Interactive Graphics in Highway Design

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The Texas State Department of Highways and Public Transportation has an automated photogrammetric data-acquisition system that uses aerial stereo-photo digitizing systems, which are integrated through video graphics, in order to produce digital models of the geographic areas on which highway facilities are proposed to be constructed. Highway design engineers then use a computer-supported system of engineering programs in order to interact with the digital model and proceed through the necessary logical processes at remote terminals to superimpose the design of the proposed highway facility on the existing terrain and develop the required engineering criteria for construction of the facility. The graphics related to these processes can be handled in either the video or hard-copy mode. In addition to generating the usual graphics provided in a set of construction plans, the system allows the designer to view three-dimensional displays of the proposed roadway and bridge structures as they will appear to the driver when completed. The system is applicable to all similar engineering problems, such as airports, waterways, streets, and utilities. The purpose of this paper is to discuss how the automated data-acquisition system functions and how a remote network of video graphics terminals supports the highway design process in a distributed data-processing environment.

Large and complex highway facilities constructed by the Texas State Department of Highways and Public Transportation are designed in a decentralized environment; there are 25 district-level offices and more than 100 subdistrict-level design offices. Detailed digital geographic data bases (Figure 1) are developed by photogrammetric methods in a central facility and are made available to the designers through remote terminals. The geographic data bases support an integrated automated highway design system. The complexity of the design problem will determine the level of terminal support needed; i.e., cathode-ray tube (CRT), card reader and printer, drum plotter, or video graphics station. Simple projects can still be accomplished from data obtained locally by manual field methods, but because of limitations in personnel and escalations in overhead costs it is becoming more feasible to use automation for all design projects.

AUTOMATED DESIGN SYSTEM

The automated design system and subsystems used by the Department have been developed in-house over a period of more than 20 years. Several years ago the users of this system outside the Department organized a users group and, at the Department's request, established a jointly funded systems maintenance arrangement with a software consultant. The Department participates in this user group and contributes to the maintenance contract.

Hard-copy graphics have been an integral part of the design system since digital plotters were first introduced. It was evident that graphics would be the key to the acceptance of electronic computer-oriented technology by senior highway design engineers. The associated computer coding, processing, and printouts were more comprehendible when graphic representations were generated. Currently, young engineers are seeking employment with the Department because of its automation environment.

Video graphics were introduced to Department design engineers at the local level about 3 years ago (Figure 2). The response from both the design staff and their managers has been so positive that the demand for this capability is growing faster than support resources can be provided. The support problem in Texas is also complicated by the Department's decentralized organizational structure and

Figure 1. Graphical representation of geographic data base.

