ASCE Manuals and Reports on Engineering Practice No. 61

Introductory Manual On Computer Services

ERICAN SOCIETY of CIVIL ENGINEERS

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Prepared by the Committee on Coordination Within ASCE of the Technical Council on Computer Practices of the American Society of Civil Engineers

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MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July, 1930, and revised March, 1935, February, 1962, April, 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his everyday work, rather than the findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the general direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of that Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each work shows the names of the committee by which it was compiled and indicates clearly the several processes through which it has passed in review, in order that its merit may be definitely understood.

In February, 1962 (and revised in April, 1982), the Board of Direction voted to establish:

> A series entitled 'Manuals and Reports on Engineering Practice,' to include the Manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such Manual or Report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past Manuals. Numbering would be consecutive and would be a continuation of present Manual numbers. In some cases of reports of joint committees, bypassing of Journal publications may be authorized.

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PREFACE

As a practical matter, word of mouth is the primary medium of information for computer users. If you need information about hardware (a new terminal, a new plotter, color graphics, . . .), software (an area you haven't worked in, available algorithms, free programs, . . .), or even consultants or a cheaper service bureau, your best bet is not the library but the telephone. Perhaps computing is just developing too rapidly and perhaps someday things will settle down. But today, your friends are your most effective sources of information.

This very dynamic state-of-the-art can make life difficult on many levels: The novice probably does not, by definition, have any knowledgeable friends to call for help; the business manager of an engineering firm constantly finds himself shooting at a moving target in his attempts to control his constantly changing computer department; and even the poor "expert" has to deal with a hardware picture which can only be termed unstable—and likely to become more so.

This volume, the "Introductory Manual on Computer Services," represents a modest attack by the Committee on Coordination Within the ASCE of the Technical Council on Computer Practices upon this relatively unwieldy state of computer affairs. We are attempting to write down some rules of thumb and basic good advice you would get from your knowledgeable friend if you could find him in his office—and if he had the time.

We have aimed this manual particularly at the novice and most particularly at the novice who thinks he might want to take his office into computing. We first discuss the basic facts of computer life and then show the not-so-novice how he can buy in for himself. In another effort (which is well under way) we will discuss briefly specific applications such as structures, construction, geotechnical engineering, . . . , still with the novice in mind.

With respect to style, we have chosen to keep the five chapters of this manual relatively independent. That, of course, has the advantage of allowing the reader—at some personal risk—to jump in anywhere and, for example, read chapter 5 on acquiring a computer without necessarily reading the four chapters that precede it. The equally obvious disadvantage of this manner of proceeding is that the reader who wishes to go directly from cover to cover will find certain redundancies. And, of course, material of this type tends to become dated quickly.

This volume finally represents some four years of hard work by our Committee and considerable good will from Larry Feeser and Rensselaer Polytechnic Institute who have underwritten its early production cost. Its writing and editing have involved many people who have been magnanimous with their time. It is the wish of every one involved that this effort prove useful to the ASCE.

TCCP Committee on
Coordination Within ASCE

May 1982

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Chapter 1

The Role of Computers in Civil Engineering Practice

INTRODUCTION

The modern electronic digital computer became a reality in the late 1940s. The early history of the transformation of this new tool from a laboratory curiosity to an essential component of civil engineering practice is not well documented. However, by the late 1950s two trends had clearly emerged. On the one hand, the rapid expansion of the aerospace program precipitated the development of new, powerful analysis capabilities (first, matrix structural analysis and, later, finite element methods) predicated on the computer's capability of handling large sets of discrete equations and requiring a basically new, general approach to modeling civil engineering systems. On the other hand, the equally rapid pace of design and construction of the interstate highway system introduced the need for computer applications involving basically simple calculations (earthwork quantities, horizontal and vertical alignment, etc.) on enormous volumes of data. The early earthwork or "cut-and-fill" programs are still classic textbook examples of imaginative, systematic conversion of simple, essentially graphical manual tasks to precise data processing procedures. These dual trends of using the computer's *capacity* to store and manipulate very large models, and its *speed* to process large volumes of data are still the primary manifestations of the use of computers in civil engineering practice.

