COMPUTER APPLICATIONS IN CIVIL ENGINEERING EDUCATION

by

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Introduction

The computer age is upon us. Applications ranging from the ubiquitous arcade games to the sophisticated systems controlling the space probe bear witness to this silent revolution.

Yet in our country it is only comparatively recently that computers have begun to be applied in the engineering field – in the practice of the profession rather than in engineering education. It is time that engineering schools begin to become actively involved in educating future engineers on the creative, effective use of the computer.

This paper attempts to show how a computer may be effectively integrated into the undergraduate civil engineering curriculum by examining the nature of the computer, the civil engineering design process and the ways a computer is used in the design process. From these consideration and from the range of computer systems available, a plan of action is suggested. Finally, an attempt to look into the future is made.

The Engineering Design Process

Figure 1 illustrates the different steps in the engineering design process. Initially, the satisfaction of a need is stated (design objective). The manner by which the satisfaction of this need is to be performed within existing constraints is described (problem specification). Alternative solutions are set up (conceptual design). The response of each solution is computed (analysis). The computation involves the setting up of a model (mathematical, physical, or analog); the application of physical and engineering principles in the "testing" of the model; and, the derivation of the response of the model. The response characteristics of each alternative solution is compared with previously developed acceptance criteria. Each alternative solution is then examined minutely. Is the solution acceptable? If not, can modifications be made? What modifications must be made? Etc., Etc. Once these questions are answered, the final solution is arrived at.

It is noted that in evolving the final design several runs through the loops in the engineering design process may have to be taken. It is this number of passages through the loops that makes the engineering design process, though repetitive in nature, tedious in execution.

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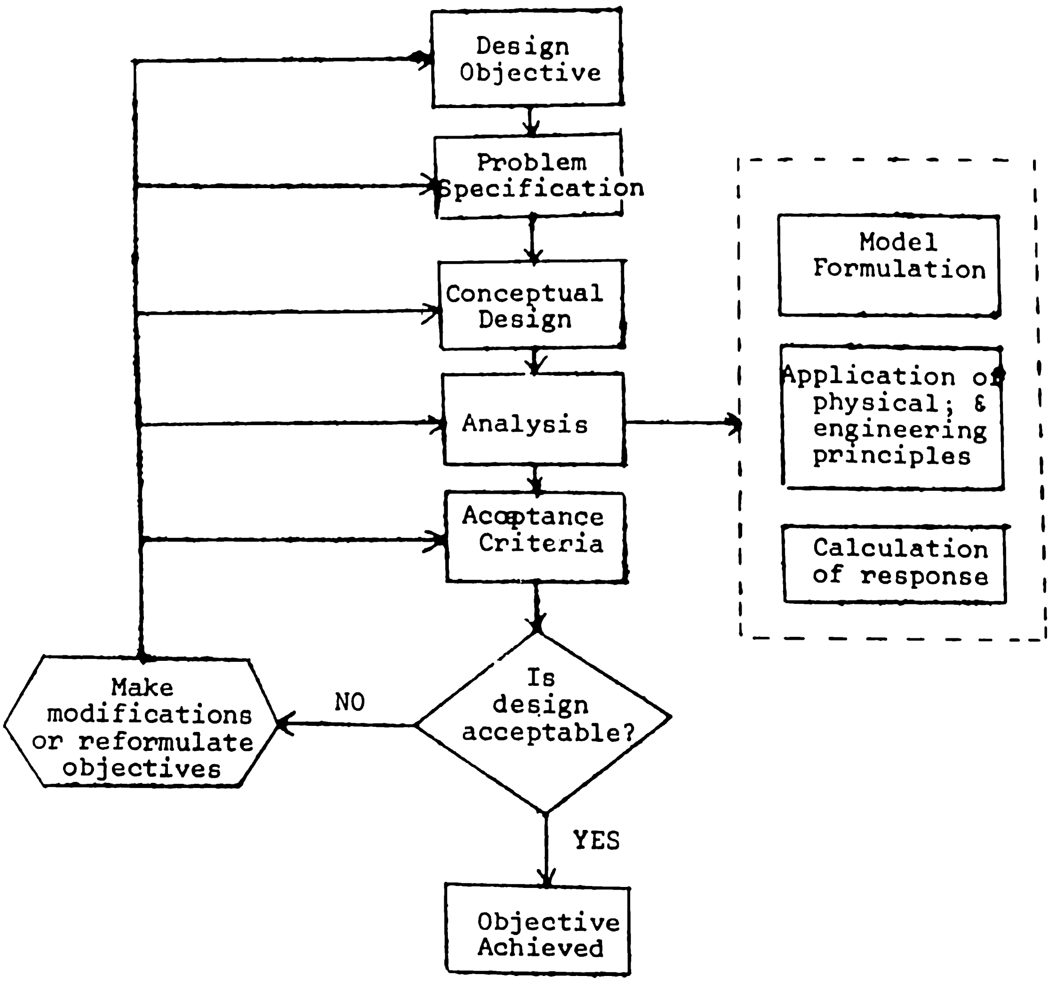