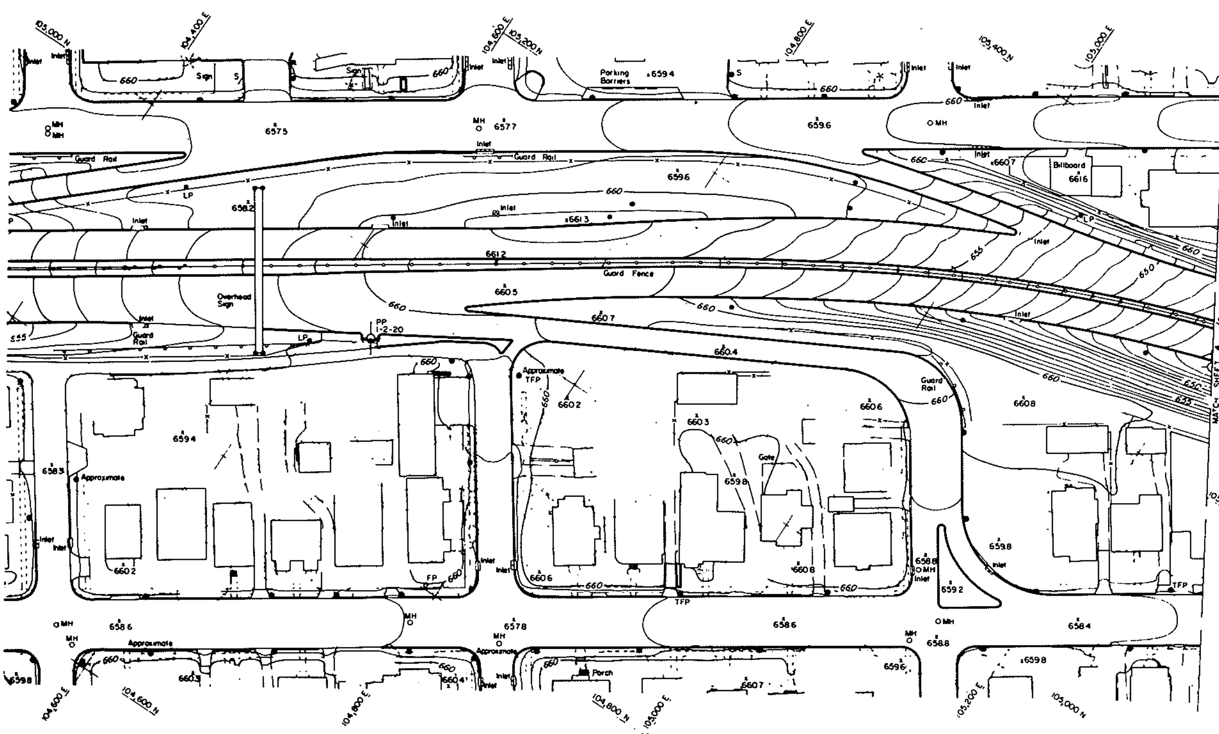
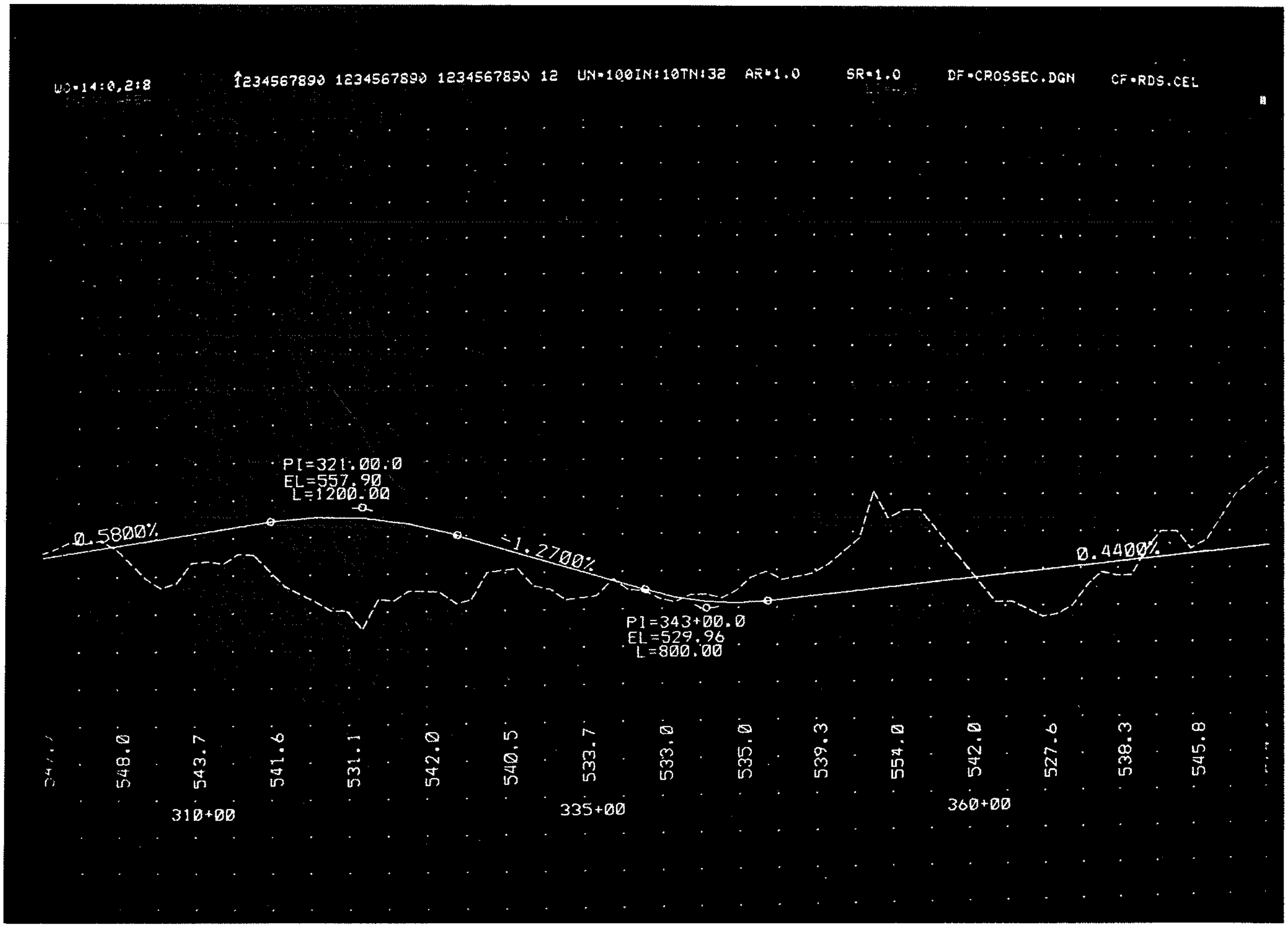


Figure 2. Automated highway design system graphics (roadway profile).



the projected work load. The Department's current commitment is to complete projects worth $1 billion each year for a 20-year period (based on 1976 dollars with a built-in automatic inflation factor).

The Department has further automated the design system so that it interacts with a management information system for project history, finance, accounting, and management controls, Unfortunately the scope of this paper does not permit discussion of the total interactive information system.

The end product of the automated highway design system is a data base from which a set of plans and specifications are produced. These plans are provided to contractors when they bid on the project, and they are also used for the construction of the project (Figure 3). The same data base is used to produce three-dimensional views of the highway facility as it has been designed. These views are superimposed on the existing terrain for final review by the designer or the contractor before bidding.

