AUTOMATED ROAD DESIGN

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The end product of road design is a safe and adequate highway that serves the transportation needs of the public without seriously disrupting the environment. The more immediate product of road design is a set of plans and specifications that represent a dimensional and qualitative description of the road to be constructed.

Two basic resources are provided to a contractor who is preparing to build a highway: plans and specifications and the procured and cleared right-of-way. These resources answer three important questions for him; they tell him how, how much, and where. A long, complex sequence of investigations, computations, decision, negotiations, and graphic and written documentation must be made to answer these questions. Each of the steps in the sequence can be accomplished by manual methods, but modern technology can automate many of these steps.

Electronic computers are properly thought of as the primary method of automation. This is particularly true in computational or data manipulation activities that are prevalent in roadway design. For purposes of this discussion, however, I would like to define automation as any mechanized tool that augments or eliminates manual processes. Thus, any equipment is considered an automated device that can assist in acquiring, comparing, and manipulating data; facilitate decision-making; or represent either graphically or verbally roadway design information pursuant to the cleared right-of-way and the plans and specifications.

This rather broad definition of automation extends the range of possibilities for automating the various phases of the road design activity. The decision to automate a process should not be based on the availability of automation; it should be based on whether automation can bring about a definable design benefit. Any automated step is accompanied by expenditure and must be evaluated on the basis of significant return on investment in the form of more productivity from engineering and support personnel; improved and optimized designs resulting from the ability to make more design trials with the same personnel; shorter time to completion in various design phases; reduced cost of the design phase; and lower construction costs achieved through optimization. The important consideration is that automation must buy something. This does not always come in the form of reduced cost, but it must be in real, identifiable benefits that produce a definite return on investment.

The spectrum of activities in roadway design is indeed extensive. At one end of the spectrum are the answers to how, where, and how much. At the other end are many factors that generate a need for the road and many constraints that are imposed on the final design by existing conditions. There is a set of processes involved with the study and analysis of traffic demands and requirements that provide input to roadway design. These processes have been automated to a large degree, and the results of this automation are passed on to road design processes. This phase, however, is not considered within the scope of this paper.

When the need for a road begins to be identified, a host of pre-existing constraints is immediately imposed on the where and sometimes on the how and how much. These constraints include physical terrain features, prior construction, and a wide variety of socioeconomic factors. Some attempts have been made to apply automation to the acquisition of these data and the analysis of these constraints. Success to date is limited, but opportunities are extensive. This, too, is considered outside the scope of this paper.

The exclusion of traffic studies and socioeconomic constraints still leaves a broad topic of discussion that includes the acquisition of data, the determination of the physical dimensions of both the road to be constructed and the right-of-way, and the documentation of design in written and graphic form.

There are really two distinct phases that should be recognized: preliminary design and final design. The processes are quite similar but the intent varies. Precise dimensions, quantities, and drawings are required in the final design phase; data on existing physical features need to reflect the precision desired. On the other hand, in preliminary design less precision and detail can be tolerated, and less precise physical data can be used. The intent of preliminary design is not to produce contract documents but to evaluate various alternative locations or routes for the highway. This distinction between preliminary and final design must be kept in mind. (This paper will be directed primarily toward the precise final design activity.)

Almost all of the significant automated road design procedures have been developed since World War II. Photogrammetric mapping procedures and electronic distance-measuring devices are the results of the technology developed during that war. Other technological improvements led to the development of digital computers; digital computers then gave rise to a family of digital data acquisition equipment and graphic computer output media. In effect, the digital computer spawned other automation devices that are compatible with it.

The first generation of computers introduced new possibilities for data manipulation and computations. The computation of these computers, though slow compared to current standards, was much faster than that of any prior machine. Repetitive computations could be made at almost unbelievable speed. Computation of earthwork cut and fill volumes was one of the first automated road design procedures. The big problem was not the computation but the movement of large volumes of data and design parameters to and from the computer. It was also difficult to change from one computing task to another and even more difficult to string a long series of different types of tasks together.

The second generation of computers introduced better input and output devices, better means of switching from task to task and stringing tasks together, and auxiliary storage in the form of tapes that allowed data to be held for future reference within a sequence of computations. With these advances, more features and capabilities were added to computer earthwork programs; programs became more sophisticated; and the integrated system concept was born. This concept seeks to minimize input to the computer and to maximize output from it. This is accomplished by arranging sequences of computer programs and passing data between them in compatible format without the need for output and input between processes.

Third-generation computers, which have better operating systems to accommodate the systems concept and direct access storage devices to make systems more flexible, advanced these techniques.