The development of both the range and scope of today's computer applications from the early pioneering efforts has been so dramatic as to deserve to be called revolutionary. It has also introduced a host of considerations which affect the intelligent and effective use of this tool. Succeeding chapters of this manual address these considerations in detail; therefore, only a few salient points need to be mentioned here.

The dramatic increase in capabilities and reduction of costs of computer *hardware* is well known. Today's handheld programmable calculator compares favorably in speed and capacity to Eniac, at one thousandth of its cost, a hundred thousandth of power consumption, and one three hundred thousandth of volume. At the other end of the spectrum of available hardware, large-scale computers may have ten thousand times the speed and a million times the storage capacity of Eniac, at only ten times its cost. The rapid proliferation and cost/performance improvement of computer hardware will continue in the future.

The cost of programs, or more generally *software*, on the other hand, has remained static, if it has not actually increased to the point where software can represent 75% or more of many total computer system costs. Furthermore, a large fraction of the software cost, amounting to 80% in some cases, goes towards the upkeep or *maintenance* of existing programs. A portion of this cost is understandable; as every novice soon learns, there is a big difference between knowing how to perform a given procedure manually and how to program that procedure so that it performs correctly and reliably in all possible situations. However, an unacceptably large portion of the cost of software is still due to the lack of proper program development and maintenance tools, or the lack of awareness and use of existing tools among civil engineers.

Responsible and intelligent use of computers requires that attention be given to the many hidden or intangible costs beyond those for hardware and software. These include the "front-end" costs of initially developing or adopting programs, the continuing costs of education and reeducation of users, the organizational costs of modifying office practices, or even reorganizing offices to better utilize computer facilities, and the professional costs (and possibly liability costs) as the engineer's working mode shifts from a direct, visual, personal involvement with the problem at hand to a more abstract, less intuitive interaction with a program written by someone else and residing in a faraway impersonal machine. The entire issue of costing computer services is made difficult by the particular nature of civil engineering where design and execution responsibilities are so frequently separated.

One aspect of the role of the computer has not changed at all from the day of the first civil engineering applications. This is the realization that the computer is only a tool. No matter how large a fraction of the design process is performed by computer programs, the professional, ethical, and legal responsibility for the results produced by programs rests solely with the engineer. Coupled with this is the fact that all programs deal with a model of the real world, and that design programs in particular incorporate assumptions, limitations, practices and interpretations of the real world which may be unique to the organization or individual who developed the program. Thus, a paradox emerges. The value of *utility* programs, such as equation solvers or drafting packages, is measured by how well they perform, under all possible circumstances, on different machines with different input data. By contrast, an engineering *application* program most valuable to the organization that developed it may fail to perform to the satisfaction of another organization which is likely to use different assumptions or design practices.

The preceding observations are all made with a single objective: to impress on the reader of this manual that the first requirement in considering the introduction of computer services into any aspect of civil engineering practice is to exercise the utmost caution and highest level of professional discrimination in determining the appropriate level and extent of conversion to computer methods and tools.

EXPECTATIONS

Potential users approach the introduction or expansion of computer services with a number of different expectations or objectives. The more common ones are briefly reviewed and critiqued in this section.

Reduction of Costs—The expectation of increased efficiency, in terms of providing the same service at reduced cost, is frequently mentioned by new users. This expectation is undoubtedly achieved in some repetitive, routine applications such as certain drafting, detailing, and specification production tasks. However, in the majority of cases, it is replaced by substitution or expansion of services, at essentially the same cost, in response to the other expectations to be discussed.

More Accurate Modeling—The expectation that the model of a particular design problem, implemented in a computer program, can economically be made more comprehensive and realistic than the model handled by manual methods is frequently cited by users, and one that can almost always be met. The need for more comprehensive modeling, analysis, and design may arise either from internal or external factors. The internal motivation arises when the designer of a tall building realizes that the assumptions about frame behavior built into the moment distribution model are unacceptably restrictive, or when a construction manager realizes that his bar chart model is insufficient to deal with the many decisions facing him (in addition to time precedence). Similarly, external factors enter when the increasing complexity of civil engineering technology, the need for much more comprehensive planning and design, and the increased concerns for safety, energy, efficiency and the like require that the engineer use more complex models to realistically represent design problems. Increasingly, the models appropriate for the new class of problems can only be economically implemented as computer programs.

