ENGINEERING SYSTEMS: AN OVERVIEW

W. A. Wilson, Jr., North Carolina State Highway Commission

The use of automated systems in engineering has eliminated much of the tedious work that has been necessary in the design and construction of transportation systems. High-speed computing systems enable the highway designer to consider many new options that were formerly beyond his reach because of time limitations. Automated systems are in almost constant use during roadway construction; they are used for transportation needs analysis and corridor selection and in the building process itself.

I will discuss as many automated systems as is possible, touching briefly on systems that are currently in use and looking ahead to systems that may be available in the near future.

The original concept of the TIES project was to integrate all of the major functions involved in building a highway. These functions are planning, location, right-of-way, design, construction, and maintenance. The major effort expended to date has been concentrated on the design subsystem, which is composed of roadway, bridge, hydraulics, and interchange design.

The Texas Highway Department is currently developing the roadway design subsystem for the TIES project. All of the program modules for this subsystem have been written and are in various stages of testing, evaluation, and documentation. The subsystem will be composed of the following design processes: electrotape data reduction; theodolite data reduction; geodetic traverse adjustment; side-shot calculation; intermediate point calculation; analytical aerotriangulation; strip adjustment; terrain edit and store; earthwork design; profile and cross section plot; design data edit and store; command-structured geometry; volumes/haul calculations; and perspective plot. Additional plotting capabilities will include modules for the following: general geometry plot; areas plot; alignment plot; and geodetic traverse plot.

Self-motivational training material related to the roadway design subsystem is in preparation. All course material developed will be field-tested in several states to ensure its effectiveness as a training aid. Its form will be such that it can be readily reproduced as needed for training purposes.

Most states are now using photogrammetric processes to obtain data about corridors that have been selected for design. The speed with which the data can be collected and put into a useful format makes possible the investigation of a corridor in much more detail. This comprehensive study of the factors that may have a bearing on the ultimate design of the roadway should result in the best possible design.

After a corridor has been selected, a corridor line is established and run in the field. Electronic data collecting equipment is used so that information about the line may be obtained as quickly and as accurately as possible. The use of such sophisticated equipment as Geodimeters for relatively short lines and tellurometers for lines of greater length have eliminated the need for tedious transit and tape surveys. Readings from these instruments along with information on atmospheric conditions, such as wet and dry bulb temperature and barometric pressure, are fed into a computer, which computes the actual length of line and its bearing. While this line is being run in the field, control panels are set at frequent intervals along the line to provide vertical and horizontal control.

When the corridor line and control panels are set, a time to fly this line must be established. To obtain photographs that show as much detail as possible, it is necessary for the rays of the sun to be approximately parallel to the corridor line and at the same time to be at a vertical angle to the earth of greater than 30 deg. The azimuth of the line and dates on which the line may be flown are submitted to the computer section, and the exact times that those conditions will be met are returned.

After the photographs are obtained, a detailed contour map is prepared on a stereo compiler. This map is turned over to the preliminary designers, who study a variety of lines to achieve a design that meets all the necessary criteria. By using an earthwork system in conjunction with horizontal and vertical alignment systems, the preliminary designer is able to arrive at valid quantity estimates for the various lines that he is investigating. Once a preliminary design has been selected, the design line is tied to the corridor line and can be placed on the original photogrammetric manuscripts. The preparation of plan sheets and cross sections can then begin.

While the photogrammetric department or drafting personnel prepare sheets, geological and hydrographic final investigations are made by using the preliminary data. One automated process that has reduced geological investigation time is the use of seismological methods of subsurface investigation, which replaces rock boring. In this system, a sound generator is used in conjunction with a seismograph to determine the speed with which sound waves travel through the material being tested. This speed tells with a great degree of accuracy the content and density of the material. This system has been refined to such a degree that it is possible to determine whether rock will have to be blasted or whether it is rippable. Information such as groundwater tables may also be determined by using this method. Geologists are also utilizing the speed of computing systems to perform slope analysis (whether a given slope will be stable in a particular soil type).

Hydrographic investigation and design should be greatly aided by the use of systems such as the Texas hydraulic system. This integrated system provides the engineer with the tools necessary to examine in detail many aspects of a hydraulic system that in the past required many individual computations. This system can be used in simple projects such as the design of culverts or in complex projects such as the design of an entire storm sewer network.