Unfortunately each new generation usually necessitated redevelopment or extensive conversion of existing programs. Sometimes the new computer was used inefficiently to simulate the old computer process. In each generation, the development activity was repeated over and over because of incompatibilities among equipment. As an example of this wasteful repetition, a recent computer journal placed the number of computers used for commercial applications at 40,000. It then asked the reader to estimate how many programs might have been produced for a typical commercial application, the payroll check-writing program. The astounding answer quoted was more than the population of commercial computers.

Current systems for road design are far more sophisticated than their predecessors, the stand-alone programs. They do the same things much faster and much more flexibly, have many more features, are easier to communicate with, and make better use of output devices. Notable among these are ICES developed by M. I. T., UNMES developed and expanded in a cooperative effort by a number of western states, the TIES roadway design subsystem developed by the Texas Highway Department in cooperation with the Federal Highway Administration, and the BECOM system developed by a French consulting firm. Each of these is committed to the system concept and to the use of third-generation computer equipment. Each, of course, has advantages and disadvantages and directs emphasis to certain phases of design. Similar systems have been developed by a number of state highway organizations and consulting engineering firms in this country, and significant parallel efforts have also been made in several foreign countries. It is of particular interest that many of the advances in automated equipment, other than the computer, have originated in Europe.

The TIES roadway design subsystem is a good example of automated road design. This system was designed to use not only the computer but also any automated process that produces a return on investment for the road designer. It is committed to the system concept of integrating the flow of data through the various processes with minimum manual intervention. It features program modularity, computer equipment independence, compatible high-level languages, data structuring techniques, code efficiency, automated data acquisition, and input-output media.

The TIES roadway design subsystem integrates more than 200 computer processes that are placed at the designer's disposal to be used in any combination or sequence to achieve the desired results. All of these processes work with an integrated data base that serves the function of data transfer between processes. This data base or file also serves as a dynamic project record. Figure 1 shows the major capabilities that are integrated with the project data base. Although the subsystem is strictly automated, it was designed to take advantage of all available automation tools and to integrate their capabilities with that of the computer. This integration will be shown by discussing both the computer and noncomputer processes.

The entire field of aerial photography and photogrammetry is one of the foremost areas of automated road design. Remote sensing is a new, related field that is beginning to be used by road designers; interpretation of aerial photographs and mosaics has for a long time provided the designer with a useful tool for reconnaissance in preliminary location studies.

Photogrammetric mapping is a new and indispensable tool of the designer that allows him to make precise measurements and representations. It reduces the work of the surveyor, designer, and draftsman by making available extensive data without the need for extensive ground surveying. The ground surveying required for photogrammetric mapping is called control. The complete control data include accurately located points in each photograph to ensure proper measurements from stereoscopic models.

Several automated tools are available to assist in establishing the necessary ground control. One of these is an electronic distance-measuring device that can be used to eliminate tedious ground measurements. The computer system includes processes for reducing both electronically measured distance readings and precise angle measurements. In the process of reducing these automated field measurements, the system stores the resulting data for future design processes.

A control traverse serves not only as orientation for the photogrammetric mapping but also as the backbone of the entire road design process. The computer system is again used to analyze and adjust the angle and distance data in the control traverse and to reduce and store all traverse points and relate them to both the state plane coordinate system and a surface plane. Data thus stored are available for any purpose.

By using electronic distance-measuring equipment, we can save time by spacing the points on the control traverse at greater distances. Other automated tools can be employed to supplement the traverse so that control points are available in each photograph. A stereo analog device such as the Zeiss stereoplanigraph can mechanically bridge several photogrammetric models to supplement the control traverse. Another approach is the use of monocomparators and stereocomparators such as the Zeiss stereocomparator to make measurements on individual photographs. The computer system can then be used to analytically perform the bridge that is done mechanically by the stereoplanigraph device. In both cases, another computer process of the system is used to adjust the strip of photographs and produce the desired supplementary coordinate points in each photograph.

The full set of control points makes it possible to orient the pairs of photographs to produce stereoscopic models, from which maps can be drawn, and measurements can be made in X, Y, or Z planes. It is here that other automated tools are used. Digital scalers are available that can make X, Y, and Z measurements directly from the stereoscopic models and record them on cards or other media that are immediately acceptable by the computer.

The Texas Highway Department is currently working on a computer application that is not a part of TIES but that will automate the drafting of maps. Planimetric features will be digitized with an XY digitizer and supplemented by line and symbol codes. The digitizer output will then be input to the computer that will produce automatically plotted planimetric maps. Topographic maps can be produced in a similar manner. When perfected, this system should eliminate considerable manual work now expended in producing photogrammetric maps.