Ability to Consider More Alternatives—Many civil engineers embark on computer use, or expand existing uses, with the expectation that in this fashion a larger number of alternative designs can be investigated and the best one chosen. This appears to be an expectation satisfied in almost every instance, and many engineers feel that this capability has provided the most significant improvement in design services, as well as a significant increase in their confidence. The ability to consider more alternatives at a given stage of design is important. Even more important is the ability to consider alternatives early in the conceptual or preliminary design stages, when design decisions based on comparisons of these alternatives have the biggest impact on the cost and success of the finished design.

Closer Integration—Another of the expectations frequently mentioned is that of integrating more closely the flow of design work, both internally and externally. Historically, civil engineering applications have developed in a piecemeal fashion. Most civil engineering organizations seem to repeat that pattern internally, until one day they realize that their staff spends large amounts of time transcribing output from one program into input data for other programs. At this point, if not earlier, consideration is given to "tying together" or integrating programs and data for a more efficient flow and better control. Similar external considerations arise in multidisciplinary or multi-organizational projects where the information flowing among participants is increasingly generated by computer programs as well as input to other programs.

Improved Office Practices—The last of the expectations is that computer programs can significantly improve office practices. This improvement may be measured in external terms such as faster speed of response or better quality of the design product provided to clients, or by internal terms such as standardization or "streamlining" of office practices.

OVERVIEW OF COMPUTER USE

In the remainder of this chapter, a critique of computer use to date in civil engineering is presented together with an attempted extrapolation to the future. This critique and projection are intended to serve two purposes. First, the critique is intended to distill for the reader the collective experience in civil engineering computer use over the past 20 years. Second, the projection is meant to provide a sound professional basis for planning the introduction or extension of computer applications.

This overview is necessarily based on the experience of individuals and organizations with a long track record in this area. This fact should not unduly concern any organization beginning in this field; on the contrary, it is hoped that this survey, and this entire manual, can serve as a means to transmit to new users the experiences, both positive and negative, gained in the process.

ACHIEVEMENTS

In civil engineering organizations that have introduced computer applications, these applications have by all measures become indispensable and irreplaceable ingredients of their practice.

In the analysis of structures, water resource and transportation systems, and other civil engineering problems, the shortcuts and simplified methods of the past have been replaced by general techniques which permit the analysis of the most complex systems through a detailed level of modeling. In a similar fashion, many of the tedious, detailed steps of detailing are routinely processed by computer programs. The production of drawings in many cases is now considered simply a by-product of detailing. Where organizational arrangements permit, the data generated by the detailing process can be used directly in production for ordering and scheduling, as well as for direct control of cutting, bending, drilling, and other fabricating machines.

The effect of computer applications on civil engineering practice and research has been much more pervasive than just generating or substituting tools for the design processes. The ability to do analysis of a vastly increased scope has significantly expanded the range of systems being designed and used. Not only have new systems been introduced, but existing systems have become much more widely dispersed as the cost of analysis is no longer a determining factor in selecting possible solutions. Similarly, the ability to model complex behavior has created the need for vast areas of research into material and behavior properties to supply the parameters for analytical models.

The increased ability for iteration and redesign has forced us to review our basic design premises. Safety factors, allowable stresses, etc., have been historically calibrated in an environment where a good design was one in which one member (or, at most, a very small number of members) was at the allowable stress or limit load level in one loading condition. Today, a few iterations can produce a design where every component of the system is at the allowable level in at least one loading condition. Yet, we have not recalibrated our design values for this vastly different situation. One of the significant ingredients in the move towards load factor design, and probabilistic design concepts in general, has been the concern for redressing the balance between dynamic analysis capability and static design criteria.

The increased reliance on data processing has had equally powerful ramifications. We have begun to think of civil engineering projects as truly physical systems, with the goals, environment, and constraints among components and their responses defined much more explicitly than in the past. This realization has naturally led some organizations to data base representations, with all the analysis, design and detailing information, logically, consistently and hierarchically organized into a single repository of information.