If the plan sheets are prepared by the photogrammetric department, they are taken directly from the manuscripts made from the aerial photographs. Thus all the topographic features are shown as they actually appear. This saves much of the time required for a draftsman to interpret and plot from field notes. At the same time that the plan sheets are prepared, cross sections are taken along the centerline of the project by means of a stereocompiler or a terrain data translator. These sections are punched directly into cards that may serve as input to an earthwork system. The cross sections can be plotted at this time by a plotter driven by a computer so that the designer may have graphic evidence of exactly what he is working with.

In the final design stages, the computer proves most valuable to the design engineer by allowing him to do trade-off studies between optimum design and minimum cost. Ordinarily, the earthwork is the most expensive single item in any roadway contract, and computers are ideally suited to such repetitious tasks as earthwork computation. There are many different earthwork systems currently in use; the capabilities of these systems range from handling simple design to working with complex design. It should be noted that the roadway design subsystem of TIES earthwork design probably has more capabilities than any other system currently in use.

The design engineer, using almost any earthwork system, can include such features as independent horizontal alignment for multilane facilities, independent vertical alignment for multilane facilities, boulevard ditches with independent grades, hinge point method of slope design, and bench slope design in mountainous terrain. The ability to change any or all of the various design features allows the design engineer to obtain rapidly an estimate of the cost of these changes. One study that is frequently used is slope design as opposed to guardrail warrant, i. e., whether it is more economical to flatten fill slopes to eliminate guardrail or to install the guardrail. This analysis is made possible by a guardrail program that is usually a subsystem of an earthwork program and that bases guardrail warrant on embankment geometry as outlined in National Cooperative Highway Research Program Report 54.

The design engineer may also experiment with various vertical and horizontal alignments in order to obtain a roadway that operates as freely as possible. The North Carolina State Highway Commission in cooperation with North Carolina State University is studying a roadway simulation system that will allow the engineer to determine and change the operational capacity of a proposed roadway.

All of the information pertaining to a stretch of road, including information such as vertical alignment, horizontal alignment, design speed, and vehicle loading, is entered along with the time interval at which checks are to be made. The output of the program gives the following information: (a) the number of vehicles that have entered the system, (b) the number that have left the system, (c) the number that have passed other vehicles successfully and the number that have failed, (d) the speed of the various vehicles, (e) the headway of each vehicle, and (f) the number of accidents. When the data were tested against actual conditions, it was found that vehicle flow as simulated by this program was very close to actual flow. Programs such as this will allow the designer to measure the effectiveness of a proposed roadway and will allow him to experiment with options that may result in more efficient operation.

After all the design is completed, the right-of-way and construction limits are plotted on the plan sheets. Individual property plots can also be plotted at this time, and in some states these individual plots may serve as legal documents. The right-of-way takings may also be computed at this time. All of these plots and computations must rely on horizontal alignment systems that range in complexity from very simple ones that handle only straight-line work to very complex ones that have the capability to handle spiral curves.

Many states are utilizing the storage and recall power of the computer to keep up with the progress with which right-of-way is being acquired. This gives the right-of-way engineer a powerful tool in making determinations of where additional effort must be applied in order to keep the acquisition of right-of-way on schedule or, in rare instances, to push the letting date of a project ahead because of the entire right-of-way being acquired ahead of schedule.

Computing systems are also used in Pennsylvania to make predictions as to how long the right-of-way acquisition for a particular project will take and how much this acquisition will cost. These predictions are based on a data bank of right-of-way information accumulated in the past and constantly being expanded.

Some states have systems that maintain the current status of all projects. This includes the number of man-hours that have been worked on the project by each job position, which is taken directly from payroll cards. A system such as this, a right-of-way program such as that used in Pennsylvania, and remote terminals would allow the engineer to know instantaneously the progress of a project. Bridge design and final roadway design can proceed simultaneously.

Engineers in New York have been working on the bridge design segment of TIES and have developed an integrated bridge design system that will do most of the design work and some of the plotting for relatively simple bridges. Although this system handles only about 20 percent of the bridges designed currently, it is expected to handle about 80 percent in the near future. Eventually this system should be applicable to all states. Each of the seven major programs in the system can be used separately.

Programs are typically used for the following: establishing span lengths, working horizontal and vertical layouts, designing beams or girders, designing bearings, designing piers or abutments, and working all kinds of elevations. Layout and elevation programs will handle bridges on any combination of tangent, spiral, or circular curve, with variable rates of superelevation and grades or vertical curves. Beam design may be used for simple or continuous spans, composite or noncomposite, steel I-beam, plate girder, or prestressed concrete. Piers may have multiple columns or a hammerhead design with one column. Superstructure construction elevations can be given for beam lines, overhang lines, and header lines. Reinforcing steel may also be worked and printed for inclusion in the final plans.

