH-11-8910
12. Sponsoring Agency Name and Address Texas State Dept of Highways and Public Transportation Transportation Planning Division P. O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Interim 1/77-9/78
		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration, under the study title: "Development of an Interactive Graphics Aided Design System".

16. Abstract

This is the second of three interim reports to be prepared on a four-year study to develop an Interactive Graphics Aided Design System. It is a summary of the General Design Report for the Interactive Graphics Aided Design System being developed. The report gives, in addition to a summary of the general design, a discussion of some of the philosophies used in designing the system.

The overall objective for the study is the development of a roadway design system utilizing graphics cathode ray tubes as an interface between the designer and the computer with emphasis on graphics input and output. The development is to use as a base existing engineering design systems and specifically the Roadway Design System (RDS) developed by the Texas State Department of Highways and Public Transportation. In addition to the engineering design systems, the Interactive Graphics Aided Design System will utilize the digital geographic data base produced by the Texas Automated Mapping System for the base survey information.

17. Key Words Roadway Design System, Automated Mapping System, interactive graphics, roadway design, computer map graphics	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 49	22. Price

Form DOT F 1700.7 (8-69)

INTERACTIVE GRAPHICS AIDED DESIGN SYSTEM
SUMMARY OF GENERAL SYSTEM DESIGN

by

William L. Crawford

Research Report 520-2

Development of an Interactive
Graphics Aided Design System

Research Study 1-19-75-520

September 1978

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.

Table of Contents

List of Figures

INTERACTIVE GRAPHICS AIDED DESIGN SYSTEM
SUMMARY OF THE GENERAL SYSTEM DESIGN

Introduction

The Interactive Graphics Aided Design System (IGADS) is being developed by the Texas State Department of Highways and Public Transportation (Texas DHT) as a tool for the highway designer. Funding is by the U. S. Department of Transportation under contract DOT-FH-11-8910 and Texas DHT. Monitoring of the contract is performed by the Federal Highway Administration's Office of Development, Engineering Services Division. The contract is the result of an unsolicited proposal from Texas DHT to FHWA proposing to develop an interactive graphics design system using both the Roadway Design System (1) and the Texas Automated Mapping System (2). The development is a natural extension of the two separate above mentioned batch oriented systems. The Roadway Design System (RDS) is an integrated system for roadway design encompassing most of the computational requirements of highway design. The Texas Automated Mapping System (TEAMS) is a system for engineering surveying using aerial photogrammetry and resulting in a digital data base usable for engineering design. Both systems make extensive use of hard copy graphics produced on digital plotters as an output medium. IGADS is intended to be an extension of these two systems and not a replacement.

The purpose of this report is to summarize the reason for developing an interactive graphics design system, record some of the concepts or philosophies used in its design, relate some of the problems encountered in this effort, and describe the capa-

bilities the system will provide the engineering personnel of a transportation department. This report also provides an update of the projects status.

Roadway Design System

RDS is a powerful, complex system which has been adopted by many organizations for use by their engineering personnel as documented by FHWA Report No. FHWA-DP-30-1, "Computerized Roadway Design System" (3). It is used by varying types of organizations including 10 state transportation organizations and 6 public agencies. It has also been distributed to 14 foreign governments, 35 consulting companies and 7 colleges and universities. Users include organizations performing earthen dam, airport and channel design, in addition to roadway design. Technical support of the system for some of the users is provided under contract by C. W. Beilfuss, consulting with the American Association of Transportation Officials.

The title is somewhat of a misnomer. The Roadway Design System makes no design decisions; however, it provides engineering personnel with calculation capabilities in most areas of highway design with the purpose of aiding them in making design decisions. A discussion of RDS capabilities is contained in several documents; the most recent is DHT Departmental Research Report 520-1, "Conceptual Design of an Interactive Graphics Aided Design System" (4).

Two aspects of the system which differ from most prior computer programs performing similiar functions are as follows. First it is an integrated system allowing transfer during one computer run of calculation results from one process such as geometrics to another such as horizontal alignment thus minimizing the manual transfer of calculation results from one run to another as required of non-integrated programs. This reduces

errors in copying data and speeds the calculation process for the user since he has fewer computer runs. Secondly, it can use a project file for the purpose of retaining information from each computer run. This allows recall of the data for making more calculations, modifying previous calculations to make corrections or aiding in the iterative process of roadway design. An example of this iterative process is the (1) calculation of design cross-section configurations, earthwork quantities, overhaul data and related output, (2) review of the results, (3) determination of needed revisions because of such features as earthwork volume imbalance, excessive overhaul and/or drainage improvements, (4) modification of the input for a subsequent calculation, and (5) a repeat of the process as required with minimal input to optimize a design.

Texas Automated Mapping System

TEAMS is a system of individual automated processes and computer programs. The system automates the aerial photogrammetric process for transfer of photographic imagery to a digital data base manipulable by computer programs and for production of high quality, accurate, fully annotated digital plots. The title should not be construed to imply that the process is "automatic". Instead, the system provides tools to gather the photogrammetric data, transform the data to a computer file, and plot the file with minimal manual intervention. The system is outlined in several documents including DHT Departmental Research Reports 520-1 (4) and 40-1F, "Implementation of an Automated Mapping System" (2). The system was developed by Texas DHT in an evolutionary environment in order to maintain photogrammetric production in the Department. The current system is being re-systemized in conjunction with but not directly as a part of the development of IGADS. It is used by DHT and is being implemented by two other state transportation organizations. Part of the re-systemization is to separate the file management and plotting functions. The extensive plotting capabilities of the system are being generalized to form the plotting system for IGADS and RDS as well as the production of map plots. The modified system will not change the basic function but will provide more capabilities for the various users.

Why Interactive Graphics?

Engineering personnel typically use three forms of informa-
tion in the design process: (1) input for calculations whether it
is design notes or computer program input, (2) results of the
calculations either in design notes or computer program output
and (3) graphical representation of the design and survey
information either manually drawn or digitally plotted by a com-
puter.

RDS and TEAMS each provides these three functions but with
some limitations. For example, RDS prints both a list of the
input and the results of the calculations. In addition, the
system has extensive digital plotting capabilities. The primary
use of these plots is for visual editing of the calculations.
Cross-section and haul plots are exceptions to this as they are
usable for furnishing the contractor with documentation of the
intended design. In general, however, 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.

TEAMS prints a list of its input and the results of the
calculations it performs. In addition, it produces plots of
greater accuracy than are normally obtained by conventional
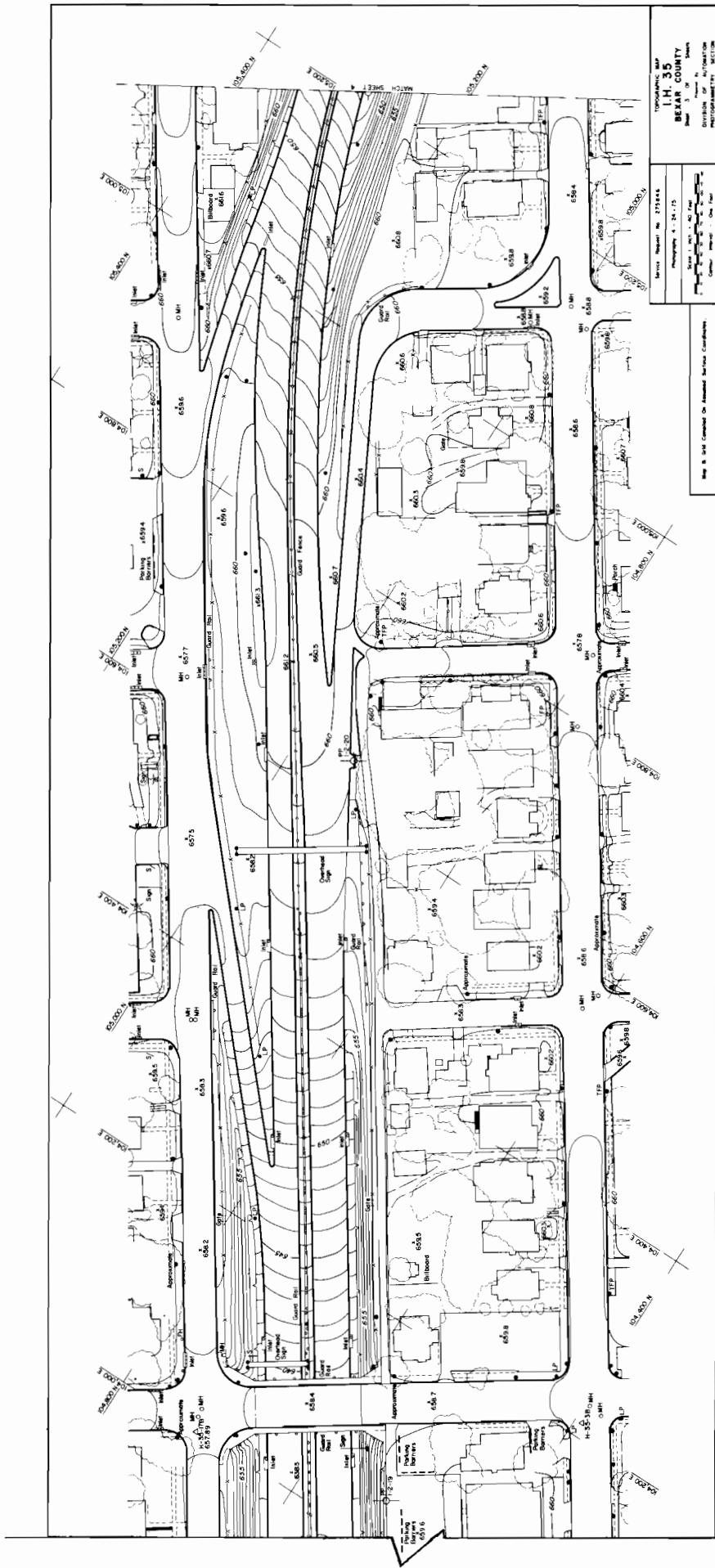surveys and manual drafting. Figure 1 is an example of a design