Equally important, these organizations have begun to view the design process itself as a production system, with the individual activities coordinated and managed in a consistent fashion. Where organizational structures permit, the systems approach has been extended beyond design into fabrication and construction, and on to operation and maintenance. This systems ability has permitted us to move into a design environment in which diverse design considerations are much more tightly integrated than ever before, in which planning, design, and construction timetables have been drastically shortened and overlapped, and in which a host of new design considerations (environmental, quality, disaster mitigation, energy and material conservation) must be intimately integrated with traditional design criteria.

Admittedly, the full benefits of large-scale data and process integration are available today only to a few large organizations. However, even the smallest organization will soon find that computer use, by its very nature, provides some immediate benefits in better organized design information and office practices.

SHORTCOMINGS

The present use of civil engineering computer applications, impressive as it is, has some serious shortcomings. Precisely because we have been so successful at adopting the computer to our needs, our present usage reflects, and even accentuates, the philosophy, psychology and organization of the profession. This subject can be explored in a number of dimensions.

The civil engineering profession has been aptly characterized as "diverse, dispersed, detached, and discontinuous." This characterization is clearly mirrored in our computer programs. Diversity is evident in our collective ownership of programs for a bewildering variety of problems spanning all areas of civil engineering. However, our dispersion has prevented us from intelligently pooling our program resources and has resulted in an unconscionable amount of duplication of effort. The fact that so much of civil engineering design practice is detached from other aspects of the industry (e.g., planning and architecture at one end, construction on the other) has restricted us to implementing only pieces of the total process. Integration with other disciplines is difficult, if not legally impossible, as in public construction where a contractor bidding on a project cannot have access to the designer's machine-processable data. The discontinuous nature of our organizations, where design and construction teams are formed for specific projects and then dissolved, is reflected in a great number of "throwaway" programs which often prevent us from developing and building truly general systems.

The frequently discussed split between the academic and professional branches of our discipline is also clearly reflected, and often exaggerated, in our computer programs. The academic or research practitioners are primarily concerned with behavior, analysis, and modeling. Computer programs developed as part of these activities tend to be exploratory in nature and do not have the requisite generality, "ruggedness," and user facilities directly usable in practice. By contrast, professional practitioners are primarily concerned with production tools, often concentrating on detailing and other routine aspects of design. Because of the pressing need of business, developers of these programs tend not to include improvements and new concepts arising from research.

Finally, the project orientation of the profession is clearly reflected in the manner in which we develop computer aids. We are professionally so accustomed to approach problems on a project basis, each project being a unique assemblage of problems, resources, and personnel, that we naturally approach the design of application programs on the same basis. In contrast, our engineering colleagues in more production oriented disciplines, as in manufacturing, approach their computer needs in a production oriented atmosphere, applying their standard production tools ("bread-boarding," prototype testing, benchmarking, quality control, etc.) to their software development.

The preceding critique is not to be construed as a negative statement. On the contrary, it is intended to show that as engineers worthy of that title, we have, individually and collectively, adapted and even optimized a revolutionary new tool to our needs, circumstances, and mode of operation. If there is any criticism, it is precisely that we have been too adroit and too successful in this adaptation to our specific current circumstances, without using enough foresight in preparing for the full potential and use of computer applications.

In the following sections, an attempt is made to predict some of the future directions of civil engineering computer applications in terms of the needs for future applications and the opportunities for meeting these.

FUTURE TECHNICAL NEEDS

Undoubtedly the most pressing driving force for future development in civil engineering applications will continue to be the engineers' relentless need for new and better technical solutions. Four major trends can be distinguished in this category.

First, there will be a continuing need and incentive to develop models, algorithms, and procedures for representing and processing more and more complex civil engineering phenomena. Every one of us can cite a number of real engineering problems for which our current behavior and material models, and therefore our computer programs, are simply not adequate.

Second, as the scope of civil engineering continues to expand and its interaction with other disciplines becomes more tightly coupled, there will be an increased need for models for new phenomena, environments, and loads not considered previously.