Figure 1. THE ENGINEERING DESIGN PROCESS

Source: Beck, C.E., "Computer Capability in Engineering Design", <u>Consulting Engineer</u>, July 1966

In this era of rapidly escalating prices, the engineering designer is under extreme pressure to provide the most efficient and economical solution with the requisite degree of safety and performance standards. This thus necessitates more alternatives to be considered, more sophisticated analytical techniques to be used, etc., etc. In short, the engineering designer simply has to take more trips around the loop than ever before required. Any means or tools to reduce the tedium is welcome. This need was already perceived in the past as may be gleaned from this quotation attributed to Liebnits:

> "It is unworthy of excellent men to lose hours like slaves in the labor of calculation which could be safely relegated to anyone else if machines were used."

Engineering Education and the Engineering Design Process

Engineering education aims to teach the student not only skills in analyzing a given alternative solution but also to develop the ability to perceive possible alternatives and more importantly, to develop the judgment necessary to formulate and evaluate these different alternatives.

A civil engineering project, no matter how small, is a "systems" project. The system is composed of many interacting elements. The milieu of a civil engineering project is not merely technical. It has an impact on economics, on the environment, on human beings. The characteristics of the system is such that any change in any element will produce changes in the system and, therefore, on its impact on the different elements of its milieu. As previously mentioned, changes of this nature require the taking of a number of trips around the loops of the engineering design process.

While the learning process of a civil engineering student should require a study of a real-life project, because of the time constraints imposed by an engineering course schedule using manual methods, severe limitations exist. These time constraints have forced what has been described as "trivial and contrived problems with many simplifying assumptions" (Caffrey and Mossman, 1967) to be presented to the student on the *process of computation* rather than on the *evaluation and assessment of the results.* This is diametrically opposite to what Hamming (Hamming, 1962) has so succinctly put:

"The Purpose of Computing is Insight not Numbers"

The availability of the computer can now relieve the student of this tedium and now opens to the engineering teacher a whole new vista of realistic problems. More importantly, the use of the computer results in very desirable side-effects on both the student and faculty user. Again quoting from Caffrey and Mossman (Caffrey and Mossman, 1967):

> That it is *possible* to program the computer is no less important than that it is necessary to do so. This requirement forces the human user to

> understand in great detail, and with keen logical insight, what it is he wants to do. This *computer imperative*, forced on the human user by the fact that the computer does only what it is instructed to do, is itself a powerful stimulant to the mind. The computer frees man from the drudgery associated with repetitive and mundane clerical labor, but it does not free him from the necessity to think, especially about the criteria he wishes to apply to enable the computer to trace its way at nearly the speed of light along manifold branches of a systematic process and finally arrive at what he wants to know.

As Caffrey and Mossman subsequently state, the computer has in effect become "an extension of the human mind."

Uses of a Computer

Regardless of the field of application, the use of the computer is indicated for the following types of problems (Rodgers, 1978):

Single Answer to Massive Questions – An example of this type of problem taken from civil engineering is that in choosing from several alternatives locations of a port, the one which will produce the greatest possible benefit will be chosen. The sheer number of factors to be taken into account requires the use of the computer.

