Increasing Productivity of Engineers Through the Use of Electronic Computers

L. R. SCHUREMAN, Highway Engineer
Bureau of Public Roads

● IN A symposium at the 35th (1956) Annual Meeting of the Highway Research Board, the potentialities of the electronic computer as a means of increasing engineering productivity were stressed.[1]

At that time, exploratory work in the Arizona Highway Department, the California Division of Highways, and the Bureau of Public Roads had just begun to produce tangible results. In Arizona, a method had been developed and adopted for the computation of centerline grades on a Univac 120 punched-card electronic computer as the initial step in the mechanization of earthwork computation. In California, methods had been developed and adopted for performing survey computations and earthwork computations on an IBM 604 electronic calculating punch. (Subsequently an IBM 650 electronic computer was installed and these methods were adapted to it.) The Bureau of Public Roads, in collaboration with the Computer Division, Bendix Aviation Corp., had developed a method for computing earthwork quantities on a Bendix G-15 electronic computer. This method was demonstrated at the ARBA convention at Miami Beach in January 1956.

From these initial applications, highway engineers have been quick to recognize the possibilities in electronic computers and during the past year interest has grown tremendously. Regional conferences of officials and engineers of the state highway departments, the Bureau of Public Roads, computer manufacturers, consulting firms, and contractors' organizations were held in Chicago, Albany, and Atlanta. At these conferences, electronic computers and their application to highway engineering operations were explained, demonstrated, and discussed.

Engineers in the state highway departments and in the Bureau of Public Roads have been and are devoting much time and effort to further exploration and a number of additional applications have been developed or are in process of development. This paper is essentially a report on these applications and other aspects of computer use.

THE ELECTRONIC COMPUTER

The type of electronic computer best suited to highway engineering work, and the one which has been used in all of the applications developed thus far, is the general-purpose digital computer. As its name implies, the digital computer works with digits or numbers. The other type of electronic computer is the analogue computer, in which quantities or physical conditions such as pressure, temperature, or flow are represented by analogous electrical quantities.

The electronic digital computer is simply a computing machine which can add, subtract, multiply, and divide. However, in addition, it can follow a predetermined continuous sequence of operations without human intervention; it can compare two numbers and follow either of two courses of action, depending on which number is the larger; and it can store numbers in its "memory" for use as needed in the computation. These characteristics, together with its fantastic speed of operation, make the electronic digital computer an extremely valuable device for the solution of problems involving large masses of data or large numbers of mathematical operations. The desk calculator can complete, as an average, about four or five arithmetic operations per minute, but a medium-sized electronic computer can complete many thousands of such operations in a minute. It can do this 24 hours a day, month after month, with an average down-time of only about 10 percent.

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[1] "Increasing Productivity in Engineering" L. R. Schureman, Highway Research Board Bulletin 134, p. 62, (1956).

To use the computer for the solution of a problem, it is necessary to feed into it a prepared detailed instruction series that governs its sequence of operations in solving the problem. This is called a program. Depending on the complexity of the problem, the preparation of the program may take weeks or months. However, once completed and checked, the program, expressed in coded form on tape or cards, or wired on control panels, can be placed in the computer in a very short time. It can be used over and over, year after year, whenever that particular kind of problem is to be solved. As many programs as desired may be developed for the same computer, so that it may be used at 9:00 a. m. for earthwork computation, at 9:30 a. m. to produce a payroll, at 11:00 a. m. for a structural design problem, and so on.

In the development of a computer program, the problem first must be carefully defined and analyzed. It is then broken down into its component parts and these parts are further broken down into elementary mathematical operations, all arranged in proper sequence for the solution of the problem. This sequence, expressed in the form of a flow chart or a precise step-by-step written procedure, is then translated into "machine language" so that the program can be used by the computer. It is then carefully checked on test problems and released for use.