The initial files of the data base are digital descriptions of the existing culture and terrain that are oriented to the State Plane Coordinate System and U.S. coast and geodetic elevation data. These files can be represented as hard-copy, video planimetric, or topographic map sheets (Figure 4).

The cultural and terrain data files are developed from aerial photography by using a unique automated photogrammetric process--the Texas automated mapping system (TEAMS). The automated process actually begins with ground-control surveys that use total station field surveying equipment, which can record all horizontal and vertical distances, angles, and elevations directly to magnetic tape. The recorded data are input through telecommunication terminals to a digital processor located at the central office, where it is interpreted to determine the usual geodetic parameters of the survey line and the generation of a line drawing. A satellite doppler surveying system has been funded and will be implemented for these surveys as soon as the equipment can be ordered and the techniques developed. An interferometry satellite surveying system is also under consideration for this application.

A minimum number of horizontal and vertical control points are established on the ground because they can be supplemented with additional photographic control points obtained through an analytical stereotriangulation process in order to meet required map accuracies. Horizontal and vertical data are read from aerial photography by using electronically supported high-resolution optical equipment, designed specifically for this purpose, for input to a computer program to generate an accurate coordinate location and elevation determination for each point selected. The capability of providing supplementary control points reduces the cost of a field survey by approximately 80 percent. The result is a plotted grid coordinate system that has all control points identified in their exact positions for orientation of the aerial photographic stereo

Figure 3. Flowchart of the automated highway design system.

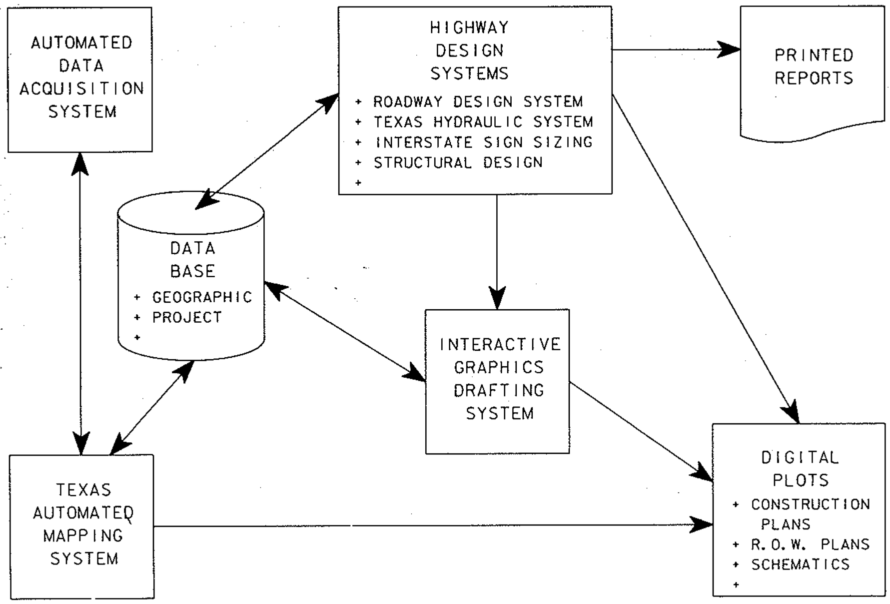


Figure 4. View of planimetric and topographic maps on a graphics station.