Highly Repetitive Calculations in which Each Answer Becomes the Premise of the Succeeding Calculations – A civil engineering example is the analysis of a three-dimensional structure under several loading combination.

Conversion of Data Forms – The automatic digitization of data extracted from a contour map is another civil engineering example of this type of use.

Memory Data Banks – An example of this is the storage of rainfall and other hydrologic data for different regions of the country for later use in the design of irrigation, water supply or power projects.

Academic Uses of the Computer

Although the uses of a computer in an academic environment are of the same type as those encountered in an engineering office they tend to be more varied. These uses have been categorized (Caffrey and Mossman, 1967) as follows:

1. As a tool of research.
2. As a subject of research.
3. As a tool of instruction.
4. As a subject of instruction.

Research Use of the Computer – The role of a computer in research is a vital one. However, the two research uses listed are outside of the scope of this paper and will not be discussed other than to say that the computer is an ideal vehicle with which to initiate and carry on research on a theoretical level as this type of research does not require as substantial an expenditure as does experimental research.

Table 1

Available Computing Hardware
(Adapted from Jones and Carkeek, 1978)

Category	Hardware Item	Appropriate Cost	Note Numbers	Some Examples
1	Non-programmable Scientific Handheld Calculator	$10 - $200	1,2,15	Casio fx-2000 TI 30 HP 32E
2	Programmable, no off-line storage	$80 - $200	1,3,15	HP 25 TI 57
3	Programmable with off-line storage	$200 - $1000	1,2,3,4,5,6,7,15	HP 41C TI 59
4	Desktop Computer	$3000 & up	2,4,5,6,7,8,11,15	HP 85 HP 98xx Wang 2200 IBM 5110
5	Personal or hobby-type Microcomputer	$500 - $10,000	9,10,11,13,15	TRS 80, model 1 Apple II+
6	Mini-Computer	$20,000 - $100,000	13,15	Micro Nova HP 1000 PDP 11/40
7	Midi-Computers	$100,000 - $300,000	14,16	HP 3000 Eclipse PDP 11/70 Wang 2200 VS
8	Large Mainframe Computers	$300,000 up	14,16	IBM 3000 series CDC Cyber Univac 1108

The Computer as a Tool for Instruction – Because the computer relieves the user of the tedious pencil-pushing associated with the analysis of a complete engineering project, an instructor can assign as an exercise a complete system (perhaps scaled down to fit the computer being used but complete nevertheless) to study. By the use of available programs, the student can simulate the system's response to varying conditions. Several advantages accrue in the use of simulations. A parameter sensitivity analysis can be performed; irrelevant factors can be eliminated; and more experience can be gained in a much shorter time than would be possible in the real world. Properly designed, simulations can be highly motivating if not outright fun for the student. In many cases, simulations permit the student to observe and understand events which might require years to observe in the real world. At the same time, simulations eliminate what might otherwise be dangerous experiments on real systems.

It is this use of the computer that makes it a valuable adjunct to the instructor and it is primarily for this use that a school should acquire a computer.

The Computer as a Subject of Instruction – Computer science courses are normally taught for two reasons:

1. They prepare computer professionals and specialists for a career in computers.
2. They provide the skills for users so that they may look upon the computer as a familiar and essential tool in their professional work.

The latter reason is of importance in a civil engineering curriculum. A student should be taught not only how to program in a high-level language but he should be given courses which teach him how best to set up his computation procedures (algorithms) to make effective, efficient use of the computer as a tool. It is unfortunate that some schools, in using the computer for the first time in a curriculum, make the mistake of setting up a programming language and leaving it at that, hoping that somewhere down the line after graduation the student will pick up by chance, exposure to the necessary techniques which will turn him into a proficient computer user. There is no better way to kill a student's interest in computers than to require in the curriculum this kind of a course and then provide no further contact with the computer in subsequent courses. On the other hand, schools should not go to the other extreme where students are expected to write for themselves the programs needed to simulate the systems to be studied. This too can very quickly dampen a student's enthusiasm for the computer.

