product data collection equipment, it must be realized that any business machine or mechanism with data settable switches might be equipped with tape recording devices such as have been described. Such machines as accounting machines, adding machines, time clocks, and many others could be equipped with the Punched Tape Recorder. The foregoing description also covered only a very limited application of the system to department store uses. It is obvious that the number of instances in which this automatic by-product data collection system is applicable is almost unlimited.

In conclusion, let us summarize the National Cash Register Company's automatic by-product data collection system. The system captures on punched paper tape, as a direct by-product of the normal business machine's operation, selective data pertaining to the entries through the keyboard of the business machine. As a still further step in automation, a means has been devised by which fixed descriptive data in the form of prepunched media such as price tickets may be transferred automatically to the punched paper tape being prepared by the operation of a business machine equipped with a Punched Tape Recorder. Through the use of this Media Reader it is now possible to automatically transfer data from the prepunched media to the paper tape, while operating the business machine in the normal manner without additional machine operations.

Computers Challenge Engineering Education

F. C. LINDVALL†

WHEN QUANTUM theory was newly stirring the world of physics, an older professor was reported to have said to his graduate students studying this subject, "I don't believe you young fellows understand this stuff any better than I do, but you all stick together and say the same thing." You computer enthusiasts say a great deal, some of which I understand. Your computers differ in detail and complexity, yet have much in common in concept and capabilities and in the fantastic rate with which new models appear. They have their limitations, but nobody underestimates their potentialities. Nor are the glamorous, rosy dreams of coming applications as far beyond the horizon as we might think. You know better than I the magnitude and momentum of the development effort and the tremendous interest which has been generated in all areas of technology and business.

In science and engineering education as well, computers have stimulated much excitement, critical thought, and even some concern. In fact, the computer is one of the more spectacular new developments which are a challenge to education. As a result, we in the colleges of science and engineering are being forced to examine the implications of this challenge. We are also being urged to offer courses in computer fundamentals, logic, design, components, applications, and use, not to speak of complete curricula leading to degrees in computer engineering. Some schools have strong research interests in modern computing and may be justified in offering such instruction. At the same time, other customers for our graduates give equally convincing arguments for more or less specialized instruction in, for example, control systems, instrumentation, automation, systems engineering, operations research, nuclear engineering, and information theory. Needless to say, we are somewhat confused and bothered beyond mere professorial petulance over these challenges to comfortable academic routines.

† California Institute of Technology, Pasadena, Calif.

We cannot, and, I believe, should not, attempt in the colleges to meet these challenges by detailed specialization in all of these new and emerging areas of current interest and importance. We must, instead, do the more difficult job of examining each new development for those features that are truly basic, extracting the concepts that are new and fundamental, and synthesizing the important generalizations that have lasting value. This exercise of self-discipline, sticking to fundamentals, is not easy. The other course, that of following avidly in the classroom the exciting new developments, the intriguing applications, and the fascinating new details, is more fun, has high entertainment value for the student, and is an easy, pleasant way to teach. But, it has the elements of a gold brick, the superficial appeal—the form, but little substance. The values are apt to be transient.

Thus, in appraising new developments, engineering colleges must evaluate critically the fundamental character of these new advances—what is now involved and what is anticipated—so that curricula and course content of the basic sciences and engineering sciences may be improved as fundamental education for future professional application. We must always be critical of that instruction which is specialized training rather than comprehensive education.

To sharpen focus on this problem, we can examine three major areas of computer work which may occur on a college campus: research, computational service, and teaching. These areas, of course, have considerable overlap. Some colleges have already made important contributions in computer research and development. Others have major programs of work, and new activities will undoubtedly develop. These will include: logical design, related mathematics, techniques of physical problem formulation and solution, analysis and synthesis, component research, machine development, and special-purpose computers, to name a few obvious subjects. Much of this activity would closely parallel commercial research and development, but with different objectives that complement the teaching effort and advance fundamental knowledge.

Colleges, through proper research, can contribute more effectively to the fast-moving art of computing than to some of the older, well-established engineering activities.

Computer use on a college campus is relatively new and limited to a few schools, but desired by many. We found at our school that when several departments examined imaginatively the possibilities of high-speed digital computing applied to their existing and potential problems, interest intensified and a computer became a "must." All that stands in our way is two or three hundred kilobucks.

The projected use is as a service center for all campus needs but with individual investigators responsible for their own coding and programming. This general use should develop rather widespread knowledge of modern computation and stimulate investigation of many problems too tough to solve without such computational aid. Studies in computer use will evolve problem formulation, circuit or system synthesis, simulation, special functions, coding, and programming. Data handling and dissemination is another important function—the reduction of experimental data to usable form, thermodynamic properties being a good example.

Formal instruction pertinent to computing can have specific as well as general aspects. Of general character are computer fundamentals including logical design; applied mathematics that incorporates a new philosophy and approach to problem formulation for computer solution; related mathematics, such as Boolean algebra, probability and statistics, group theory, matrix algebra; and mathematics "laboratory" for numerical methods, iteration procedures, and relaxation methods.

More specific instruction could include computer circuitry, components, storage devices, input and output systems, programming and coding, laboratory experience, checking routines, and trouble shooting. However, from the educational point of view, such instruction should be watched critically lest it be too specific to particular computers, devices, and those systems subject to a high rate of technological obsolescence. The significant generalizations can easily be obscured in such instruction by a horde of details which may be only of transient value in the hustling computer art.

Thus we come again to the perennial question which applies as well to all fields of technology as to computers: what can the colleges do best for the student and what can industry do best? We see with increasing clarity that colleges can only begin the education of the engineer—that instruction must be fundamental, broad in scope, and applicable to large areas of technical development. Time should not be diverted to instruction in details that apply only to a narrow segment of industry. Industry itself can supply specific information better than colleges can, and recommends strongly that the colleges concentrate on the basic sciences, the engineering sciences, and the humanities.