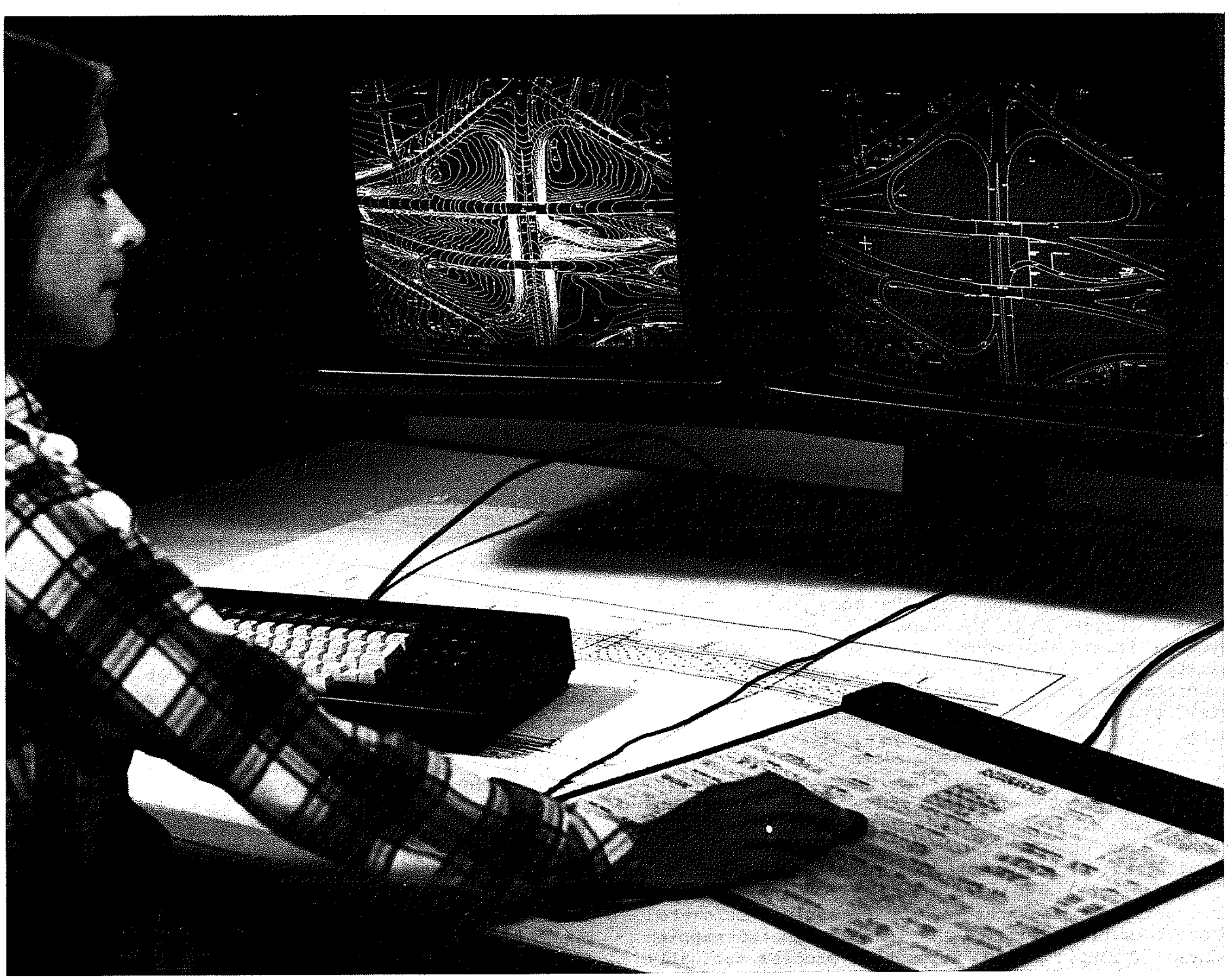
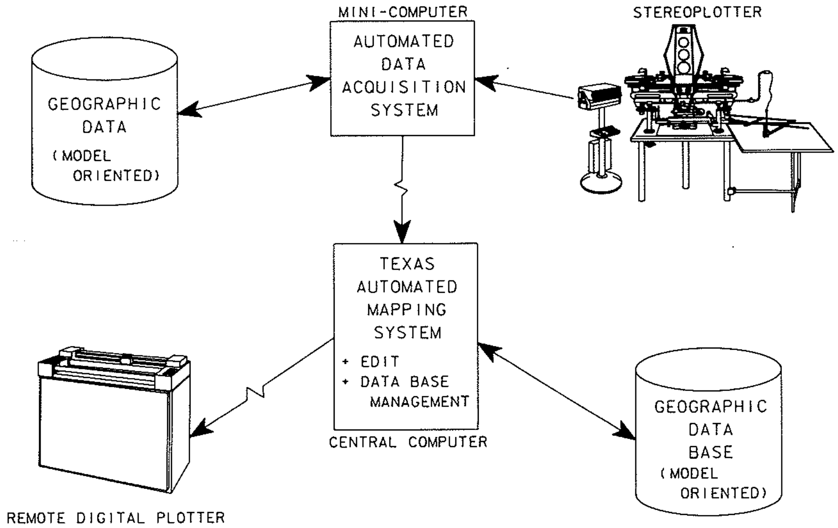


Figure 5. Flowchart of the automated data-acquisition system.



models from which the desired terrain detail will be obtained.

Data from the model are then obtained by using analog optical train stereoplotters modified to accommodate electronic X-Y-Z digitizers and encoders with visual displays that are interfaced with a minicomputer (Figure 5). New automatic adjustment capabilities have been designed into the software to permit the operator more flexibility in setting the model and positioning the coded data relative to the control survey. Fifteen plotter coding stations, operating simultaneously, store the coded data on a magnetic disk supported by a minicomputer.

The communications console of the minicomputer transmits the file from the minicomputer disk to a large processor in the central computer center, with instructions to the system to call up a support program and build instructions for a remote digital drum plotter. The stereoplotter operator handles the routine of building the file, transmitting the file from the minicomputer to the central processor, and then calling for the plot on the digital plotter. The graphic representation of the stereo model is checked for errors, and corrections are made if necessary. The operator signs off on the file when it is complete and correct (Figure 5).

The file in the central computer is then accessed by the interactive graphics minicomputer and written to a disk for further manipulation. An operator trained to use the video presentation of the photogrammetric model makes the final edit by viewing the original aerial photographs in stereo and making any corrections by interacting directly with the file (Figure 6).

Information that is needed to make the graphics more usable must be added to the file from sources other than the aerial photographs. Examples of the information needed are street and stream names, unique objects, and symbol labels; titles, borders, and special numbering may also be desired. These items are entered on a second video graphics terminal. The sheet laid out in the final display may consist of several models from consecutive pairs of stereo photographs. The definition of the file that supports each display is also determined and identified.