Another extensively used automated data acquisition process is the digitization of terrain data from stereo models. This can be accomplished in either random, grid, or cross-sectional form. (TIES now makes extensive use of cross-sectional data.) In this process, the digital scaler automatically records stations, offset distances, and elevations in computer acceptable media. A computer process is then available to edit and store terrain cross sections and make them available for many subsequent design purposes.

The computer system allows the designer to make use of maps and stored data to establish the final dimensional aspects of the road. The digital plotter, the main auxiliary automation device, is used to complement the computer in almost every process of the system. The designer can make use of any capability in the system in any order he chooses and can accumulate data in the project file and produce a wide variety of plots.

The designer might choose to use the general geometry process. With this, he can use a command-structured input to perform almost any analytical geometry computation using the points that have been previously stored. He can compute and store other points, lines, and circles; compute boundary descriptions and areas; establish parallel or perpendicular lines; and perform many other computations. The results of these computations are stored and are always available for later design activities.

As an example of later use of stored data, the designer might use some of the control traverse points and other computed points to establish horizontal alignments. From coordinate information on PI's and other alignment data, the horizontal alignment process will compute the stationing and properties of horizontal alignments. As many as seven alignments can be computed and stored by this process. An annotated plot of alignments is easily obtained as a by-product of the process. After alignments are established, the designer might elect to use the terrain plot process to produce profile plots along each alignment. He may also ask for cross-sectional plots of the stored terrain data. He can use these plots to help establish vertical alignments and other design parameters.

The designer would then be in a position to enter vertical alignments, templates, and other parameters that describe the three-dimensional aspects of a road. The data thus entered are edited and stored by a unique scheme for storage and retrieval, the design data edit and store process. This process formats the data such that they can be used for a number of other processes.

An example of a process that uses previously stored geometry data, horizontal alignments, and other design data is the offset geometry process. It is similar to the general geometry process but can automatically compute coordinates and elevations related to the various alignments. It can also compute elevations on the roadway surface. This process, which is related to alignments, provides a very handy method of computing right-of-way geometry.

Several specialized processes are also available for use after sufficient information is stored. The general plot processes are used to produce complicated plots that display the geometry that has been computed. These are controlled by the system user.

The alignment relation process computes the relations between pairs of alignments and makes the computed information available for earthwork design at a later stage.

The roadway elevations process produces extensive listings of elevations at requested offsets and station sequences and is used when a large number of elevations are needed. The geometry process is used when single elevations are needed.

The earthwork design process is the workhorse of the system. It combines all of the pertinent stored data concerning terrain cross sections and design parameters into complete design cross sections and up to six roadways having independent vertical and horizontal alignments connected by medians and intersected with the terrain. Special ditch grades and bench grades can be introduced into both median and side-slope design. The process uses an efficient single-pass design procedure that makes use of a unique data structure.

The design plot process provides for plotting design cross sections with or without the terrain cross sections and for plotting of design vertical alignments.

The volumes and mass ordinate process is a report generator that provides summaries of volumes and mass ordinates for all alignments or for selected alignments in accordance with the designer's request.

The haul computations and haul diagram plot processes use the mass ordinates that have been compiled to compute haul quantities and produce a plot of the haul diagram.

At the completion of the earthwork design phase, all information required for producing perspective views of the roadway from any vantage point is available. The perspective plot process converts design cross sections, vantage points, and other plot parameters into a format required to interface with the perspective plotting routines being developed in Region 9 of the Federal Highway Administration.

The integrated file structure of the roadway design subsystem records all pertinent design data and makes them available through the auxiliary graphic and printed reports process for any type of graphic or printed report that may be desired. A number of such reports are currently included in the system. Many others are planned and should be easily accomplished. All of the graphic and printed report features of the system are designed to assist the user in arriving at his final design and in producing the required documents. The digital plots are particularly advantageous here and may be used in connection with another automated procedure, the engineering reproduction procedure, which uses camera reduction techniques for making composite drawings that become a part of the plans. A wide variety of engineering reproduction techniques are available for automation of highway plan production.

All of the data either input, computed, or captured for storage in the road design subsystem may be classified in one of three categories:

1. Tabular data that can be stored and retrieved by table number;
2. Data that are related to specific terrain cross-sectional stations (all of these data may be stored and retrieved by station number with retrieval beginning at any selected station and continuing sequentially); and
3. Data that cover station ranges for one or more separate alignments and that include horizontal alignment, vertical alignment, template, slope selection criteria, median, special ditch grades, and other similar types of data.

Each type of data in the last category covers a range of stations. The problem of storing and recalling is further complicated because the station ranges are not related to the different kinds of data. This nonhomogeneous nature is shown in Figure 2.