The Illinois Division of Highways is in the process of developing a computerized highway bridge rating system. This system, through computer analysis, will allow structural engineers to conduct inventory and operational bridge ratings. Bridge ratings indicate the load-carrying capacity of a structure after an analysis has been conducted by using a truck load and axle configuration. The rating system also will enable engineers to automatically re-rate structures when changes in bridge use or condition occur. This is particularly important because legal load limits may change sometime in the future.

Pavement design is another area in which the potential of automated systems is just beginning to be used. The Center for Highway Research at Austin is currently working on a pavement design system that should prove most helpful. In this system, the pavement design engineer enters information concerning traffic, materials, maintenance, and construction as input, and a variety of pavement designs that meet the requirements are returned along with their anticipated cost and life expectancy.

Once the entire right-of-way has been acquired and the final design is complete, the final plans must be prepared for the letting of contracts. At this time, all automated systems are aimed at providing the contractor with the information he needs in order to bid on the job and the resident engineer with the information he needs to oversee construction of the job.

After the final pavement design is selected, the earthwork system must again be used to secure a final earthwork listing. This listing may contain information such as shoulder and ditch elevations and other information that may not appear on the preliminary earthwork listing. An earthwork subsystem that is also used at this time is the mass diagram plot, which aids the contractor in establishing haul lines, determining borrow pit locations, and locating areas for the disposal of waste material.

After all the quantities are computed and all the information necessary to construct the project is collected, the proposal is assembled, and an engineer estimates the anticipated cost of the project. Equitable prices for the various items in the contract are arrived at in North Carolina by using a bid average prices program as a subsystem to the bids program. These averages are categorized by type and location and usually afford an excellent basis for arriving at a price for any item. It is now economical to estimate the cost of each component project and then, by using the computer, combine these estimates into one combined estimate.

A most important part of any contract or proposal is the project's special provisions. Because these provisions are often the same for similar projects, this is an area that lends itself readily to an automated system. In North Carolina, we are using a magnetic tape typewriter system for writing these special provisions. Each special provision carries a code letter and a number; therefore, when the proposal is being written, the provision can be called by code number and automatically typed into the proposal. This system decreases the need for extensive proofreading and thus considerably speeds up the work of the plans and proposal section.

Along with the preparation of the proposal, some states are using the critical path method to determine such information as early and late start calendar dates, early and late finish calendar dates, and the critical path.

On the day that bids are opened, the computer is used to extend all computations in the contract and to print out a listing of all the bidders and their bids on the various items in the contract. An analysis is also made between the engineer's estimate and the low bidder on each project, and the percentage difference is tabulated.

After the contract is awarded and before construction actually begins, the resident engineer may make use of a system such as North Carolina's construction elevation program that provides the resident with elevations of up to five points to each side of the centerline of a typical section. These elevations may be obtained at any interval desired; 25 ft is the distance most often used. The input consists of the grades, typical section, superelevation, and tangent runout for the project. This system has greatly reduced the tedious process of computing offset elevations, particularly in superelevated sections.

While the project is being constructed, monthly estimates for the various items in the contract are prepared so that the contractor may be paid for work that has been accomplished. Such a system is now used in Connecticut and is expected to be used in North Carolina. This is an application to which computers are readily adapted, and an application that can save much laborious hand calculation. When the project is completed, these monthly estimates can be combined into a final estimate and the contract settled more quickly than with the methods currently in use.

Photogrammetry is also used at the end of a job. Studies have shown that earthwork computations from aerial photographs are as accurate as computations based on cross sections taken in the field by hand. As a project is cleared, it is flown and photographed for original sections. Controls are established both vertically and horizontally by the use of panels at frequent intervals. The original sections are compiled and punched into cards and, after being edited, are stored until the grading of the project is completed.

After grading has taken place, the project is flown and photographed again. These as-graded photographs are used for the taking of the final sections. Two methods of taking final sections are used in North Carolina. The first is the taking of the entire section on projects that are to be graded only; the second is for the resident engineer to supply the template or subgrade sections on a project that is being paved and for the photogrammetric department to supply the balance of the section from the ditch out to the tie points. The North Carolina final estimate volumes program will handle sections that are entirely taken in the field, sections taken by photogrammetric methods, and a combination of the two. The final estimate volumes program will compute excavation and embankment quantities and borrow pit calculations.