In an engineering problem, the engineer's knowledge, accumulated through years of study and experience, is embodied in the program. Once the program is completed and released, this knowledge is thereafter applied automatically, thus relieving the engineer of repetitive analysis and routine computation. In this way, the engineer and the computer form a team in which the capabilities of each are used to best advantage.

The knowledge, imagination and judgment of the engineer used in devising a design proposal for a specific project must, of course, remain with the engineer—it cannot be mechanized. The value of the electronic computer lies in its use in the analysis and evaluation of the design proposal or of alternate design proposals. It cannot replace the engineer, but it can serve effectively in increasing his productivity.

APPLICATIONS OF THE ELECTRONIC COMPUTER IN HIGHWAY ENGINEERING

At present electronic computers are being used for survey computations; for the computation of centerline grades; for earthwork computations, both at the design stage and for final payment; for both geometric and structural design computations for bridges; for traffic studies, including the development of trip desire charts, and the assignment of traffic to a proposed new route or system of routes; and for a number of less complex operations.

More then 20 states are either using electronic computers on highway engineering work or are awaiting delivery of them. Others are considering installations. Some states, and the Bureau of Public Roads, are using computer facilities at service bureaus, universities or other agencies. In addition, a number of consultants either have computers or are using computer facilities commercially available.

The computers being used in the states or on order include the Bendix G-15, the IBM 604, the IBM 650, and the Univac 120. The Bendix computer uses punched tape, the others use punched cards. Other computers of comparable capabilities are available and may also enter the field.

Survey Computations

In the California Division of Highways, survey computations involving an average of more than 2, 000 courses per day are now being performed on the electronic computer, covering location, interchange and bridge design and layout, and right-of-way takings. The computations include the determination of unknown lengths and/or bearings, error of closure, traverse adjustments, coordinates, and areas for closed traverses, and are performed in a central computing unit which serves both the headquarters office and the eleven district offices. Survey data from district offices are processed and mailed back to the districts, usually on the same day as received. The time required for the computer method, including the preparation of input data, is about 20 percent of the time required using manual methods. The cost is about 40 percent of the cost by manual methods.

Similar programs have been developed and adopted by the Texas Highway Department and the Nebraska Department of Roads and Irrigation.

The Bureau of Public Roads is developing a program for location traverses which will compute bearings and coordinates starting from any point of known coordinates, using measured course lengths and deflection angles.

The Oregon Highway Department is using electro-mechanical punched-card equipment for survey computations, with plans for converting to an electronic computer in the near future.

Grade Computations

In the Arizona Highway Department, the program developed for the computation of centerline grades, previously mentioned, is being used in day-to-day operations. The grades are computed in a continuous process through vertical curves and station equations. The time required for the computer method, including the preparation of input data, is about 25 percent of the time required using manual methods.

The Louisiana Highway Department and the Ohio Highway Department have completed similar programs, and the Illinois Division of Highways has included grade computation in its program for the computation of earthwork quantities.

The Texas Highway Department is investigating the feasibility of developing a program for determining the most economical grade line for a given profile and given basic design criteria.

Earthwork Computations

Earthwork quantities are presently being computed on electronic computers in Arizona, California, Texas, Washington, and the Bureau of Public Roads, both for use in the design stage and for final payment. The time required for the computer methods, including the preparation of input data, ranges from 5 to 10 percent of the time required using manual methods. Data on relative costs are being developed; however, rough estimates indicate that the cost by computer methods is from 20 to 25 percent of the cost by manual methods.

For earthwork quantities at the design stage, the input includes the cross-section data, centerline grades, and design template data, with provision for superelevation, curve widening, and varying side slopes. The computer produces a tabulation of the cut and fill volumes at each station and the difference between them adjusted for shrinkage or swell, the cumulative volumes of cut and of fill, mass diagram ordinates, and slope stake coordinates.

For the computation of earthwork quantities from staked cross-sections, the procedure is similar except that slope stake data are not included in the computer output. When final sections are used, the computer input consists of the original and the final cross-section data.