6

Figure 1. Example of a Design Map

7

map compiled at a scale of 1"=40' which illustrates the information available to a designer. TEAMS 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 to be able to generate an RDS computer plot that includes geographic data from a TEAMS data base and also be able to display these together on a graphics terminal. The development of interactive graphics capabilities for RDS is intended to minimize these limitations.

To explain how this can be accomplished, interactive graphics must first be defined. An interactive system (with or without graphics) provides the user direct control of the computer. He gets "immediate" response from his input to the computer allowing rapid iteration of design problems. Immediate in this reference is relative and depends upon the function being performed. Since the user realizes the amount of computer processing involved, he should be satisfied with a reasonable length of response time when he requests an extensive calculation such as computing the design cross-section generation, end areas, earthwork volumes, cross-section plots and overhaul calculations for a section of highway. He probably will not be satisfied, however, with waiting any excessive time for a geometric calculation to be performed that he can accomplish on the new hand-held electronic calculators. Now he uses a batch system such as RDS for his calculations because it allows input of all

data without him reinputting the results of individual calculations before proceeding. Then the processing is done all at one time. But there are many instances where a user needs the results of a series of calculations to make a design decision before proceeding. At the present time he must input the problem and wait for the results, analyze the results and then make another computer run to make needed revisions. In an interactive system (with or without graphics) he receives the results as he proceeds through the problem giving him direct control of the process. Therefore, he will be able to make design decisions with minimal disruption of his thought process. An interactive system also allows the necessary trials of various options to be processed more rapidly while optimizing a design.

Although in a true interactive system all calculations are performed as soon as the required data is input, in highway design there are some functions such as design cross-section generation, contouring, and roadway elevation generation which involve rather extensive calculations. For IGADS it is not considered justified to have a user wait at the terminal while these types of calculations are performed; therefore, the user will be guided (prompted) through his input for these functions and then he will request the calculations to be executed while he performs other functions. In these cases, IGADS will not provide interactive calculations but will provide interactive graphics input.

On the other hand, there are numerous functions in RDS and, therefore, in IGADS which require interactive calculations and/or interface with design files for a user to interact with the pro-

9

gram. Many of the geometric calculations involving horizontal alignments are like this. For example, the calculation of the coordinates of a point at a given offset from an alignment must be made before the location of the point can be graphically represented; therefore, to make IGADS an interactive graphics system, it is necessary for some calculations to be performed as soon as the data is input. This allows the user to visually edit the results of the requested calculations. An interactive system (with or without graphics) also allows for prompting or guiding a user of the system. It 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 intermediate review of the calculations to reduce errors which naturally occur. Several organizations including one user of PDS have developed interactive input systems on their main-frame computer, but these do not provide graphics interaction.

An interactive graphics system not only provides the user with interactive alphanumeric input as discussed above but it also provides him with a graphic representation of the input and output. This differs from batch systems in that their 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. This is not to imply that the user will just "point" at the screen to obtain a coordinate value for input such as the P. I. coordinate for a horizontal alignment although this would be a legitimate method of input in some instances. "Pointing" at the screen would be more frequently used to identify points or graphic elements such

10

as lines and arcs needed in the current calculation. This is a highly used function in PDS and will eliminate the need for the user to look up the identity number of the desired element. Interactive graphics will also allow the user to have readily available on the screen for reference his required work drawings. Since the work drawings will be developed as the designer computes the required dimensions and then they will be accurately filed, a draftsman will start with the results of the design to develop the required plan sheets without having to trace or draft the computed information. The basic work drawing at the beginning of the design process will be the photogrammetric design map displayed on the screen sufficiently accurate for measurement of basic design information. 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 templates. 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. The concept of using a 19" diagonal screen similar to a TV screen (Figure 2) to obtain input may seem space age nonsense, but anyone who has seen a demonstration of one of the commercially available interactive graphics drafting systems is quickly convinced otherwise. The accuracy is obtained through the resolution (number of divisions per inch) of the input device, and computer program analysis of the desired action. Most of the input is obtained from mathematical computations and the screen is just used to quickly communicate to the computer the desired calculation.
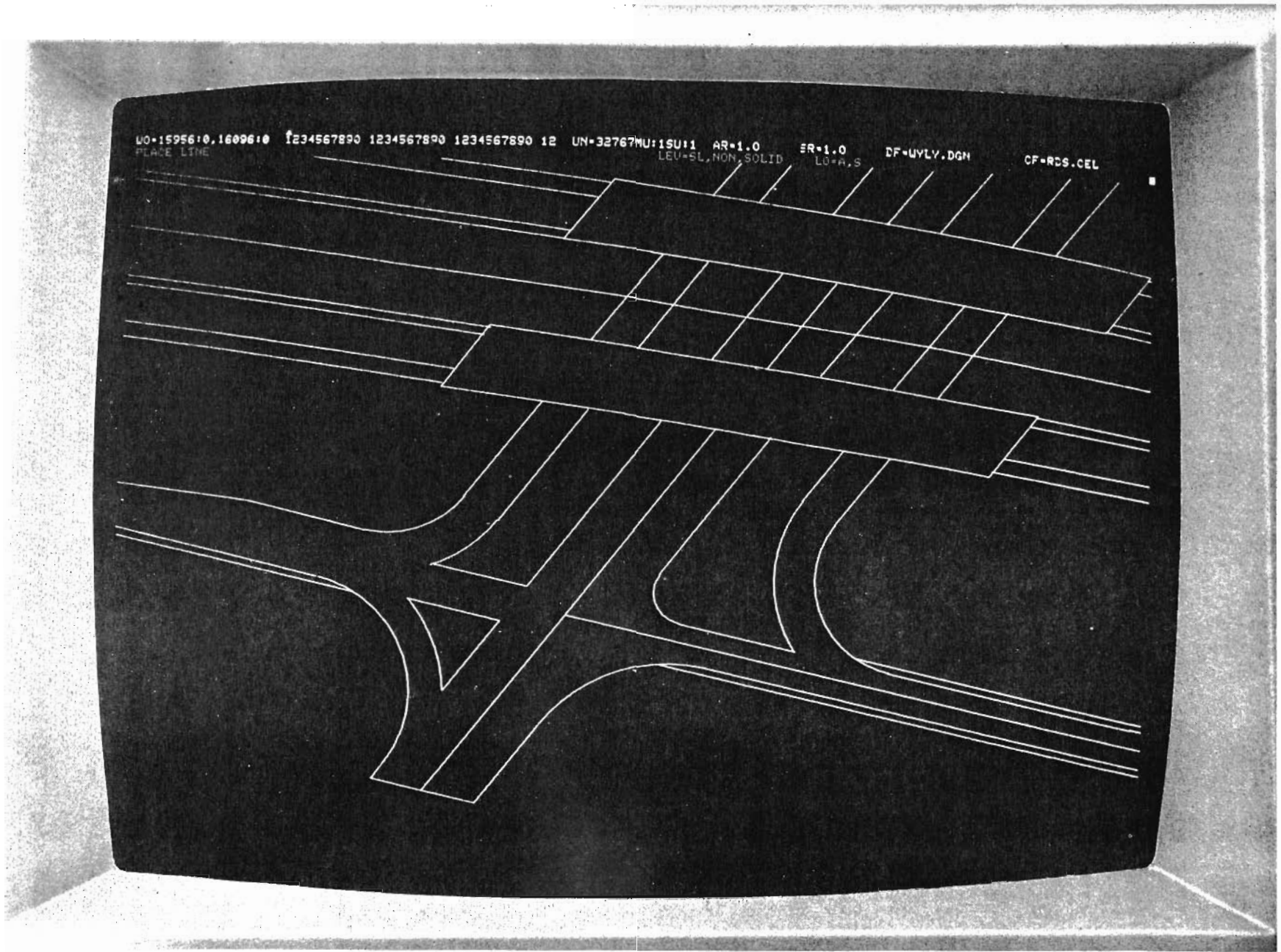
Figure 2. Example of an Interactive Graphics Display Screen

There are other reasons why interactive graphics is considered a justifiable capability. These come primarily from the experience obtained by DHT and other users of engineering systems in implementing and training personnel in their use. For example, computer prompted input minimizes a training of design personnel in the use of a program. It also brings program enhancements to the designer in a minimum of time and with a minimum of retraining.