Judiciously introduced, designed and implemented, courses on the use and programming a computer can provide the students with skills needed in his highly computer-oriented age.

A Course of Action

The following discussion is based on the premise that the most effective role of a computer in a civil engineering curriculum is when it is used for the analysis of a complete, albeit scaled-down civil engineering system.

In order to arrive at a course of action, it is necessary to examine the different types of computing equipment available and then to discuss which phases of the system simulation process each type is best adapted for. Tables 1 and 2 are presented (considerably modified from their original form) for this purpose. Table 1 (Jones and Carkeek, 1978) enumerates and describes the different available computing hardware. Table 2 (Greeve, 1977) categorizes the different engineering computation modes and indicates the various types of computing equipment adapted for each mode.

In the context of Philippine conditions where capital outlays for equipment are difficult to come by, the first three computation modes are probably the most practical. Except for the most affluent of schools, Computation Mode IV, because of the sophisticated computing equipment required, will remain a goal to aim for but probably not capable of realization for the foreseeable future for most engineering schools.

Computation Mode I is useful in view of the fact that not every professional will be able to avail of computer facilities. Thus a certain amount of skill in manual computation will be needed. Because of the proliferation in the number of manufacturers and models of handheld scientific calculators of Category (a) every student should have one for dedicated personal use. Category (b), the programmable handheld scientific calculators with no offline storage is of limited use. It can be used as an ordinary calculator for Computation Mode I problems. Its programmability's utility is somewhat limited in that any time the calculator is put off the program is erased from memory. Thus every time a program is needed, it has to be keyed into the memory and then a check problem whose answers are known has to be run to ensure that the program was correctly keyed in, before the calculator can be run in its program mode. Some models have so-called continuous memories which keep the program existing in the memory even if the calculator is switched off. However, if another program is needed, the user has no choice but to repeat the procedure for entering a program previously described.

Computation Mode II problems in somewhat reduced form than as described in Table 2 can also be solved using the handheld calculators of Categories (a) and (b) although the student will have to be taught how to structure his computations, preferably by means of tabular solutions specially when there are many repetitive steps, in order to reduce the number of opportunities for error. Programmable calculators with off-line storage in the form of magnetic cards or magnetic tapes in cassettes (Category [c]) and desk top computers with similar off-line storage (Category [d]) can be used to advantage for problems requiring Computation Mode II. The size of memory (number of storage registers) and the problem that can be handled will depend upon the number of program steps available. Where the number of operations or the number of quantities to be operated on outstrip the memory or number of program steps, segmenting the procedure may be resorted to. Thus, a program may be broken up into as many modules as necessary to ensure that the individual modules will fit the memory. As each module is executed, the results of its computation will be stored in off-line storage. The next module in line is then rolled in and executed using the intermediate results of the previous module as its input data. This process is repeated as many times as is needed to completely solve the problem. The constant rolling in of modules and outputting and inputting of data slows the process down very much as compared to what would be the case when both the entire program and the data reside in memory. It is difficult to make an estimate of the size of problem of Computation Mode II that can be solved because of the extremely wide range of capabilities presented by different models of the various manufacturers. If the programming is in keyboard-oriented machine language rather than in one of the high-level languages used in some desk-top computers, programs which are developed will be limited in portability to other machines of the same type and not be "portable" to another type.

Computation Mode I problems have very little instructional value from the point of view of system simulation. Larger problems of Computation Mode II do have a degree of illustrative value depending upon the size or programmable calculator of Category (c) or desk-top computer of Category (d) used.

When considering a complete civil engineering system of Computation Mode III as premised at the beginning of this section, the different computer types, Categories (d) through (h), provided they are equipped with the requisite peripherals, are indicated. For the amounts of money usually available for such a purchase by schools in the Philippines, a fully-expanded personal or hobby type microcomputer with a printer and at least two minifloppy disk drives of Category (e) would be indicated as a minimum. User programs to be used in the system simulation will have to be developed by the school's faculty because as far as the writer knows, outside of some construction estimating programs and surveying programs, such programs are not commercially available. The development of the program is beneficial since not only will the programs be tailored to the needs of the school's course but their development will also provide their developers with a deeper insight into the system whose simulation they are programming for.