The third trend will have to be a countertrend to the first two. As our models become more and more comprehensive and complex, they also require more and more data to be known before the model can be used. Consequently, these models become usable only at later and later stages of design. In response to this increasing mismatch between the available analysis tools and the needs of designers, the trend towards developing simplified models usable in early design stages will have to accelerate. To date, we only see very specialized models in this category, corresponding roughly to the analysis programs of the 1950s.

The last trend, closely related to the previous one, will respond to the need for synthesis tools. There is a philosophy expressed by many engineers that there is no need for synthesis tools: If analysis results can be "instantaneously" returned to the designer, he can do the exploration, hypothesis-building, and searching among alternatives to arrive at a synthesis. However, the needs of designers are so pressing, and the number of alternatives to be searched is so large, that a major trend in developing synthesis tools will have to emerge to assist the designer both in the initial synthesis of solutions and in the selection and optimization of component parameters.

ORGANIZATIONAL NEEDS

Civil engineering computer programs are not influenced or motivated by technical considerations alone. Two powerful organizational trends will provide a major impetus to the development of computer applications.

First, there is little doubt that the future of the civil engineering profession as a whole points to greater integration, both horizontally (i.e., closer interaction among the different design disciplines) and vertically (i.e., closer coupling among planning, design, and construction). At the same time, the breadth of design considerations will continue to be significantly enlarged. Whether management of design is integrated or not, the increase in design integration can be accomplished only by increased reliance on shared, integral data bases made possible by computers, networking and data communication. Thus, this area will be one of the most rapidly changing ones, with the present piecemeal data bases extended to complete, integrated data bases. Some of the most challenging work ahead will be in the development of such data bases, including the maintenance of consistency and integrity of data worked on by different design disciplines, frequently in different geographical locations.

A second type of organizational change or integration will have equally drastic effects. To date, design and regulation have been only weakly coupled.

With the increase in complexity of our civil engineering projects, the increased environmental impact of these projects, the severity and cost of possible failures, and the increased legal liability of designers, the coupling between design and its regulation will be drastically tightened. It is clear that the present process, involving a shelf full of normative documents and years of hearings to ascertain that all applicable provisions have been complied with, simply cannot continue. Therefore, a major trend that will emerge will be work on formulating and organizing design standards and other normative documents so that they are more directly relevant to the design process, and in expressing these standards so that they are more readily usable both for design and for conformance checking. A closely related trend will be the move by regulatory agencies and owners to apply the same quality assurance and control methods to computer programs used in the design process as are now applied to the systems, structures, or components produced by the design process.

PSYCHOLOGICAL NEEDS

As computer applications become more pervasive and complex, the psychological needs of the users of these programs will become much more important than they are at the present. There will be a major trend to incorporate educational and training facilities into the programs, so that user expertise and self-confidence can be systematically cultivated and improved. The format and level of man-machine communication will be extensively studied and significantly improved.

On the input side, the old "battles" between fixed and free-format input, user initiative versus computer prompting, etc., will fade in favor of extensible languages, allowing each user to incorporate his own idiosyncrasies into his dialogue. On the output side, the user is deluged by tabulated, printed, and plotted output vastly exceeding his comprehension limits. Considerable research effort is needed to better understand users' comprehension needs and limits, and to develop output facilities which respond to these needs and, eventually, can adapt to the users' increase in comprehension and learning.

OPPORTUNITIES

Trends in future computer applications will be influenced as much by new opportunities as by new needs. Indeed, we could not begin to think of meeting these needs if we did not foresee a corresponding increase in the opportunities open to us.

On the hardware side, the proliferation of computing resources, ranging from ultra-powerful, parallel computers to sophisticated mini, micro, and handheld processors, will continue. These developments, coupled with continuing decreases in hardware and communication costs, will permit many new applications presently considered prohibitive.

The opportunities on the software side will be at least as significant as on the hardware side. The emerging discipline of software engineering has the promise of significantly affecting and shaping the trends in computer applications in three areas. Not surprisingly, these areas closely parallel the three professional areas discussed previously.

At the technical level, new languages and other software facilities will significantly broaden and enhance the capability of developing new civil engineering applications. At the organizational level, the concepts and techniques of software engineering can provide the software designer with an orderly mechanism and a set of appropriate tools to build application systems. It is immaterial