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 traveling 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 for analysis of such items as environmental impact. 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 available 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 system.

The computer systems to be viable tools must also be dynamic. As technology and design requirements change, the systems have to be updated. This creates more of a problem in maintaining user documentation and training of part-time users. Due

13

to the complexity of the systems and enhancements, training of
users is also a problem particularly in a decentralized design
environment such as used by Texas DHT. For training its engi-
neering personnel in the use of automated processes, Texas DHT
uses a centrally based field engineering staff of four people
(two registered engineers and two engineering assistants with a
minimum of 20 years experience each) along with a few individuals
in some of the Districts serving in a similiar capacity in their
Districts. It is the considered opinion of the project team
developing IGADS that the reliance on these individuals for
training purposes would be reduced with the proposed interactive
graphics system allowing the centrally based field engineers to
concentrate more on the tasks of project planning and coordi-
nating requests for automated services such as photogrammetric
mapping.

To assist infrequent users of RDS, IGADS is being developed
with a prompted type of input to guide the user through the
calculation process. (An example will be discussed later in this
report.) The process is one in which the system interprets the
answers given by the user to questions (prompts) displayed by the
system to branch to the needed calculation and allow entry of the
required input. The input will then be edited to inform the user
of any detected errors. The need for prompted input is due to
the multiplicity of calculation tools in RDS. For example, the
geometry process has over 100 optional calculation functions.
Provision for the more experienced user to bypass many of the
higher level prompts is also provided. The system will be some
what self instructional and any enhancements made to it will be

14

available to the user on the screen as they are made along with instructions.

The users can be more proficient with an interactive graphics system and a more responsive system will make them more productive. For example, a recent analysis by one of the larger Texas DHT Districts involved in the design of IGADS indicated a potential monthly savings in direct costs of approximately $10,000. This analysis was based upon a fully operational system which will also allow the trial of more optional designs in less time and, therefore, could provide for reduction in construction costs. The system will also allow construction personnel to obtain required construction staking information in a more responsive time.

The inclusion of other engineering tasks such as hydraulics and bridge design into IGADS in subsequent development will make the system an even more valuable tool to a transportation department. As a study of the value of interactive graphics in bridge design, Texas DHT's BENTCAP program is being designed and developed as a part of IGADS. This effort is being coordinated with Bridge Division personnel of the Department.

To provide user guidance in the design of the roadway design portion of IGADS, a team of engineering design personnel from various DHT Districts has been consulted. Members of the centrally based Field Engineering Unit (the training personnel mentioned above) have also had direct input into the design. The design is a result of this varied experience and study by the

15

project staff.

Why a Mini-Computer System?

Departmental Research Report 520-1 (4) outlined the basic
concepts of IGADS and discussed the use of a mini-computer for
processing. There are several reasons why the project team has
proposed IGADS to be a mini-computer based system. Before
discussing these reasons, it should be emphasized again that
while IGADS will be mini-computer based, it is not a replacement
but an extension of RDS which is a main-frame computer batch
system. This proposed mini-computer based system is in line with
recent trends in the computer industry to use main-frame com-
puters for the handling of the large data bases and computer sys-
tems requiring extensive computer power to perform their proc-
essing efficiently, and the use of mini-computers to control the
input and output devices and perform minor calculations at sites
remote from the main-frame computer. Advances in mini-computer
technology have produced machines with as much power, if not
more, than earlier main-frame computers used by transportation
departments in the recent past. This makes the IGADS concept now
feasible. Removing from the main-frame computer the control of
the input devices required for interactive graphics engineering
systems eliminates the impact the more time consuming functions
performed by an engineering design system would have on other
users of a telecommunication network. The longer response times
(on the order of 30 seconds maximum) imposed by engineering func-
tions are acceptable to engineering personnel, but the reduction
of response this would impose on management type systems would
not be acceptable. Use of a mini-computer based system will also
allow concentration of the input required to be transmitted to

17

the main-frame computer for processing thus reducing communication line contention. Implementation of IGADS on one of the more powerful mini-computers should also allow the implementation of other distributed data processing systems on the same equipment.

The conversion of all computer systems involving plotting to the Texas DHT General Plotting System (to be discussed later) and the installation of a digital plotter controlled by the mini-computer would allow the preview of all plots on a graphics display screen prior to the actual plotting. This would allow enhancement of the plot using the proposed Interactive Graphics Drafting System (also to be discussed later) which would also be resident in the mini-computer and then production of a hard copy plot. All of this could be accomplished at the remote site. Installation of adequate printers and card readers as part of the mini-computer facility would allow organizations currently using remote job entry terminals to replace them with the mini-computer facility further justifying the installation. For the Texas DHT District reporting a potential savings of $10,000 monthly, a preliminary estimate of the cost of a mini-computer installation capable of performing most of the functions discussed above is approximately $9000/month including support personnel based upon a five-year amortization of the equipment costs. Less expensive installations are possible for using IGADS.

The trend to central computer centers in many states makes some of the transportation organizations of these states remote users of the main-frame computer; thus the mini-computer based system is a potential alternative for them. Other transportation

18

organizations and FHWA with dedicated main-frame computers operate as decentralized design organizations just as Texas DHT does making them remote users of IGADS. Transportation organizations operating with centralized design and having a dedicated main-frame computer would not have to install a mini-computer facility as extensive as outlined above. The benefit of reducing the impact of an engineering graphics design system on their telecommunications system would still be an advantage.

One important factor in the decision to make IGADS a mini-computer based system was the need of an interactive graphics drafting system to complete the process of automating the transfer of a highway facility design to right-of-way and construction plans. It was not considered within the scope of this project to develop a drafting capability since there are several commercially available comprehensive interactive graphics drafting systems. Most of these systems are mini-computer based and have already developed the required equipment interfaces. In at least one case familiar to the project staff, these firms have made enhancements to the basic equipment to optimize their operation. Maintenance of the complete installation (with the possible exception of some minor equipment required by IGADS) is available, minimizing the need to develop in-house maintenance support. Utilizing the equipment furnished by one of these firms reduces the requirement to perform the electronic engineering necessary to develop the equipment interfaces. IGADS is being developed to allow more than one firm to respond to a bid proposal. Since the system is being developed on the equipment available to the project staff which was purchased from one of

19

the firms licensing interactive graphics drafting systems, the
required program interfaces will be available for that system.
Any request for bids by another organization desiring to install
IGADS would need to specify that the interfaces to the drafting
system selected be furnished or the organization would have to
develop them. It has been reported to the project staff that
eight transportation organizations have purchased or are in the
process of purchasing the same interactive graphics drafting
system being used for IGADS development purposes. These pur-
chases are based upon the merits of using an interactive graphics
drafting system. The addition of IGADS will further enhance the
power of the installation.

How Will IGADS Work?

IGADS is only one component of a total concept being developed to further automate the roadway design process from the initial survey to production of the required design documents. The general design of the development is being prepared in another report and only a summary will be presented here to acquaint the reader with some of the basic concepts. The total development effort consists of four major components (illustrated in Figure 3) which are linked by a project data base for calculations and graphics files for graphics display. These components are (1) surveying performed by TEAMS, (2) calculations performed by RDS with input through IGADS, (3) plotting performed by the General Plotting System and (4) drafting performed by the Interactive Graphics Drafting System. RDS and TEAMS have been discussed briefly and will not be covered here; however, one aspect of TEAMS should be mentioned. While TEAMS will be a major component of this system for Texas DHT, it is not required to be implemented by another user of IGADS. Output from a map system other than TEAMS could be used as long as a data base was used or was converted to the Graphics Interface Format. If it is not desired to implement a mapping system, the survey information could be input through the Interactive Graphics Drafting System which would provide the Graphics Interface Format. The graphics display of the survey information would then be displayable by IGADS for use in design.