A course of action is now suggested. Although the following seem to indicate separate, sequential steps, in reality they will probably be more or less concurrent.

First is to choose and acquire the computer system. As discussed previously, either a personal or hobby type microcomputer with a printer and two disks as a minimum or a minicomputer of Category (f) with equivalent peripherals should be the smallest system to consider. Larger systems of Categories (g) or (h) would be even more desirable if funds are available. At least one high-level language should be supported. The system software, particularly the utility programs, must be easy to learn and easy to use. The manufacturer's documentation must be at least adequate but preferably comprehensive and if possible be more or less at the beginner user's level.

In acquiring the computer system, several considerations must be taken into account. The following are offered in view of the fact that such an acquisition involves a major portion of the school's equipment budget and a mistake in the choice represents a difficult error to rectify:

1. Costs – The first consideration are the costs: system acquisition costs, operating costs, maintenance and servicing costs, etc., etc. A school's capital outlay for a computer system determines the most expensive system that can be purchased

and operated. In this matter, costs are of primary importance. However, this does not mean that the lowest cost system is the best choice. Other considerations which will be discussed could very well be the deciding factors.

2. **Availability of Service and Spare Parts** – Inevitably a computer will have one of its components break down. By the very nature of its envisioned role, the intensive integration of the machine in course work, "down time" cannot be tolerated for long periods. Thus, it is absolutely essential that a service organization with an adequate supply of spare parts must be in existence. This may be difficult for a school to ascertain because dealers in their eagerness to make a sale will always state that service and parts are available. An indirect way to determine if such is the case is to make a survey of the number of installations of the particular computer system under consideration in the country. If there were many, there is a good probability that a service facility exists. If on the other hand, only a handful of installations exist in the country, the chances of those systems being "orphaned" are very high.

3. **Manufacturer Support** – Another consideration is the quality of support of the manufacturer after the sale outside of service and maintenance. Does the manufacturer provide updates of operating system and system programs? Does the manufacturer provide upgrading hardware modifications? These are of importance if the system is to be kept up-to-date.

4. **Dealer/Manufacturer's Training Facilities** – Immediate use by a school of a computer system upon delivery requires that the faculty (and operating personnel, if any) who will use the computer must not only know how to use a computer but must also be conversant with the characteristics of the particular computer system to be installed. Thus training must be made available prior to the delivery of the computer. Otherwise, the expensive computer will not be productive in the sense described until such time as the faculty (and operating personnel) have become proficient in the particular system used. From the experience of the writer, in spite of the availability of training from the dealer/manufacturer's representative, at least six months of actual operation of the system is required before any serious work can be started.

Quite outside of the foregoing, there are still other factors which if present will ease the attainment of reasonable success. Efforts to assure their presence must therefore be exerted. These are paraphrased by the author from (Greve, 1977):

1. There must be a desire by both the engineering faculty and the school's administration to accept and use new methods and for the faculty to learn these new methods provided that they are economically feasible.

2. The use of more complex methods for problem solving requires time for introduction, time for re-education and time for adoption of the methodology and procedures involved. The administration must be ready to release part of the time of the faculty for such purposes. This is absolutely necessary because it is extremely rare for such a jump from hand calculations to complex computer methods in one giant step. Each phase of growth must constitute a step of improvement or enlargement of capability.

3. There must be a capital commitment by the administration of the school to finance these changes and growth even if they are not immediately effective nor the benefits obvious.

A Peep Into the Future

So far the applications discussed have centered on the use of the computer as a computational tool. However, the computer has much greater potential in education beyond computation.