The design data edit and store process uses the "design data block concept" to provide a unique method for storing and retrieving data. It simply compacts all of the various kinds of data into a certain size block; when the block is full it keeps track of the stations covered by the block (Fig. 3). Then, when any type of data is required for a certain station, this system can retrieve the proper block and all the required data can be automatically extracted as required by a system utility routine. This concept makes the single-pass design possible.

In addition to tailor-made data structuring, the TIES roadway design subsystem uses modularity to achieve a flexible system. If a design procedure changes or another state uses a different procedure, the affected module or modules can be easily replaced without disrupting the system. The use of system utility modules greatly facilitates the addition of new processes to the system. As an example of this, it is never necessary to develop new elevation computation routines. A system module is available for this computation. The control driver is constructed such that it can be expanded to accept new processes.

Figure 1. TIES roadway design subsystem.

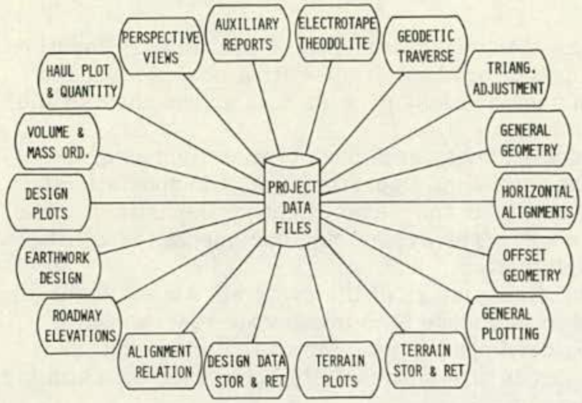


Figure 2. Station range data (data nature).

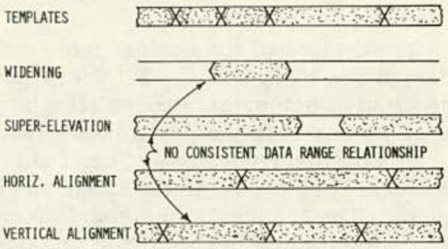


Figure 3. Station range data (design data block).

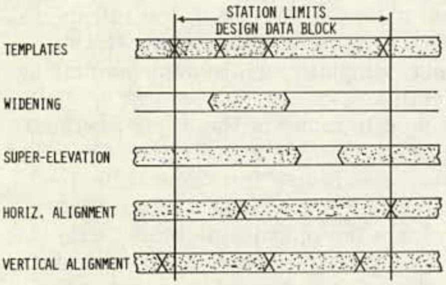


Figure 4. PROMPT terminal.

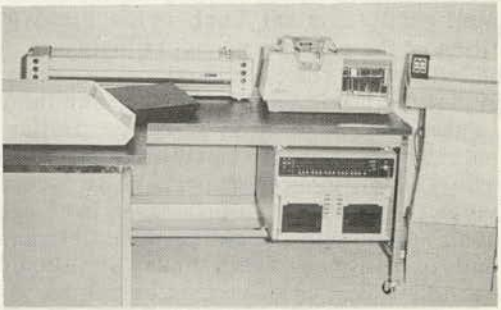
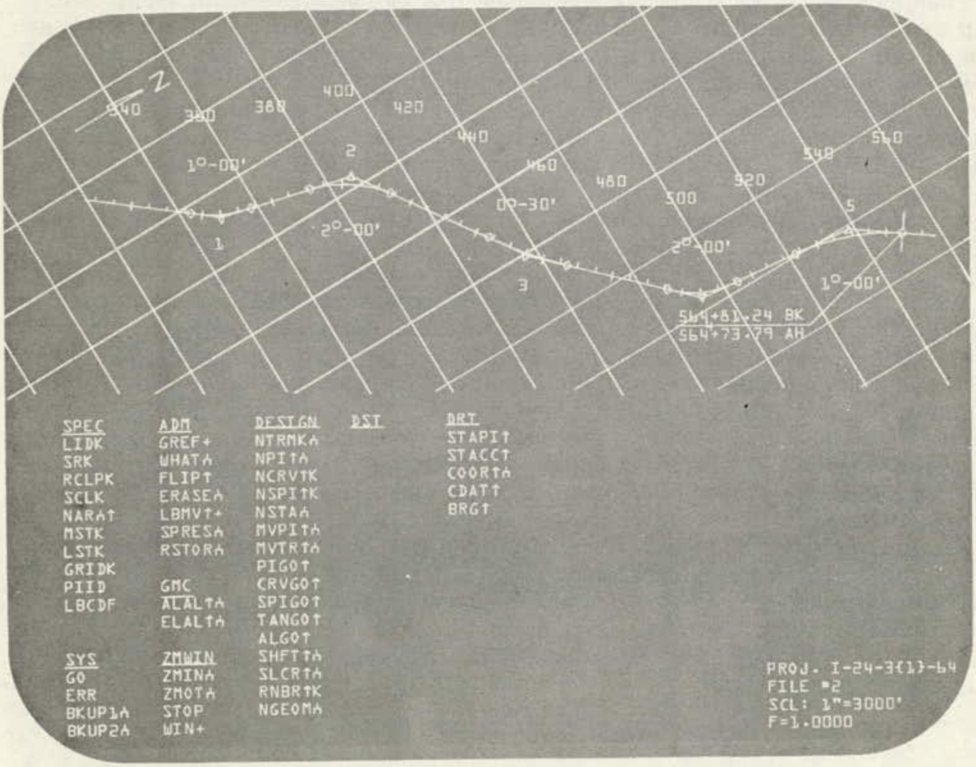