The General Plotting System (GPS) will provide the capability of plotting any data presented in the Graphics Interface
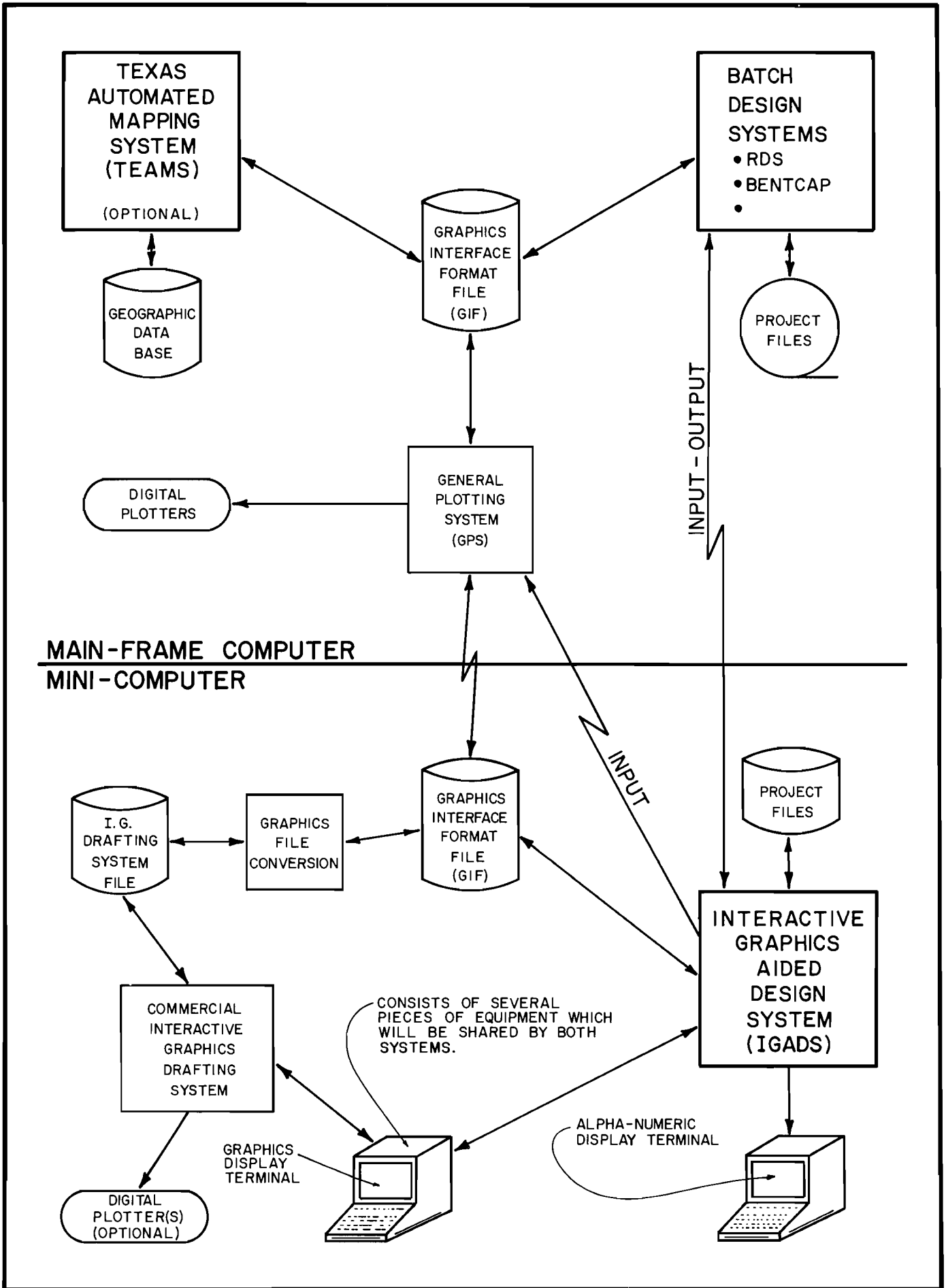
21

Figure 3. Components of IGADS

Format. This system will allow plotting with character formats defined by the user such as LeRoy fonts. Several character types will be available initially. These will consist primarily of those required to produce design and county maps. Line symbology (such as dashed and double lines, fences, trees and centerline) will also be available. As with the characters, the user will have the ability to develop his own line symbology types. Provision will be made to allow the user to display or plot edit versions of the graphics with less complicated line symbology and character types which will be more efficient to generate and plot. The ability to select features from the file (to eliminate unneeded features such as trees and utilities) prior to plotting and/or displaying will be provided. The resultant file can be broken into smaller segments such as plan sheets. Multiple files with different coordinate systems such as plan features and vertical profiles can be rotated and translated into the same coordinate system for display and/or plotting. This would allow the development of plan-profile views. The General Plotting System will also provide the file conversion required to work with data on the Interactive Graphics Drafting System. GPS will support several types of plotters including high speed drum and high quality flatbed plotters. It should be noted that drafting performed solely in the Interactive Graphics Drafting System will be plotable by GPS using any one of the plotters. Input for GPS will be both card and through the use of IGADS.

Commercial interactive graphics drafting systems typically provide full engineering drafting functions in an interactive graphics environment. Complete drafting of engineering drawings

23

can be performed by use of a stand alone commercial drafting system. This has been demonstrated by the varied engineering organizations using the systems in production including transportation organizations. A notable example is the Michigan Department of Highways and Transportation which operates a system three shifts a day and has reported that they produce more than 100 plan sheets a day. With the implementation of IGADS, the basic graphics would come from the design process thus eliminating the need to reinput into the drafting system the basic design to produce the required plan documents.

It is beyond the scope of this report to discuss how IGADS would be used in the design process of a highway facility from the basic survey to plans and specifications. This will be covered in the general design report including functions other than roadway design. To summarize the basic philosophy: the system is being designed to allow development of graphics representations of one process such as schematics which can be transferred as a computer file to another process such as right-of-way and/or roadway design for modification and enhancement to continue the design process. (Note: These capabilities would be available, but not mandatory, thus allowing use of the system to be defined to suit the philosophy of the organization operating it.) The purpose is to allow the results of one process to become the basic "work drawing" for the next processes. This is to eliminate as much "redrafting" of the same basic information as possible. Since the files will be stored on a project basis, copies of the same basic information can be given to more than one team of designers for continuing the design concurrently.

Since IGADS will be the basic interactive system develop-
ment, following one calculation process step by step through
IGADS may provide insight into the operation of the system.

Example Of Horizontal Alignment Calculation:

1. Assume that the basic information available at the
    beginning of a project design is a photogrammetric
    design map file and control traverse. Assume also that
    supplemental ground surveys are referenced to physical
    features visible on the photogrammetric design map and
    no centerline surveys will be performed until the
    alignments (both old and new) are computed and the
    centerline surveys are needed for location of proposed
    features for right-of-way staking and construction.
    All property monuments such as right-of-way markers and
    property corners were targeted prior to the aerial
    flight and coordinates for the monuments have been
    determined during the photogrammetric process. The
    alignment to be computed begins in the curve of an
    existing roadway and, to keep the example simple,
    traverses through open country to "tie" back into the
    same roadway several miles from the beginning. Only a
    portion of the alignment will be illustrated for this
    example even though the complete alignment could be
    designed at one time. Command Geometry from RDS will
    be required for a portion of this calculation. (Note:
    There is usually more than one method of computing data
    with Command Geometry and this example is intended to
    illustrate the use of IGADS and not define an only
    solution.)

2. The equipment available to the designer would typically
    consist of a mini-computer with its peripheral equip-
    ment such as disks, card reader, printer, plotter,
    etc., depending on the installation; an alphanumeric
    display terminal with keyboard and a graphics drafting
    station. Depending on the Interactive Graphics Draft-
    ing System manufacturer, the graphics drafting station
    would consist of two graphics display screens (prefer-
    ably, although one could be used), a keyboard (only
    active when the drafting system is in use), and a
    graphics input device (preferably a command tablet with
    a free floating cursor control). Figure 4 is an illus-
    tration of a typical design station.