The highway design engineer now has all the necessary information to call up a set of programs developed for highway design--known as the roadway design system (RDS)--to establish the location, alignments, grades, geometrics, earthwork quantities, and right-of-way requirements of the roadway (Figure 7). Because all of these functions interact, the designer has the ability to try different design strategies with a minimum of effort and to analyze the results for a design that has optimum serviceability to the public on the bases of cost-effectiveness and minimum environmental impact.

The designer uses the cross sections obtained from the stereoplotter to develop cross sections of the roadway structure being designed to estimate the amount of earthwork involved. Because earthwork is normally a high-cost item on the project, it is an important part of the different strategies considered. When the project is completed, or at certain points during the construction, new aerial photography is obtained and cross sections are developed to determine the exact amount of earthwork that has been done. Generally, the contractor is paid on these determinations. Until recently, the design engineer was interacting with the system by using hard-copy graphics, hand-coded input forms, and keypunch and remote job entry terminal services because the cost of on-line telecommunications systems and remote video graphic terminals for 25 district-level design offices was difficult to justify. A number of factors have changed in the overall evaluation of these functions, and the Department currently has a commitment to a distributed data-processing network that will support interactive graphics and an on-line alphanumeric engineering design system.

VIDEO GRAPHICS

The Department currently has design video graphic stations installed in 16 district offices: Houston, Houston Urban, Dallas, Fort Worth, Lubbock, San Antonio, Corpus Christi, Wichita Falls, Tyler, Abilene, Odessa, Pharr, Amarillo, El Paso, Beaumont, and Austin. Additional districts will be added when the hardware is delivered. All districts will be equipped according to work assignments. These stations are being introduced as drafting stations, where alphanumeric video terminals replace the hand-coded and keypunch input process for engineering problems. Parallel to this implementation in the

Figure 6. Flowchart of the TEAMS process.

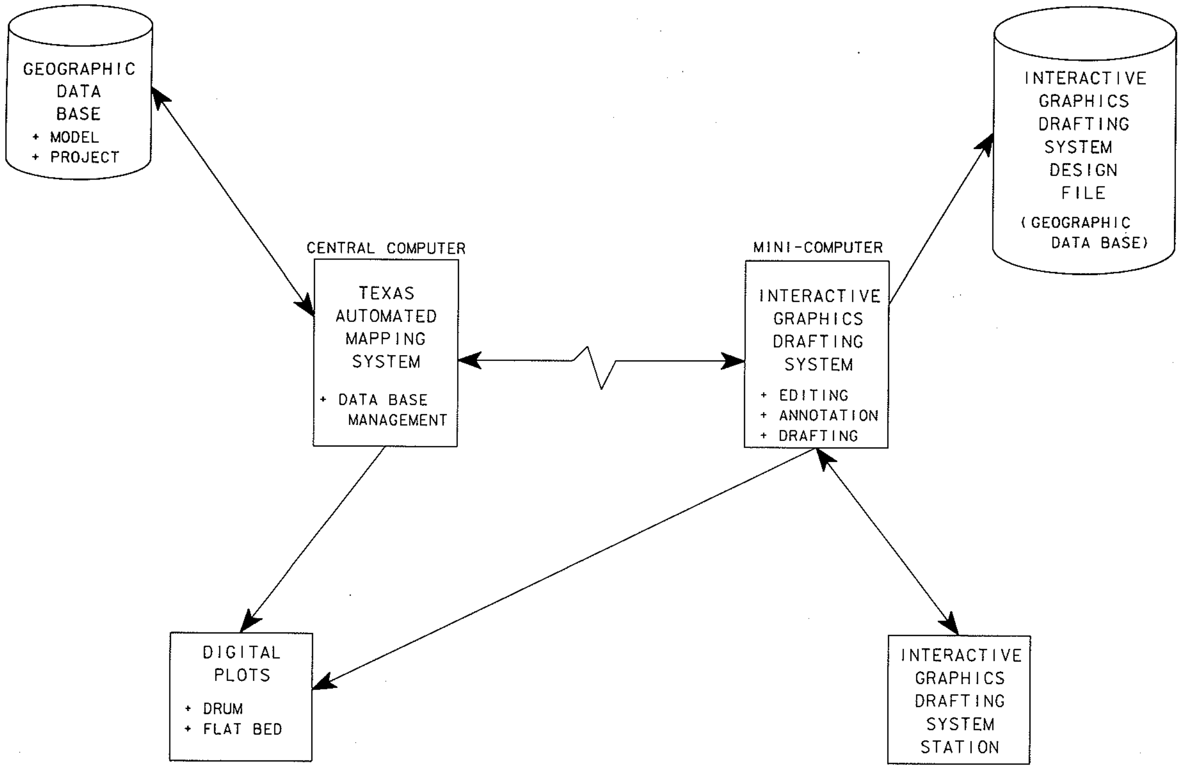


Figure 7. Flowchart of the RDS programs.