One of the educational techniques shown to be effective is the individualized instruction technique. At the University of the Philippines' College of Engineering, this technique was pioneered by Prof. Angel A. Alejandrino in his courses in Fluid Mechanics during the 1960's. Currently, Dr. Edgardo S. Pacheco has been using this technique in the course in Statics. The key to the success of the system is the student's having to work on exercises and have immediate feedback as to the correctness or incorrectness of his solution. For a small class, the instructor can handle the work load more or less by himself. When classes begin to exceed about twenty, tutors are needed. A computer could very well perform this function with the student using a terminal as the means of communication.

What will probably be the factors which will usher in more extensive use of this mode of teaching, known as Computer Aided Instruction (CAI), are the development of inexpensive color terminals and the introduction of the laser-read video disc. A video disc developed by Philips of Holland currently sold for home video applications has the capacity of storing some 50,000 odd separate frames per side each individually encoded with a unique number. A single frame represents a complete color TC screen of information. Thus this number provides the potential for retrieving at random any frame on the disc. If then, all the problem set solutions as well as text material could be put on the disc (which has enough capacity for 50,000 pages per side if one frame is devoted per page), then the computer can be programmed using either of the two Skinner programmed learning techniques. Thus, a student using the computer in this way could obtain as much drill and review as he needs to master the material. At the same time, the computer could be programmed to monitor the student's progress and summarize his performance for the instructor.

It is necessary to mention other equipment now on the market which are available even for small systems such as the personal or hobby type computers of Category (e). Among these items of equipment are: (1) light pens, (2) plotter-printers, (3) bit pads, (4) voice input/output.

Light pens are extremely useful input devices when data to be input consist of choices from a list displayed on a video display unit or of portions of a diagram similarly displayed on the video display unit.

Plotter-printers relieve a lot of tedious manual drafting when scads of output data have to be reduced to charts, graphs, or drawings. In addition, computer drafting is already a legitimate operation in an engineering office and is thus becoming an important subject for study and investigation.

Bit pads find themselves of extreme value when graphical data have to be digitized and entered into the computer. A tremendous amount of manual labor required to transcribe graphical data into a form suitable for computer input can be saved.

Voice input/output units are still in the development state but their potential for computer-aided instruction is staggering. The day may not be far off when drill and review classes will be held by a computer equipped with just such input/output devices.

All these equipment alone or in combination with each other present a mind-boggling potential for use in education. Only the creativity of the users (and, of course, finances) represent the limits to the kind of applications that are possible.

Conclusions

The ideal earning situation is one where a complete civil engineering system can be studied in depth by a student. This is best done through the use of a computer using appropriate simulation program packages. Present day prices of the personal or hobby type computer systems are such that Philippine engineering schools should be able to provide their students with such systems. To use these systems successfully requires development of the faculty's potential for the intensive, creative use of these facilities. This can come about only through the dedication of the faculty and through the whole-hearted support of the school's administration.

In this highly computer-oriented age, no engineering school can afford delaying further the integration of the computer with the different engineering curricula. The writer would even venture to say that such a delay is literally depriving their engineering students of a portion of their training vital to their future professional life.

Notes to Table 1:

1. A wide range of pre-programmed scientific functions for a variety of models are available from different manufacturers.

2. Some models have built-in tally roll printers.

3. A few models have continuous memories.

4. Magnetic cards or magnetic tape in cassettes or cartridges used as off-line storage. One model can use bar code pre-printed on paper.

5. Specific keys on keyboard assigned to particular ROM function or operation; thus programming consists of striking specific sequence of keys.

6. Some models allow printers to be attached.

7. Additional memory modules may be attached to some models. Memory modules may be pre-programmed or user-programmed.

8. Occasionally, high-level language in ROM, such as BASIC rarely APL, is used in some models.

9. Full range of peripherals may be added.

10. Usable as terminal through addiitional hardware and implementation of driver software.

11. A few models allow laboratory equipment to be interfaced to provide direct data input into computer.

12. Essentially stand-alone single user.

13. Stand-alone, single user primarily but may be used as host computer for remote terminals at price of degraded performance for some models.