3. For simplification assume the designer has already
    accessed the graphic file on the main-frame computer
    and transferred to the mini-computer disk a copy of the
    applicable portion of the photogrammetric design map.
    His RDS project file would contain the basic control
    traverse which was developed for the photogrammetric

25

11" GRAPHICS CRT

19" GRAPHICS CRT
WITH KEYBOARD

11"X11" COMMAND
TABLET

CURSOR
CONTROL

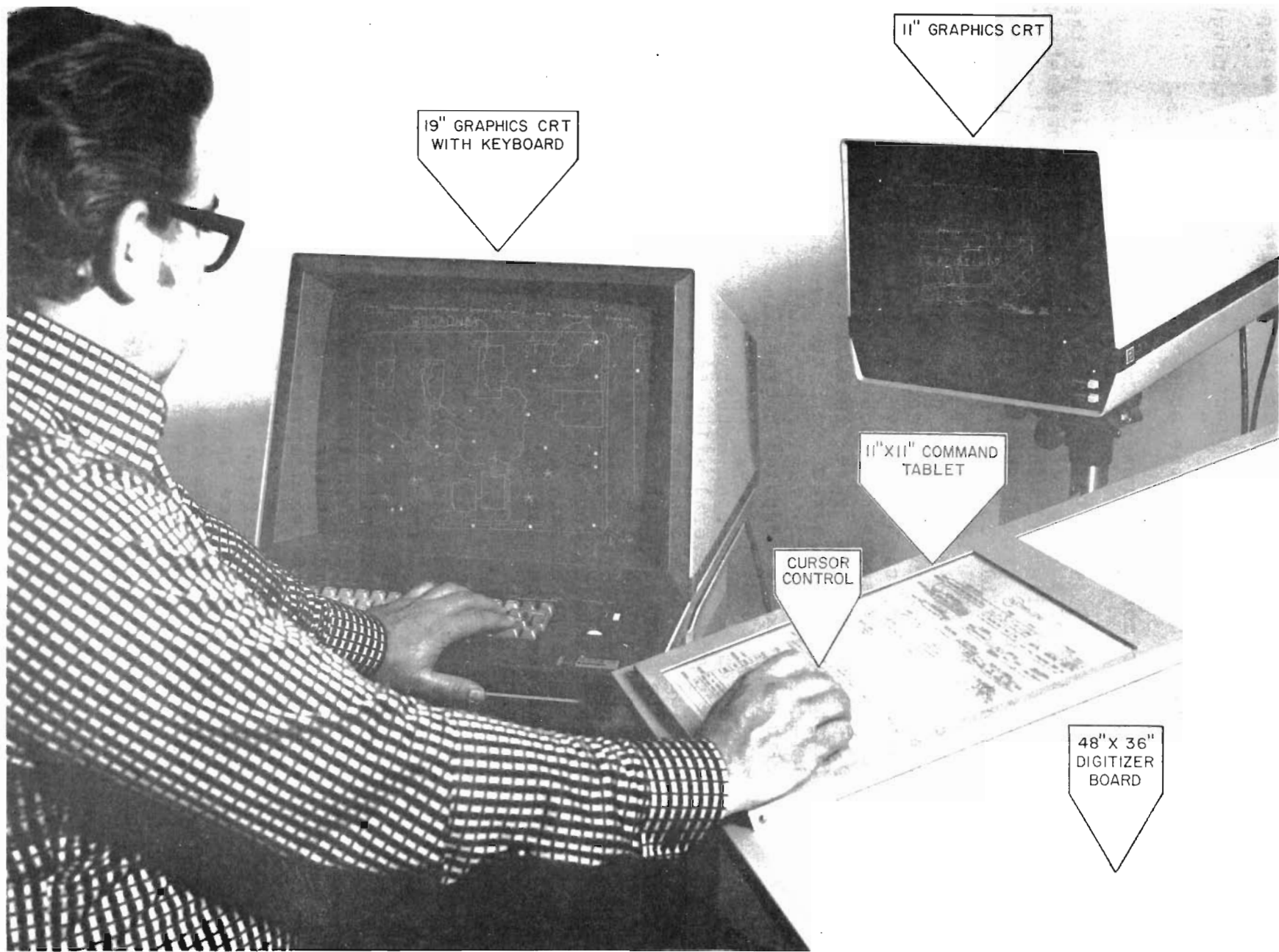48"X 36"
DIGITIZER
BOARD

26

Figure 4. Typical IGADS Design Station

process. The "plot" of the traverse will be displayable with the photogrammetric design map.

4. Since this is an alignment for a new roadway location, the designer will have determined the approximate alignment location with an "on the ground" reconnaissance and will have a record of the location for use in the office possibly as a sketch on the aerial photographs, which were taken to produce the photogrammetric design map. The location would be pinpointed in critical areas by dimensions from physical features visible on the design map and photographs. These could include large trees, buildings, fence corners and, of course, the control traverse points. At the same time other pertinent design information such as high water marks, underground utilities and other features not visible in the photographs could be located with respect to visible features for input into the graphics file for display during the design process. (Note: These could be input using TEAMS, FDS, IGADS or the drafting system.) The process for entering this additional information will not be discussed but it would be similiar to the design process which follows.

5. When the designer is ready to start a design session at the station, his first step would be to activate IGADS by activating a control key on the alphanumeric terminal. IGADS then would ask what process he wanted to use (FDS, structures, etc.). The available processes would be listed by number and he would key in the number of the option desired. In this case since he would want FDS he would key in its number and depress the carriage return. The system would then ask what project, and the user would key in his project identification. The system would check to see what files were available for that project, list them for him, and ask if he needed a list of what was on the various files and/or if he needed to delete a file. Assume in this case neither is needed; therefore, he would depress the carriage return and the system would list the FDS Design processes (Geodetic Control, Command Geometry, Design Data, etc.) and request he identify by number the process desired. The user would key in the option number and depress the carriage return.

6. All of these prompted questions would be displayed on the top of the alphnumeric terminal screen with any prompting information such as option lists below the prompt question. Where a question requires an entry the terminal will be in position to accept the input data without the user having to space to the entry field. Once a carriage return is depressed, the system will edit the input and if required issue error mes-

27

sages and reask the question. At any time the user needs additional instructions he can execute a "HELP" command and have displayed on the screen a more detailed definition of the input required.

7. Assume the first step the user elects is to calculate the P.I. coordinates of the old alignment in order to define it to the system; therefore, he would have indicated the Geometry process. The system would then respond by asking if he wanted to have graphics displayed on the graphics screen(s). Since he does, he would signify yes by keying in the letter "Y". The system would respond by listing the graphic files available and request what is to be displayed on each screen. He would request "ALL" at this time, since only the map data and geodetic traverse are available. He could have elected not to display some elements such as trees or utilities and would have been instructed to specify what was to be included or excluded. Since he specified "ALL", the system will display the data on both screens to a scale so that all data will be displayed. This may make the display of his project very small and he would revert to the graphics display commands on the Graphics Command Tablet to enlarge the area displayed on one of the screens to the scale he needs to work with.

8. The purpose of the Graphics Command Tablet is to provide a means of instructing the Graphics Display Controller what portion of a file is to be displayed on each screen and at what orientation and scale. It will have commands such as:

   a. Window – Which expands the scale of the display to view a smaller portion of the existing view with a new origin.

   b. Zoom in or out – Which changes the scale of the current drawing centered about the center of the screen.

   c. Measure – Which allows distances, areas and perimeters to be "scaled". The results of these measure commands will be displayed but will not be input into IGADS. RDS measure commands would be used if the results are to be printed and used in subsequent calculations. These commands could measure drainage areas for hydraulic calculations which are not used by RDS.

   d. Rotate – Which provides the ability to modify the axis of the display. An example would be to rotate the display so that some element such as a tangent of an alignment would be parallel to the X-axis of

the screen.   .

  e. Grid on or off — Which allows the display of a co-
    ordinate grid for reference.

  f. Delay — Which allows the user to control when the
    screen is to be redrawn. To delete an item from
    the display on a storage tube terminal, the screen
    must be redrawn. The user must wait while this is
    done. With the delay command active, the deleted
    element would be "flagged" as being deleted from
    the file but remain on the screen until the user
    instructs the system to redraw (or update) the
    screen. This reduces the wait time for the user.

9. The user would probably leave the display on one screen
  (overview) as it is, since it would serve as a refer-
  ence to the display on the other "work" screen. A rec-
  tangle will be drawn on the overview screen to cor-
  respond to the area currently displayed on the "work"
  screen. Since it will be necessary to display an area
  at a large scale to view details, the overview rec-
  tangle will allow the user to remain oriented as to the
  area being displayed on the "work" screen.   (Note: In
  other design calculations, each screen will display
  different data such as plan and profile views for
  vertical alignment design. At any time, either screen
  can be the "work" screen as the user specifies.)