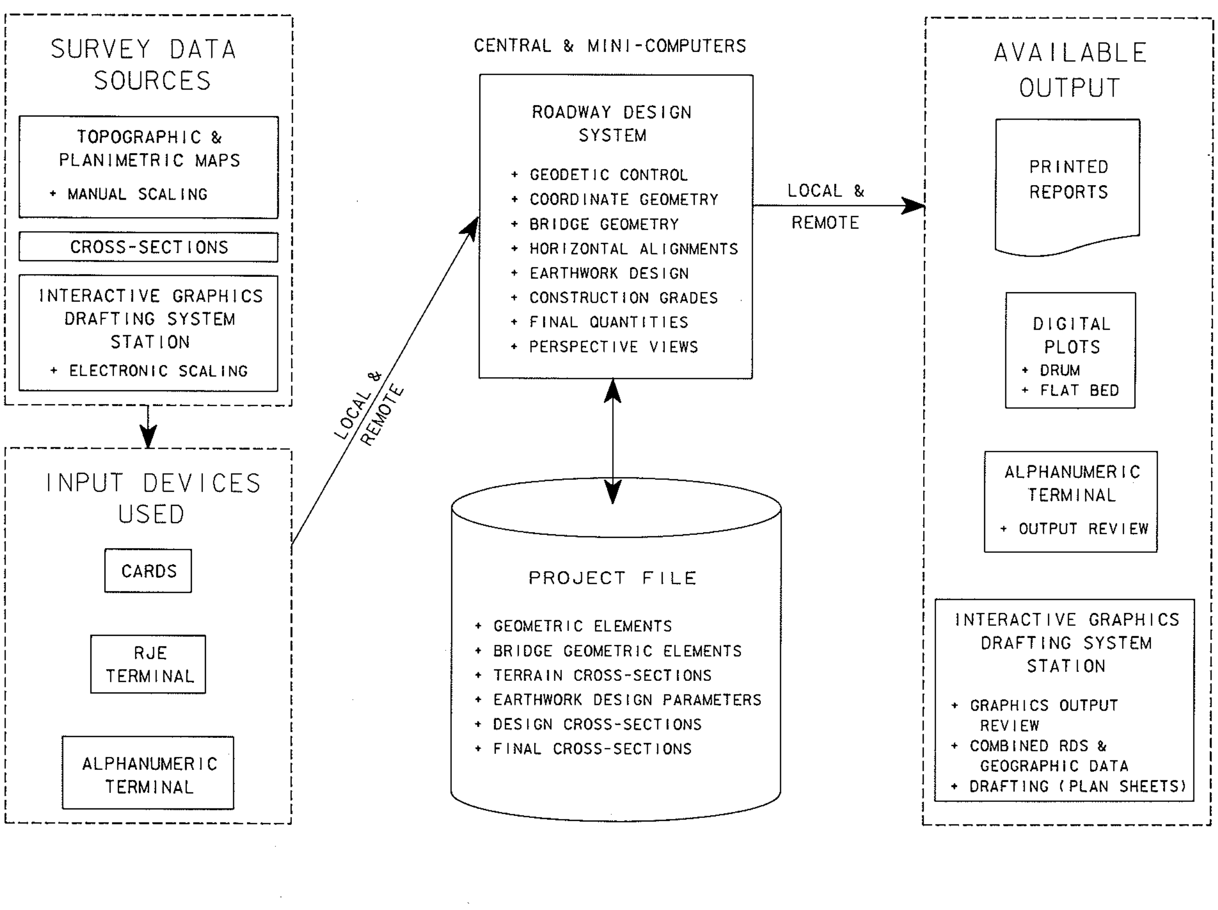


Figure 8. Flowchart of the interactive graphics engineering design system.