14. Stand-alone, single user; when provided with large enough memory, can act as host computer for remote terminals.

15. Portable ($<$ 30 pounds in weight).

16. Non-portable.

Table 2

Modes of Engineering Computations
(Adapted from Greve, 1977)

Mode I: Single Element Problem Solution

Description: Engineer divides or simplifies problem to one reasonably self-contained element.

Examples: Designing a column or beam in a structure; computing flow in a pipe or an open channel.

Equipment: Handheld scientific calculator

Advantages:

1. Engineer is in full control of computation and is aware of values during entire computation process.

2. No time delay in processing.

3. Computational steps of calculation involve simple algorithms easily verified.

4. Preparation cost usually minimal.

Disadvantages:

1. Engineer just to valuable to perform simple calculations.

2. Each step to the problem must be manually executed by engineer.

3. Dollars and time involved in making algorithms operational each time may exceed cost of work accomplished.

Mode II: Multiple Element Problem

Description: Engineering structures problem to include a group of elements to reduce assumptions on interrelated dependencies, to improve results or solutions or to speed the solution process.

Examples: A string of beams, with columns fixed at far ends, in a structure; a network of main pipes.

Equipment: Programmable calculators with or without off-line storage, desktop computers, personal or hobby-type computers, microcomputers.

Advantages:

1. In selection and reduction process engineer solves only those elements ot a larger system he feels worth solution.

2. Relatively rapid turn around compared to submitting entire problem to larger computer system.

3. Once methodology and computer programming is established and tested, many considerations of design will be automatic and complete. Office standards will be established for all users.

4. Engineer may concentrate on data and engineering alternatives rather than on grinding out numerical portions of solutions.

Disadvantages:

1. Use of more complex equipment may require introduction of other persons with other skills into problem solving process to utilize equipment and methods.

2. Solution methods may vary for method of attack by engineer or of problem.

3. Cost of verification and update and processing may exceed cost of alternative methods unless used frequently.

4. Engineer may accept black box or printed page as infallible and introduce error potential.

Mode III: Complex Segment or Phase of Problem at One Time

Description: Engineer examines or solves his problem in a more global or a larger configuration to obtain the influence of many more subtle conflicting or indeterminate influences, or simply to handle many more elements at one time.

Examples: The solution of a complete building frame for multiple loading; the study of a watershed; the study of traffic in an interchange.

Equipment: Expanded personal or hobby-type microcomputer; minicomputers; midicomputers; main-frame computers

Advantages:

1. Solves one complete interdependent or interrelated problem in one effort.

2. Engineer concentrates on description of problem and appropriate application major engineering analysis considerations.

3. Design practices and procedures become standardized in office.

4. Engineer may acquire better understanding of relationships within solution and may more easily compare alternatives and solutions on common basis.

5. Solving large segment of problem at one time reduces chance of error in dividing and handling and combining many parts.

Disadvantages:

1. May include solution and information for many trivial portions of problem. Confusing and wasting effort to reduce to meaningful relationship.

2. May involve substantial learning process on part of engineer to acquire communication and understanding of methods and solution processes used.

3. May require substantial investment in preparation of procedures, personnel, programs, equipment and administrative techniques to provide this expertise.

4. Ease of usage may tempt alternative or extra solutions not economically justified by degree of improvement of solution.

5. Engineer interfacing with computer programmers, operations people, and others in chain of solution may delay turnover or introduce errors hard to detect.

Mode IV: Complete Systems Solutions

Description: Engineer may use several engineering or even cognate disciplines and a large data base for problem description and solution.

Examples: Entire building under many combination of loads; entire irrigation systems; entire highway network.

Equipment: Large midi-computer system; main-frame computer system

Advantages:

1. Simpler data preparation and manipulation since usually they are prepared only once.

2. Total solution at one time or under one system of preparation, handling and control further reduces error resulting from working on independently structured parts.

Disadvantages:

1. Complexity further removes engineer and his judgment from solution process.

2. Greatly increased preparatory and software and hardware costs.

Note to Table 2:

Although larger computer systems than those specified for the smaller configurations listed may be used, costs as well as complexity of data preparation and user instructions may preclude their use.

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