10. Since the user needs to define the existing alignment
  to IGADS, he would probably start with a view encom-
  passing the first tangent. To change the view on the
  work screen, he would use Graphics Commands. The
  graphic command "WINDOW" would be issued by placing the
  cursor control over the position of the "window area"
  command on the command tablet and pressing the command
  button on the cursor control. This signals the system
  that the user wants a new view on the "work" screen to
  be defined by two data points. Another function of the
  cursor control is to move on the screen a "graphic
  cursor" (symbol) indicating the X-Y coordinate position
  of the cursor control. This allows the user to posi-
  tion the cursor control in relation to the elements
  displayed on the screen. For this function, he would
  place the graphic cursor at the lower leftmost corner
  of the desired viewing area and then press the data
  button to input the X-Y coordinates of the point to the
  system. The system will accept the X-Y coordinates as
  the origin of the new viewing area. The same procedure
  would be used to indicate the upper right corner of the
  desired view. The system will take the two X-Y coordi-
  nates and compute the closest engineering scale that
  will allow the view to be displayed on the screen and
  redraw the screen with the new view and indicate the

scale of the drawing on the screen. The scale of all
displays will be given for the user's information.
Note: The location of the corners of the desired view-
ing area is not critical since the view can be changed
as required.

This same type of process would be used for all graphic
commands on the command tablet, although the data
points required would be different. To further illus-
trate the graphics manipulation, assume the user
decides that the view on the work screen is not to a
scale sufficient to define the first tangent. He would
then use the Graphic Command "TRANSFER VIEW" to have
the display of the work screen drawn on the overview
screen. He would then use the "TRANSFER WINDOW AREA"
command. This moves the graphic cursor to the overview
screen which allows the definition of the area to be
displayed on the work screen to be indicated on the
overview screen. He then would define a smaller view-
ing area on the work screen covering an area in which
he needs to define a data value to IGADS. He would use
the graphic commands to change the viewing area of both
screens as required to input data into IGADS throughout
his design process.

11.   Since the user had specified that all of the available
graphics were to be displayed requiring no further
graphics definitions on the terminal, the system would
have responded on the terminal with a display of the
"MENU" command while he was performing the graphics
manipulation. An illustration of this command is given
in Figure 5. This display allows the user to bypass
the menu option selection if desired. The command
"MENU" would be pre-entered but the user could override
it by keying in the command desired. If he wants to
review the menu he would depress the carriage return
and the menu would be displayed for him to enter the
option desired. This is shown in Figure 6. His first
operation would be to enter option 1 (PONT). The
system would then display the point options available.
Since the existing alignment is down the center of the
pavement and only the edges are shown on the design
map, he would select the mid-point option. This option
allows the user to define two points and have the
system compute a point midway between them and store it
for future use. The system would request he enter or
digitize both points, one at a time. It would provide
an entry field for both X and Y coordinates. The user
could key in the coordinates or place the graphic
cursor over the point desired and press the data button
(digitizing). The system would enter the coordinates
of the point. The user could accept the coordinates by
keying the carriage return or reject and re-enter them.
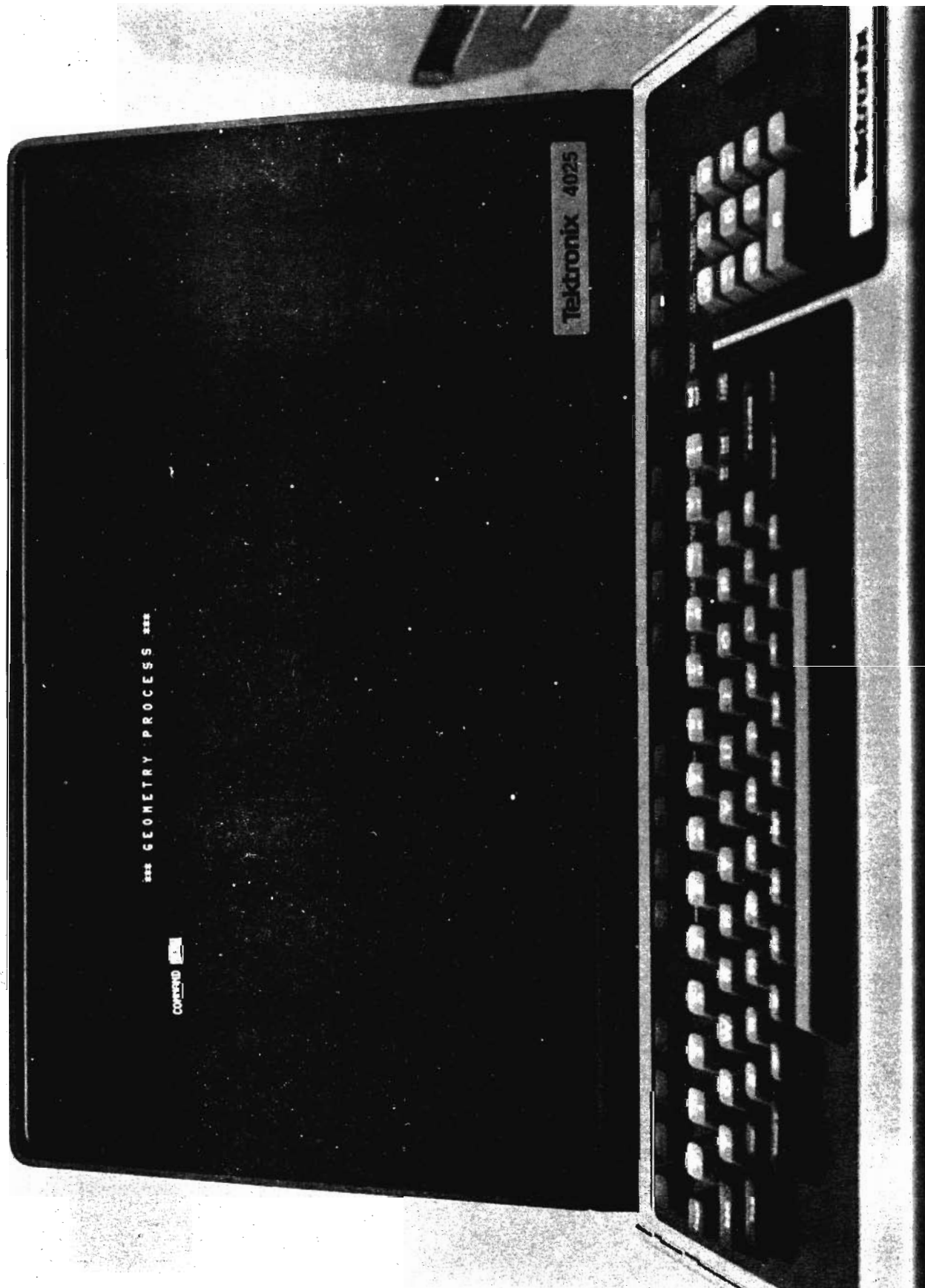Once both data points are entered, the system would