A number of other states, including Illinois, Louisiana, Massachusetts, Michigan, Missouri, Nebraska, New Mexico, New York, and Ohio, are in the process of developing computer programs for earthwork computation.

In Oregon and Montana, electro-mechanical punched-card equipment is being used for the computation of final payment earthwork quantities. Conversion to electronic computers is expected to be made in the near future.

Structural Design

Outstanding in the area of structural design is the work being done by the American Bridge Division, United States Steel Corporation, which is using an electronic computer as standard procedure in computing dimensions, stresses and deflections for various types of structures. The structures involved include continuous girder bridges with up to five spans; arches; rigid frames; cantilever and suspension bridges; and various types of trusses up to 80 panels in length. It is reported that the use of the electronic computer saves about 75 percent of the cost of equivalent calculations performed manually, with an even greater saving in designers' time. In one instance, a set of 20 equations with 20 unknowns, involving wind stresses in a suspension bridge, was solved on the electronic computer in about 10 minutes.

The Georgia Highway Department has completed and tested a computer program for geometric computations for multispan skewed bridges on curves alignment, on either a grade or a vertical curve, and with bents either parallel or not parallel. The beams are placed on chords of concentric arcs. The computer produces chord distances between intersections of the concentric arcs with bent cap centerlines, distances between the concentric arcs measured along the centerline of each bent cap, centerline grade elevations, rate of slope for each beam, and middle ordinates of the concentric arcs at the midpoint of each span. Programs are in process of development for the structural analysis of rigid-frame bents subjected to varying dead, live and wind loads, and of continuous reinforced concrete spans with variable moment of inertia. Georgia is also developing a program for the design of composite simple spans.

In the Arizona Highway Department, a program for the computation of dead load deflections for continuous beam bridges has been completed and a program for the design of retaining walls and bridge abutments is being developed.

In the California Division of Highways, a program for curved, multispan bridges similar to the one developed in Georgia has been completed. Programs have also been completed for the design of composite beams, and for the computation and tabulation of bridge reinforcement steel quantities. In addition, California is in the process of developing a program for the analysis of rectangular columns subjected to biaxial bending.

In the Washington Department of Highways, a program is being developed for the analysis of five-span continuous reinforced concrete beam bridges, which can also be used for lesser numbers of spans.

The Bureau of Public Roads has nearly completed a program for the analysis of continuous steel beam bridges of three to five equal or unequal spans.

Photogrammetry

In the area of photogrammetry, the California Division of Highways is in the process of developing a program for checking aerial contour maps using Church's four-point analytical method. When completed and tested, if found satisfactory, this program should eliminate a great deal of field checking.

In the Ohio Highway Department, a method and a program are being developed for the computation of earthwork quantities using cross-section data taken directly from aerial photographs in a Kelsh plotter. Preliminary estimates for evaluating alternate alignments, as well as more precise estimates for plan quantities, are covered. An auxiliary device is used with the plotter to measure horizontal distances with the same degree of precision possible in the measurement of vertical distances.

The three coordinates of each point on the cross-section are automatically punched into cards for use as electronic computer input. A second device is being investigated by which these punched cards, together with design data cards, are used to direct the movement of a point of light on an oscilloscope, thus delineating the cross-section and the design template at each station. By using an open shutter microfilm camera, the cross-section with the template superimposed on it is recorded on microfilm for use by the designer. Based on the designer's analysis, the design data cards are revised and used with the cross-section cards as computer input data for the earthwork computation. New microfilm recordings are made and occasional sections are enlarged, reproduced, and made a part of the contract plans. In addition, the tabulation of earthwork quantities produced by the computer, and an automatic plotting of the mass diagram, are reproduced photographically and included in the contract plans.