Figure 5. Interactive graphics display.



Source: Control Data Corporation

Expansions of the system into the areas of bridge geometry and preliminary location design are being made. TIES was developed to produce precise final designs, but the addition of numerical ground image techniques and less precise data approaches should easily adapt it to the preliminary location phase.

Preliminary versions of the roadway design subsystem have been delivered to the Federal Highway Administration and to the Oklahoma Department of Transportation for tests. Testing and implementation continue within the Texas Highway Department, and plans for testing in California are being made. The system and documentation will be distributed by the Federal Highway Administration.

A form of automation will be used for training users of the system. An audio-visual overview of the system is being prepared to introduce it to prospective users, and a self-instructional training course is being developed to give the user a more detailed view of the system. This method of training is now successfully being used on a similar system.

One other automated tool should be discussed in connection with the TIES roadway design subsystem. As is the case in many states, road design in Texas is performed in a number of decentralized locations. In these cases, it is difficult to automate the process without the use of sophisticated data communications equipment. By use of an "intelligent" terminal, such as the PROMPT terminal shown in Figure 4, the full capabilities of the computer system including plotting are available at the remote station. The bulk of the computational work is done by the host computer, while data formatting and plot formatting are handled by the intelligent terminal.

Features discussed in TIES are similar to those used in many of the other systems mentioned. All of the capabilities and uses of automated equipment are currently being used. In fact, most of the capabilities described have been in use for some time individually. In TIES the processes have been integrated and linked with system techniques, utilities, and a tailored data structure to perform the operations more efficiently. In almost every case, significant return on investment had already been established, and an even greater return on investment can be expected by using the systems approach. Many opportunities exist for refinement and integration with automated devices that are currently available or that might be available in the future.

The subject of automated road design should not be concluded without a look into the future. The most significant future development that can be foreseen is use of interactive graphic design techniques. Practically all current computer systems are based on batch or remote batch processing in which all input is entered at one time and all output is received in a batch. Interactive graphics will give the designer an opportunity to intervene in the process. He will do a part of his design and review the results graphically on a video terminal. This process will be repeated until he is satisfied with the overall design. This type of approach is now used in the interactive design of such things as electronic components and ship structures. The use of interactive graphics in highway design applications is currently being investigated by the Control Data Corporation under the sponsorship of the National Cooperative Highway Research Program and also by the California Division of Highways. The findings of both organizations indicate that interactive graphics is feasible and practical for highway design.

An interactive graphics road design system would do the same things that current design systems do, but interactive graphics would provide a two-way method of communication between the designer and the computer. Responses of the computer are almost immediate and are in the form of line drawings and character images displayed on a television-like screen (Fig. 5). The designer communicates by use of a typewriter keyboard and a light-sensing pen that allows him to indicate desired actions by pointing at a list on the screen or by pointing at segments of the drawing that are to be revised or acted on.

The designer may control a wide variety of display views and change design parameters. For example, to direct the computer to shift a PI he would point to a command name and the selected PI, both of which are displayed on the screen, and then move the pointer to a new location.

An NCHRP report (1) gives a very complete description of this subject along with the basic design requirements of such a system and an evaluation of the costs and benefits that might be obtained. The TIES roadway design subsystem was studied extensively as a part of that project, and the system's capabilities, data structuring, and modularity were judged to conform to the basic requirements of an interactive system. The project advisory committee approved a recommendation that the TIES roadway design subsystem be used as the application system for further project development. In this concept, the interactive system and terminal equipment would, in effect, become a communications channel linked to the roadway design subsystem.

REFERENCE

1. Interactive Graphic Roadway Design System. NCHRP Project 20-8, 1972.