The computer's challenge to engineering education is properly in the area of fundamentals. Fortunately, some of the significant basic factors implicit in modern computation underlie other developments in engineering science as well. Probability and statistics, general concepts of reliability, generalizations from information theory, for example, permeate modern engineering, particularly instrumentation and control of all types. Systems study, as contrasted with component study, is the coming approach to involved engineering problems. Computers or simulators of varying degrees of sophistication are likely to be parts of such systems. The science of decision-making may eventually become a recognized engineering science taught in the colleges, which the power of high-speed computing, analysis and synthesis implements. Engineering cybernetics, the more generalized aspects of servos and control, also leans heavily on concepts basic to modern computation.

The implications of high-speed computing in our classical engineering science subjects are a bit frightening. For example, structural design, whether applied to bridges and buildings or to aircraft, could be completely different in approach, if high-speed computing were generally available. Rapid iterative methods, optimization procedures, and even incorporation of nonlinear properties would give an engineer freedom to explore new design concepts. Engineering economy could be greatly extended in scope by computers, in that alternative choices could be examined quickly and tested for the effect of many parameters. In short, the whole approach to a physical problem may be different if high-speed computing is available. The problem formulation would be directly in machine terms from the basic physics without necessarily going through a mathematical formulation. We would then be less inclined to warp the physical system into formal mathematics which we can solve. This would be particularly true if nonlinearities are involved—and most of nature is nonlinear!

Students will be advised of these new horizons in basic thinking which modern computing suggests. However, the great new day is only dawning and we will fumble along for quite a while with analyses and techniques that later may be displaced. Existing methods of engineering will apply indefinitely to thousands of unglamorous but essential problems, and these the students must be prepared to solve realistically. Hence our education in engineering won't suddenly be coded and programmed for the computer art, but will include the fundamental subjects that are pertinent and will develop those broader methods of analyses and thinking that computers will make possible. We welcome the computers with their challenges, but we are not quite ready to throw away our slide rules!

An Optimization Concept for Business Data-Processing Equipment*

D. R. SWANSON†

Summary—**It is demonstrated that under certain conditions there exists an optimal relationship, based on cost and performance, between the number of magnetic tape units and the number of digital computers in a business data-processing system. The relationship is derived in such a form as to indicate how the concept might be generally applied to any kind of system. Some discussion is also given on the question of random access in business data processing.**

Introduction

I SHOULD LIKE to explore some questions which might be of interest to a prospective user of electronic data-processing equipment who is trying to determine the number of magnetic tape units that ought to be included in the system. In Section I, with the aid of well-known mathematical methods, an optimization concept for data-processing systems is developed and generalized, in Section II an example is given in order to show more clearly how to use the results and ideas that have been presented, and in Section III a similar question on the required number of tape units is discussed for a large-scale file maintenance data-processing problem.

I. Development of Optimization Concept

Presently available large-scale electronic business data-processing systems consist essentially of one or more general-purpose digital computers (or "processors"), a number of magnetic tapes, peripheral equipment such as input-output devices, and perhaps auxiliary special-purpose equipment. Reels of magnetic tape are generally mounted on "tape units" by means of which winding, rewinding, reading, and recording operations are effected. Several standard lengths of tape on reels are provided; that most commonly used now is about 2,500 feet.

For our purposes let us suppose that each tape unit can be associated with any arbitrary length of tape. I do not necessarily imply at this point that a tape unit is assumed to be technologically capable of handling, for example, a 10,000 or 20,000 foot reel of tape, but if it cannot do so then it must be assumed that either manually or automatically it is possible to install successively on that tape unit any number of shorter length reels. The total data-storage requirements of the business operations to be mechanized determine, of course, the total length of magnetic tape that must be in the system. With the foregoing assumption, however, the number of tape units associated with the given total length of tape is not fixed but can be selected on the basis of the cost and performance considerations to be discussed. A noteworthy point, incidentally, is that nearly all of the cost of a magnetic tape memory lies in the tape units rather than in the tape itself.

Let me first try, by considering a specific example, to make intuitively clear the optimization concept to be formulated. Suppose the total amount of data to be stored requires 100,000 feet of tape. On the one hand, we might provide a system with ten tape units, each handling 10,000 feet of tape or, on the other hand, we might provide 1,000 units, each containing a 100-foot reel of tape. It is evident that the latter alternative would be a great deal more costly than the former, but would have the advantage of much lower access time to information recorded on the tapes. The question of whether or not the increased performance of the latter system is worth the extra cost is extremely difficult to answer because it apparently requires knowing the dollar value of faster data processing. To see how this question is avoided, let us pursue the example somewhat further. Suppose that we add to the first (ten-tape-unit) system enough (perhaps ten or twenty) computers or processors so that its total cost is brought up to that of the second (1,000-tape-unit) system. For the same price, then, which system can handle and process data more rapidly? Or can a much better system be put together for that price, consisting perhaps of several processors and a few hundred tape units? The best system is certainly that in which a balance exists between tape access time and the effective computing speed of the several processors, so that neither tapes nor processors can be considered a bottleneck. To determine such an optimal balance requires some knowledge of the nature of the data-processing jobs to be done, but it is not necessary to know the dollar value to the user of mechanizing those jobs.

With the foregoing qualitative introduction, the problem can now be described in abstract mathematical terms, not entirely for the purpose of being obscure but rather to divorce the optimization concept from a par-

* Most of this paper was prepared while the author was associated with the Hughes Research and Development Laboratories, Culver City, Calif.

† Ramo-Wooldridge Corp., Los Angeles, Calif.