Traffic Studies

For a number of years punched-card processing and tabulating equipment has been used in the analysis of the large masses of data involved in highway planning studies. The electronic computer provides a means of further facilitating and greatly expediting the handling of these data and of increasing the quality of route planning through more thorough analyses than are feasible with conventional punched-card equipment. In a number of states, procedures and programs are being developed for converting parts of these studies to analysis on electronic computers.

Electronic computers are already being used in urban studies in the analysis of origin and destination survey data, including the development of trip desire charts, the prediction of future traffic distribution, the assignment of traffic to a proposed new route or system of routes, and the computation of benefit-cost ratios.

In the Detroit Metropolitan Area Transportation Study, using an IBM 604 electronic calculating punch, a total of 23, 500 zone-to-zone movements were assigned to a network of expressways and connecting arterials totaling 370 miles in length in less than three weeks, including all coding, card punching, processing, and tabulating of assigned volumes.

In the Washington (D. C.) Metropolitan Study, a Univac is being used to project 1948 origin and destination survey data to 1955, to compare the results with data obtained in a second origin and destination survey made in 1955-6, to prepare projections of urban travel for the years 1965 and 1980, and to apply the projected traffic distribution to the planning of an adequate highway and mass transportation system.

In the Chicago Area Transportation Study, a Datatron electronic computer is being used. Considerable experimental work is being done there in developing new and improved methods using the computer. In one method being developed, trips are traced in succession on a cathode ray tube and recorded on photographic film, thus automatically producing trip desire densities. The dathode ray tube-computer combination is also being used in fitting regression curves to plotted points. In the assignment of traffic on the computer, a "feedback" device is being used to provide automatically for the effects of overloads.

Basic experimental work is being done on the use of electronic computers in simulating traffic flow, principally at the Institute of Transportation and Traffic of the University of California, at the University of Michigan, and at Brown University.

In the Bureau of Public Roads an IBM 705 electronic computer is being used to compare various methods of predicting future traffic distribution to determine which method is the most satisfactory and also the number of iterations required for reasonable accuracy. Origin and destination surveys made in 1948 and in 1955 are being used in developing the comparisons. With a total of about 30, 000 zone-to-zone movements using six modes of travel, this study could not be attempted by manual methods.

In a nationwide traffic study being undertaken in the Bureau of Public Roads, origin and destination surveys from a number of metropolitan areas are being used to obtain trip desire data for county-to-county movement somewhat comparable to zone-to-zone movement in a metropolitan area study. This is a multiple correlation problem involving population, distance between areas, automobile registrations, income, recreational facilities, and other factors, which could not possibly be undertaken without the help of an electronic computer.

Hydrology and Hydraulics

The use of electronic computers in the solution of hydrologic and hydraulic problems involved in highway engineering is being explored in the Bureau of Public Roads. One type of problem being investigated involves multiple correlation of hydrologic data in estimating peak rates of runoff for selected frequencies from watersheds in the same physiographic area for use in the hydraulic design of highway structures.

A second type of problem adaptable to solution on electronic computers involves the determination of backwater produced by a given bridge, taking into account stream contraction, type of abutment, effect of piers, eccentricity of the bridge with respect to the flood plain, and skew. This problem occurs in determining the waterway opening required for floods of various frequencies within a given limiting amount of backwater. It can also be applied to the determination of the most economical hydraulic design for a given site, taking into consideration first cost, costs arising from flood damage (including scour), flooding of adjacent lands and effects on approaches, and disruption of traffic.

Other Applications

In the Texas Highway Department, a program has been developed and adopted for extending, analyzing and tabulating bid data at contract lettings. A similar procedure in the Washington Department of Highways is being converted from electro-mechanical equipment to the electronic computer.

In the Arizona Highway Department, a program for sieve analysis of soils has been developed.

In the Bureau of Public Roads, programs have been developed and adopted for computing the acreage of clearing and grubbing, and for the computation of borrow pit excavation.

A program for computing borrow pit excavation has also been developed at the Massachusetts Institute of Technology for the Massachusetts Department of Public Works.