*** GEOMETRY PROCESS ***

COMMAND

Tektronix 4025

Figure 5. Display of the MENU Command

31

== GEOMETRY PROCESS ===

COMMAND
SELECT MENU OPTION ▮

1 OPTIONS FOR LISTING ALL GEOMETRY COMMANDS
2 OPTIONS FOR LOCATING POINTS
3 OPTIONS FOR LOCATING LINES, CIRCLES AND COMPLEX LINES
4 OPTIONS FOR COMPUTING ELEVATIONS, OFFSET DISTANCES AND ALIGNMENT RELATIONS
5 OPTIONS FOR COMPUTING AREAS, BEARINGS AND DISTANCES, AND ANGLES
6 OPTIONS FOR COMPUTING BRIDGE DIMENSIONS AND ELEVATIONS
7 OPTIONS FOR PLOTS OF POINTS, ALIGNMENTS, AREAS, LINES, CONTOURS & BRIDGES
8 OPTIONS FOR CORRECTIONS, REVISIONS AND ADDITIONS TO GEOMETRY COMMAND FILE
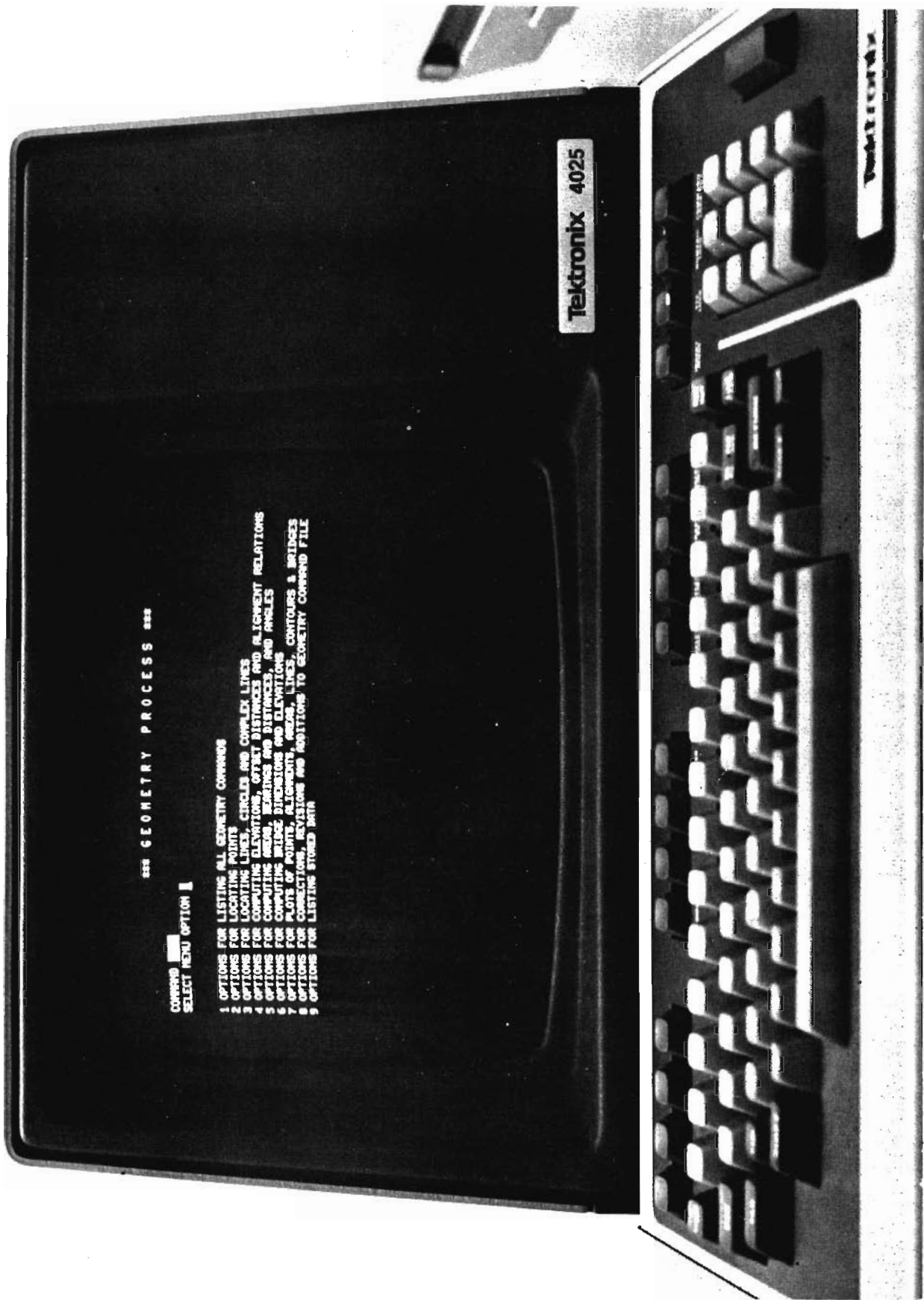9 OPTIONS FOR LISTING STORED DATA

Tektronix 4025

Figure 6. Display of the Options for the MENU Command

compute the mid-point, assign it a storage number and display the coordinates and a graphic symbol at its location. The user would have the option at any time to revise the point by use of the update command.

It would be counter productive to go through the detail of the input for the whole process for defining the alignments; therefore the remaining functions will only be summarized. However, the basic input-response discussed above will be true of all phases of IGADS. Two points should be made before proceeding. First, the graphic display of points, curves and alignments resulting from the geometric calculation is a working drawing only and the user will use plot commands to transform it into meaningful drawings, allowing him to identify the symbology and limits of each element. (Note: In geometry a line is infinite in length and its limits must be provided to represent elements such as right-of-way lines.) Second, once a geometric element such as the point above has been stored, its value can be recalled for future use by placing the graphics cursor over it to identify the element required. This eliminates the need to maintain a work drawing of index numbers as required in the batch version of RDS. Also keep in mind that the user is modifying his displays as required to view the needed area at the needed scale, and any data values he wants to input can be keyed in rather than digitized.

12.   The user would input a series of points along the tangents of the existing alignment as discussed above and use the "LFIT" command which "means" a line by the least-squares procedure along each tangent much the same as a survey party would. He would intersect the tangents for the curve P.I.'s and input alignment data. The measure command would be used to compare the computed offset of right-of-way markers with dimensions from existing plans.

13.   The proposed alignment would be defined by inputting coordinates by placing the graphics cursor at the P.I. locations or through the use of geometry to fit the alignment through critical areas. The alignment would be displayed as it was input, and the user could modify it as desired to place it in the optimum position. The location of the tangent to the existing curve would be computed using the TANG command which computes the tangent point to a circle from a point outside the circle.

14.   A plot of the results could be obtained through the PLOT commands which require the user to specify how the drawing is to fit on the paper, the scale desired and what elements are to be plotted. The resulting plot could contain his alignments, control traverse, any

33

other points or curves needed for analysis, and the photogrammetric design map.

15. Once the user signifies the design session is complete, the system will request him to designate the disposition of the mini-computer files (keep or delete); and the RDS files will be transmitted to the main-frame computer for processing, printing of the output report, update of the master project file and generation of the requested plots.

16. For further design sessions such as right-of-way calculations, the user would recall the files to the mini-computer for additional input using much the same techniques discussed above except that he now has basic information available to add to. When the designer has completed all of the required calculations for a function such as right-of-way, he or a draftsman will define how the project graphics files will be broken into sheets using alignment stations or coordinates, the orientation of the graphics on each sheet, and the sheet style to be used. These individual sheets will be developed by the General Plotting System and can be plotted or transferred to the Interactive Graphics Drafting System for finalization. (Note: The project graphics file can be transmitted to the drafting system at any time for addition of details such as annotation.) When the drafting is complete the sheet can be plotted on a digital plotter. In Texas this will be on a precision flatbed plotter. Other sheets, such as detour layouts not involving the design system (RDS) would be drafted using the drafting system exclusively.

The example given, although brief, hopefully illustrates the philosophy of the project team in developing a tool for engineers to automate their process without restricting the capability to one style or technique of design.

34

Decisions Affecting Design

Because of the complexity of the mechanisms involved in interactive graphics, considerably more time than anticipated was spent on defining user needs; and, during the early phases of the project, extra time was spent defining needs and benefits which are critical to future development. Some of the decisions affecting design are discussed below to provide the reader with insight into the complexity of the development.

1. Definition of Interactive Graphics – The author's definition of interactive graphics was discussed in an earlier section of the report. This definition has been one of the major tasks faced by the project team. The proposal for the project outlined a functional technique for the system operation; further study by the staff, however, indicated that the scheme was too restrictive to the user. This decision was reached after discussions with potential users and review of other systems and in literature review which was primarily NCHRP Project 20-8 which dealt with this specific application. Credit must be given to the project staff of NCHRP Project 20-8 for early analysis of an interactive graphics roadway design system using RDS as a base. Unfortunately the final report was not printed, but a copy was made available to the IGADS project staff and has proved valuable in the design efforts.

Most systems reviewed, both existing and proposed, were interactive in their calculation and drafting (if provided) functions but did not provide interaction with the graphic displays in the calculation process. In the opinion of the author, this interaction with the graphics provides the greatest benefit of IGADS. Without this interaction, the user must still work with the hard copy work rolls during a design session. This is not to imply that the user will not need reference material at the design station while performing calculations. However, with IGADS the amount of material required should be substantially reduced. There have been numerous discussions of how the system should function and practically everyone involved has had a differing opinion. The resulting design is the culmination of these discussions. The possibilities or ideas have ranged from a fixed format input on a video screen with no interaction to calculations on the

main-frame computer with graphics display as a by-product to full graphics interaction with the user being allowed to identify an area to be modified such as a ramp terminus and the system performing all of the required input modifications. The proposed system is considered a compromise by (1) providing comprehensive capabilities without making the system so automatic that it restricts the user into having to accept a preset method of use and (2) taking advantage of the capabilities of RDS.

2. Interactive Graphics Experience - The project team has had extensive experience in hard copy graphics and engineering system development. Their limited interactive graphics experience, while causing some delay in technical areas, has been beneficial in permitting a fresh look at the integration of interactive graphics capabilities and user needs. Hiring a consultant offset the technical limitations. To provide the graphics interaction considered essential has required extensive study. Review of the functions of existing interactive graphics drafting systems has provided valuable insight into the human engineering required to make the proposed system user oriented. Also invaluable in this respect has been the extensive experience that the project staff has with the current Roadway Design System and its use.