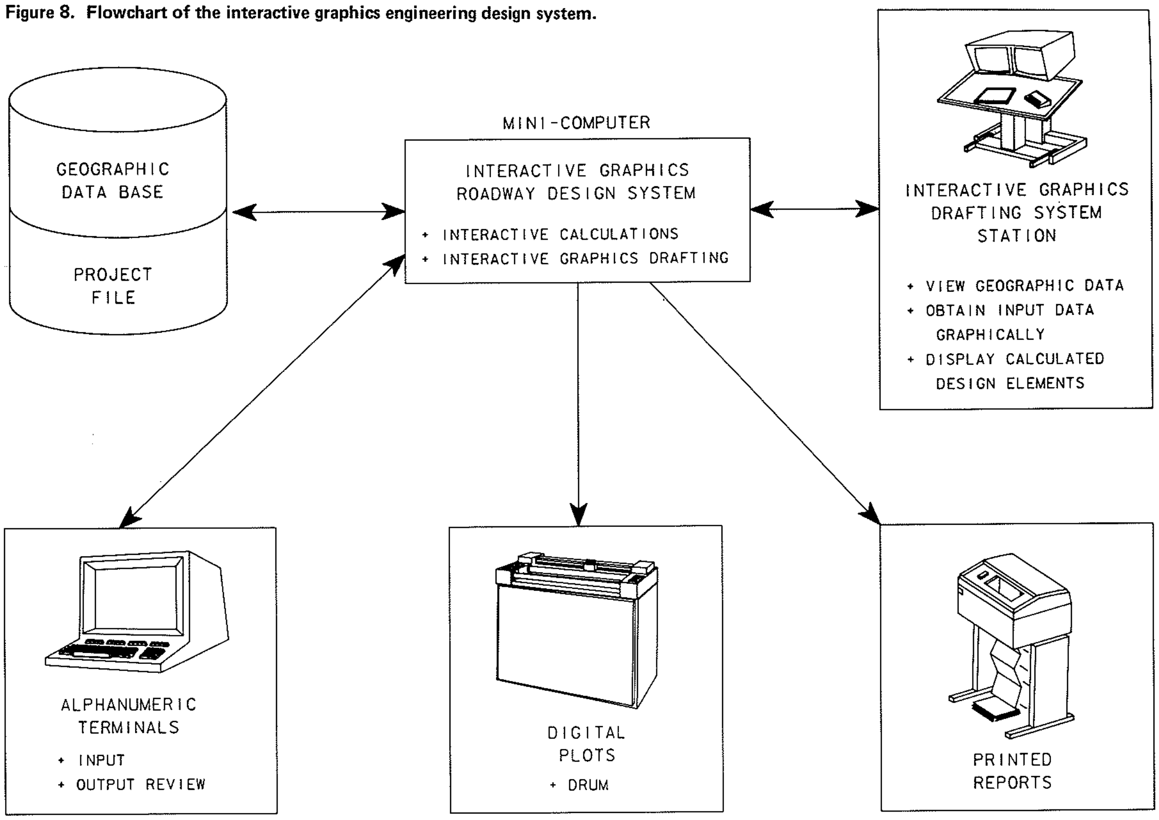
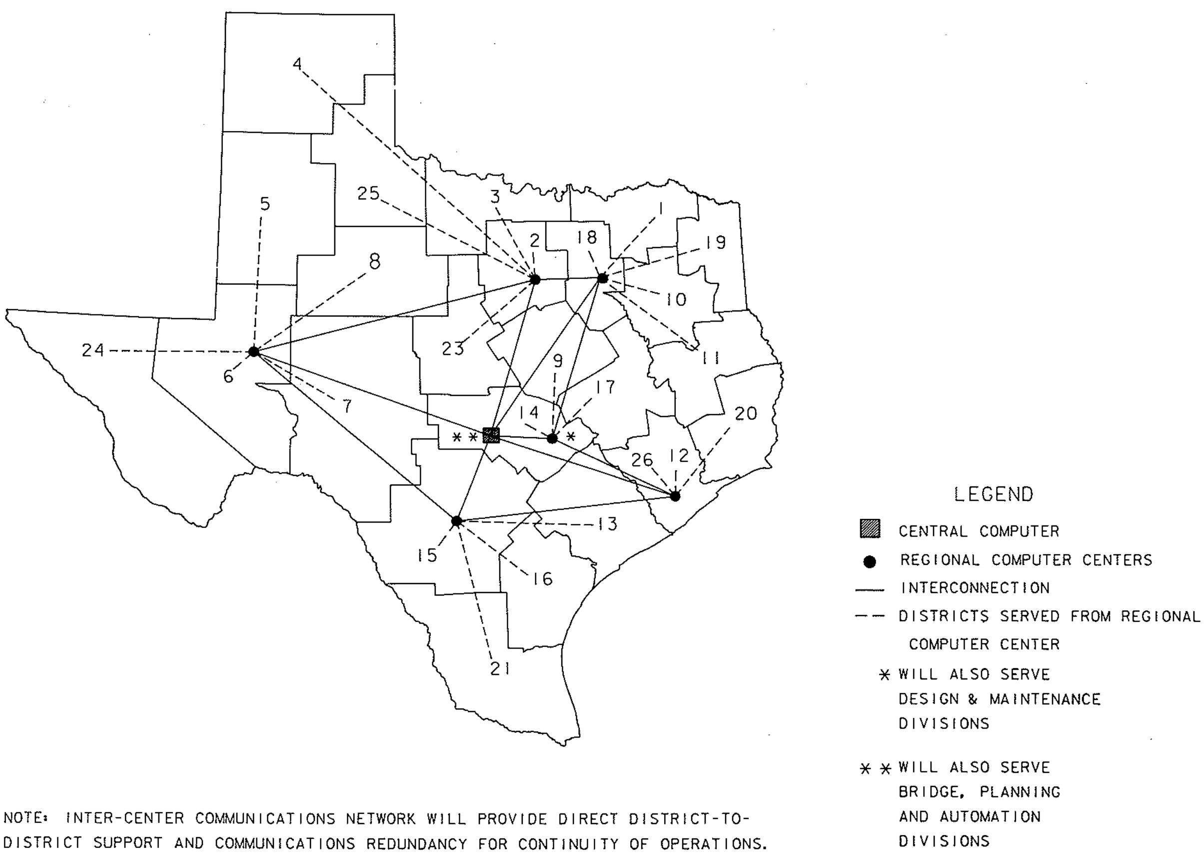
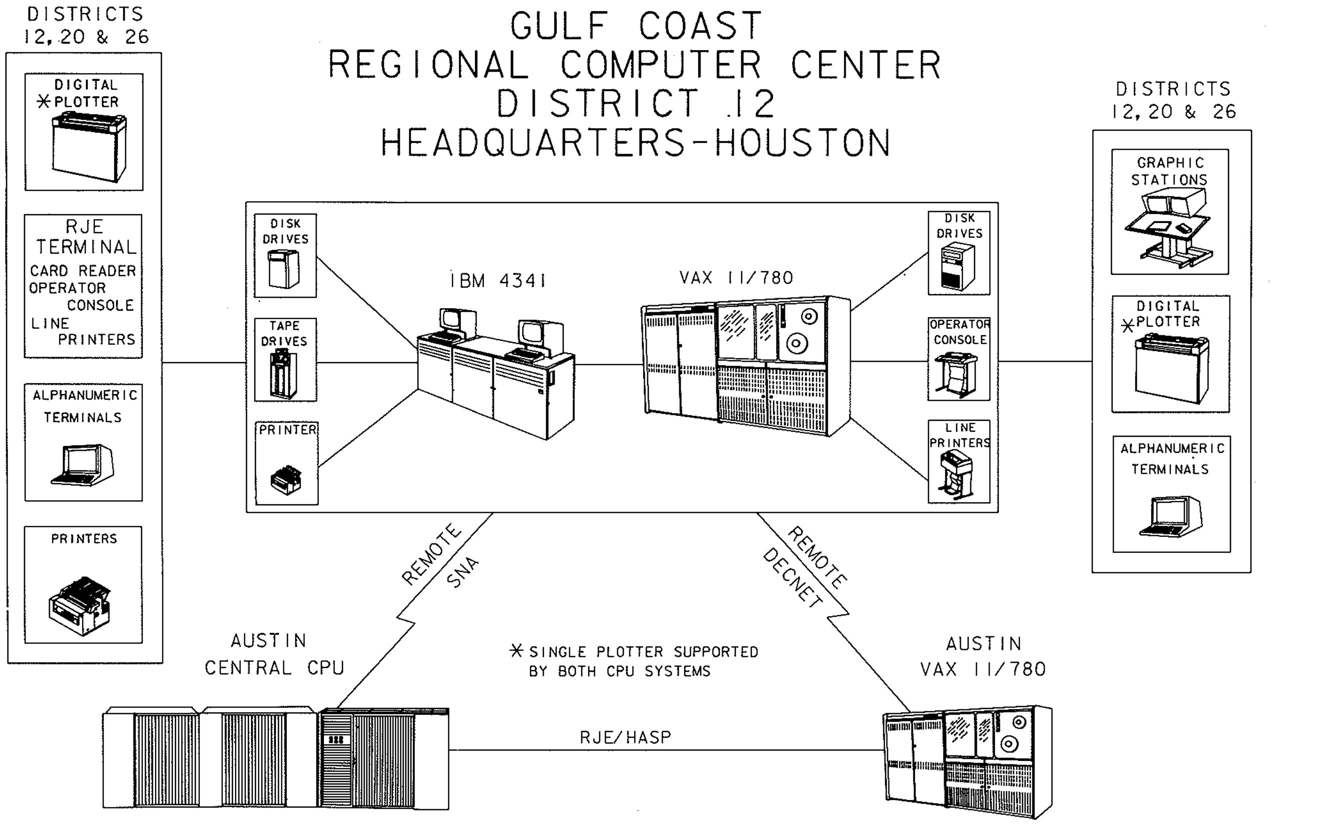