Electronic computers are to be used on the new AASHO Road Test to process and analyze the tremendous mass of data developed during the course of the test. With the millions of pieces of data involved, it is estimated that it would take 10 to 15 years after completion of the test to analyze the data and prepare the final report if the electronic data processing equipment were not used. In this application, data from electronic detecting devices will be recorded in a form which can be used as direct computer input, or in some cases in a form which can be electronically converted to an acceptable input form to further expedite the processing of the test data.

These applications of the electronic computer to highway engineering are either in use or in process of development. Some of the other areas which suggest themselves as possibilities for electronic computation include sufficiency ratings, accident analyses, parking studies, and various problems susceptible to analysis by statistical methods.

From the applications cites, it is evident that rapid progress is being made. The highway profession can justly feel proud of these accomplishments. It also is evident that the electronic computer is a valuable device for research and exploration, as well as for day-to-day operations.

ORGANIZATION AND PERSONNEL

The field is too new and is developing too rapidly for well-defined patterns in organization and personnel to have become established.

With respect to organization, however, the present tendency is to use a single integrated data processing and computing unit located in the highway department headquarters office. This kind of organizational arrangement is most flexible and provides a centralized processing, computing, and tabulating service for all types of engineering problems, and for accounting and related operations as well.

With respect to personnel, minimum requirements include an operator for the computer and operators for auxiliary equipment, together with directing personnel. A maintenance technician is not essential, as service can be obtained for a monthly charge. If the machine is installed on a rental basis, which is the usual arrangement, service is furnished by the manufacturer.

Responsibility for over-all operation, including the development of applications to engineering problems, should be assigned to an experienced engineer, trained in the use of the computer, including programming. This is the usual practice. In addition, it is usual practice to train a selected group of engineers, who are specialists in location, design, structures, planning, and other technical areas, in computer programming to enable them to assist in the development of programs in their specialized fields as part of their assigned duties. A number of states have found it advantageous to employ a mathematician, or to assign a statistician already on the staff, to assist the computer development engineer. A person trained in either of these disciplines can be of considerable help in analyzing problems, in formulating solutions, and in developing both the procedural and coded programs in the most efficient form.

CORRELATION OF PROGRAM DEVELOPMENT

With a number of states working on the development of computer applications to highway engineering operations, there is need for correlation to minimize duplication and otherwise to gain maximum advantage from the efforts expended. The Bureau of Public Roads is developing a plan for the collection and distribution of information on program development and allied subjects on a continuing basis. Plans are also under way for the development of a library of programs so that those developed in one state can be made available to all the other states.

THE FUTURE

Although the general tendency has been to follow established conventional procedures the work in Ohio and the work in Chicago are impressive examples of what can be done with the computer in developing entirely new methods. As further progress is made, it seems logical to expect further departures from existing methods, leading to more exhaustive analyses and more refined design. In Canada, a program has been developed for the structural design of a beam bridge deck which takes into account the interaction of forces on longitudinal and transverse members through the use of matrices derived from correlated deflection equations for all members of the deck acting as a grid. Although this kind of analysis would be prohibitive in cost and time if done manually, it is reported to be entirely practicable using an electronic computer. A similar method of analysis is being used in England in the structural analysis of rigid building frames on electronic computers.

With respect to computer capabilities, it seems obvious that there will be continued improvement. Memory capacity is being enlarged, storage access time is being reduced, input and output speeds are being increased, character reading devices are being perfected, and other improvements are in the making. In addition, there is a definite trend toward transistorization, which will result in reduced space, weight and power requirements. With respect to programming, more and more library routines will of course be developed, and it is quite possible that coding ultimately will become entirely a computer function.

The progress made thus far in applying electronic computers to highway engineering work is indicative of possible future progress. Each successful development leads to another, and computer possibilities would seem to be limited only by vision and ingenuity in adapting them to the needs.

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