3. Proposed System Capabilities - IGADS is the primary development of this project; however, in the design and development process, the project team is also further automating the roadway design process (primarily handled by RDS) to provide the user with tools to move from the survey to final plans with minimal manual data transfer. This is a logical step since the required data will be in computer medium. This has added to the complexity of the development effort. Typically most prior system development has been to handle specific functions such as the photogrammetric mapping or roadway calculations. Since the basic components have been developed previously, this project was a logical one to bring the functions together. This has required a study of these large systems and their capabilities and limitations (for interactive graphics) and of how they could be integrated with minimal modification. During the time this analysis was being performed several developments have taken place which have affected the design. A decision was made by Texas DHT to resystemize (rewrite) the Texas Automated Mapping System allowing a redesign of the Graphics Interface Format. While this has been beneficial to the IGADS development effort since the new system will provide more information to the user of IGADS, it has required time by the project staff to define the requirements of

36

the engineering user.

During this design process, RDS was being demonstrated by a regional office of FHWA and implemented by the other states. In the process two versions of RDS emerged: A Texas version and an FHWA version. Although both are basically the same system, there are some differences and individual states have selected one or the other version. In addition each state has customized their version to some degree. This has not to this point greatly affected the project, but it has been of concern to the project staff as to what version IGADS should be developed for. This is further complicated by the fact that the Texas DHT users have not elected to convert to the FHWA version even though the National RDS User Group voted to adopt that version as the basic supported version of RDS. Since the Texas user will be the first testers of the system, the Texas version's capabilities are necessarily the first to be developed.

4. Equipment – The project proposal stated that Texas DHT would furnish the mini-computer and terminals necessary for the system development if FHWA would furnish the development funds. The equipment to be used was that of an Interactive Graphics Drafting System purchased by the Department to support its photogrammetry operation. Detailed analysis of its mini-computer found two deficiencies; both, while not precluding completion of the development, created problems. In some operations the precision of the mini-computer was not sufficient for highway engineering calculations defined by the user to be performed on it and in some functions the FORTRAN compiler was limited. Mini-computers more compatible with the main-frame computers are now available and the Department is acquiring one which will be available for IGADS development. Designing to overcome these limitations has taken some of the project team's time.

The mini-computer system available to the project staff for development is also used for production support of the Department's photogrammetry operation and is only available on a scheduled basis. When the proposal was made, Texas DHT was in a slack period of construction projects due to lack of funding and the mini-computer was readily available. During the early phases of the project the Department was provided additional funding which has accelerated their design and construction activity making the use of the computer more difficult to schedule. The project staff has had to go to night shifts to obtain sufficient development time which, in turn, has delayed the project since the staff is not all working during the same hours.

37

5. Use of Interactive Graphics Drafting System – The
    project proposal for IGADS envisioned two uses of the
    commercial Interactive Graphics Drafting System. One
    obviously was to provide automated drafting capabil-
    ities to the engineering user. To enhance the cost
    effectiveness of this capability, it was proposed to
    pass the graphical representation of the design to the
    drafting system for the finalization of the plan sheets
    to be used as contract documents. The other function
    was the graphics screen controller. IGADS will require
    programs to draw the displays on the screen, interpret
    signals from the command tablet, and identify elements
    on the screen. Interactive Graphics Drafting Systems
    have these capabilities and it was felt that the system
    could be used to provide these functions for IGADS.
    The basic requirement was that the interface between
    IGADS and the drafting system had to be in a manner
    where more than one commercial system could perform the
    functions, thereby not linking IGADS to one proprietary
    system. This turned out to be more difficult than
    anticipated; therefore, it has become necessary to
    develop a graphics controller for IGADS. The deliber-
    ations and study involved in this decision have occu-
    pied much of the project time thus far and have added
    to the complexity of the development. Commercial
    drafting systems are constantly changing which has also
    added to the complexity of the study. (Note: This
    should not be interpreted to imply that the drafting
    system still will not be required.)

These are the major decisions which have had to be addressed

thus far in the project. Some have just been questions to

address in order to complete the project, while others have had a

direct effect on the design and have caused delay. The extent to

which the commercial drafting system could be used has been the

problem which has troubled the project staff the most. Solving

that problem has moved the project forward a long step although

it entails more project development.

38

Project Status

The design decisions and equipment availability discussed above have made it difficult to define the project status since they have affected the amount of development to be accomplished. As a means of defining the project status, the past accomplishments and remaining work will be discussed.

The initial development efforts were directed to modifying existing RDS to allow display of all of the plots produced by the system on a graphics terminal. The purpose of this effort was to gain insight into how usable highway engineering drawings are on a 19" diagonal screen graphics terminal and to obtain user experience. Since both photogrammetric maps and RDS plots needed to be displayed simultaneously, a general graphics record format was defined which both RDS and TEAMS could output for plotting and graphics display purposes. This file definition has occupied some time since it is intended to be general in nature so that most application programs can use it to pass plot data to the General Plotting System for graphics production. Since Textronix terminals are being used, this initial effort could have been performed using programs available to convert CalComp plot data to a displayable form. This was not used since the graphics had to be transmitted over data lines; and, by designing a data file format, the amount of data transmission could be optimized. It also allowed the transfer of user identification of the data elements to the drafting system for future reference. The existing versions of both RDS and TEAMS were modified to produce the graphic records, and the necessary conversion routines were written to allow transfer into the drafting system file format for

display. In the process of modifying PDS, all plotting was removed and the generation of graphic records optimized, removing duplicate routines in the various segments of the system. Use of the drafting system for display allows modification of the plots and production of plan sheets if desired. Since the plotting capabilities of PDS were removed, a stand alone plotting capability was developed to allow hard copy plotting of the PDS graphics. This capability was completed in the last quarter of 1976 and is being field tested by Texas DHT users.

Subsequent efforts have been in defining the user functions of IGADS including organizing user committees and developing demonstrations of the proposed prompted input method. This has required detailed evaluation of how the user would need to interface with the graphics displays and finding methods for obtaining the necessary graphics input. Study has also been required in determining the information necessary to be included in the geographic data base produced by the mapping system to provide the user with the needed data selection. This effort, while essential to having IGADS function properly for the user, was not anticipated in the proposal for the project and has added to the design effort by the project team.

Design and development has also been performed for an alphanumeric form display controller and the project staff is currently debugging this system. IGADS can display input forms on either the alphanumeric or graphics terminals in a prompted sequence. Work is currently being performed to provide the prompted input through the alphanumeric terminal and generate a card input file for execution by both PDS and BENTCAP on the

main-frame computers.

The general design of IGADS is essentially complete and a general design document is being prepared for submission in the near future. This report is a summary of the design and has been prepared as an advance definition of the system. Detail design of the input system is also being prepared with development being performed as segments are defined. It is anticipated that a portion of the prompted input for both RDS and BENTCAP will be operational for user evaluation and comments in October, 1978. The remaining input will be added in segments. Detailed design of the interactive graphics portion of the system will also be developed in segments while the remaining input is added. Development of the interactive graphics capability will be the last stage of project.

Also under development is the General Plotting System previously discussed. The system is currently in the test stage producing both RDS and TEAMS plots. This effort is in conjunction with the rewrite of TEAMS.

41

Conclusions

While progress on the project may appear to have been slow, much has been accomplished towards the system design. The design phase of any development effort always occupies the bulk of the time and produces the least visible results, but it is essential to assure that the final product meets the needs of the user. The user is the one who must be satisfied; therefore, the project team has made every effort to involve him in the design process in an attempt to satisfy his requirements.

The version of IGADS produced by this effort will not encompass all areas of highway design since it was not in the proposal; but, in the opinion of the author, IGADS will move the highway profession a step forward toward a truly automated design process. Tools will be available to perform the current functions of RDS in a true interactive graphics environment. Also available will be a usable interactive graphics system for a portion of structural design, illustrating a technique of automating that process from analysis to plan sheet production.

BIBLIOGRAPHY

1. Walker, Larry G. and Gene Mangum. "Roadway Design System",
    Vol. 2, User Manual. Federal Highway Administration, Report
    No. 72D-104P, November 1971, Revised May 1974.

2. Howell, Tommie F. "Implementation of an Automated Mapping
    System". Texas State Department of Highways and Public
    Transportation, Report No. THD-1-19-73-40-1F, December 1973.

3. Los, Paul R. "Computerized Roadway Design System". Depart-
    ment of Transportation, Federal Highway Administration,
    Report No. FHWA-DP-30-1, March 1978.

4. Crawford, William L. "Conceptual Design of an Interactive
    Graphics Aided Design System". Texas State Department of
    Highways and Public Transportation, Interim Report, Report
    No. DHT-1-19-75-520-1, January, 1977.

43