Figure 9. Regional telecommunications network.



NOTE: INTER-CENTER COMMUNICATIONS NETWORK WILL PROVIDE DIRECT DISTRICT-TO-DISTRICT SUPPORT AND COMMUNICATIONS REDUNDANCY FOR CONTINUITY OF OPERATIONS.

Figure 10. Typical regional center setup.



field, a prompted interactive graphics and alphanumeric capability is also being developed.

All of the RDS graphics produced as output on hard-copy digital plotters can now be displayed in the video mode. Interaction with the video display in order to modify the design can be accomplished from alphanumeric terminals because both terminals can enter the same data base, but this is still a batch process. A contract has recently been negotiated with a consultant to complete the interactive graphics software for RDS (Figure 8).

The original RDS was developed to run on IBM equipment. It has since been converted to run on Burroughs equipment and, with the latest version, on the DEC-VAX. The video graphics are programmed for DEC equipment, and the capability to run both systems on the same hardware provides more flexibility to the software.

In addition to improved production by the individual engineer and an improved product through optimization of the design, these systems distribute the work load between design offices when operated in a regional environment supported by a telecommunications network (Figures 9 and 10). This configuration permits design reviews from the controlling design office without the expense of time and travel between the respective operating sites. Thus design offices in high-cost areas, where the time available to professional engineers is limited because of other projects, can release their work to offices in low-cost areas and still retain control through video reviews. Projects let to consulting engineers for design have a contract requirement that the work be done on this system for the same reason. If for any reason the consultant defaults, the project can be completed with a minimum of interruption.

FUTURE DIRECTION

The systems described in this paper have been developed to meet the needs of a department that has an expanding work load, but has no provisions for expanding the work force. In such an environment improved production from available personnel is the only solution. Several enhancements, other than those discussed, are being developed to take advantage of new technology and to address some of the new problems that are constantly evolving.

Publication of this paper sponsored by Committee on Photogrammetry and Aerial Surveys