THE UNIVERSITY OF MICHIGAN

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS

in ENGINEERING DESIGN
in RESEARCH SCHEDULING
in INFORMATION RETRIEVAL
in PRODUCTION SCHEDULING

Transcript of the Seventh Ann Arbor
Industry-Education Symposium

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INTRODUCTION

The computer is already one of the most powerful tools available for advancing and applying scientific knowledge. It is of course impossible to predict what the future will bring, but there is no doubt that within a very few years the large majority of engineers will be capable of using computers for the analysis and solution of their more complex problems.

The purpose of the Seventh Industry-Education Symposium in Ann Arbor was to bring to our attention the ways in which computer applications are presently developing in four different areas, all important to engineers: in research, in design, in production control, and in information retrieval. The final presentation of the day described how the engineering students of today are being taught to use computers.

Several of the talks, and almost all of the discussion which followed, were taped and transcribed. Oral style was preserved intentionally. This book was prepared primarily for distribution to those who attended the symposium. Copies will not be available to the general public, so it will be appreciated very much if material herein is not referenced in formal publications. Thank you.

Raymond E Carroll

OPENING REMARKS

D. L. KATZ

Professor of Chemical and Metallurgical Engineering

Good morning ladies and gentlemen. We are very pleased to have you here this morning and I think the committee has arranged a very fine program for you. Dean Attwood is here with us this morning to bring us an official word of welcome. As you may know, Dean Attwood has spent most of his professional career at the University. In 1957 when the late Dean Brown became ill he became Acting Dean of the College of Engineering and in 1958 he became the Dean of the College. I am pleased to introduce to you Dean Attwood.

S. S. ATTWOOD

Dean of the College of Engineering

I want to take my moment or two here to extend to you the welcome of the University and of the College of Engineering to this Seventh Ann Arbor Industry - Education Symposium. Each year, as you know, we have arranged, Mr. Carroll has arranged, a general symposium designed to be of interest to all members of our Industry Program. This is in addition to more specialized meetings that are held for individual members of the program throughout the year. This Industry Program is very beneficial to us. We appreciate the assistance that many of the companies have given us in this program with their participation and their financial assistance and so on. But also we hope and feel that it is a two-way street. We have a good deal to give to you people too in the form of these symposia and publications and seminar lectures and such other things as we have to offer. So we like to think of it as a very effective and worthwhile two-way street. We appreciate your assistance both in coming and in supporting us. I would like to extend thanks on behalf of the College to the members of the planning committee who have done a lot of work to get this interesting program together today, and particularly I want to note the work that Mr. Carroll does in making the very careful arrangements and those of his assistants. And I ought to thank Professor Katz too, who will serve as chairman of this symposium. I am sure that you will have a very pleasant, informative, and useful day. Again, let me thank you all for coming and I hope you will enjoy your visit with us.

D. L. KATZ

Thank you, Dean Attwood. This program today on The Present and Possible Future Roles of Computers is of interest to you from industry, I am sure. But it is also of interest to us in the University. Here is one place where we can come together and share views and the program today, as you can see, is primarily from people in industry and so those of us who are on the faculty are going to be eagerly listening to learn of the things that we can from industry. Most of us have had an opportunity to look at the various aspects of the use of computers. Each day we find something new; we find a different way of using them -- and we are very anxious to learn as much as we can. In my associations with industry I find that this is one of the very important things in the management of companies; for the management people to understand, especially the intermediate management who are the folks who have direct contact with the folks who are using the computers for their work. You will see that we have a series of four talks from people who have a good understanding of the use of computers: in production scheduling, in research scheduling, in engineering design, and in information retrieval. The last speaker this afternoon will tell of some things that we are doing at the University in preparing students (in the various aspects of the use of computers) for industry. We will have a coffee break after the first lecture this morning and we will, at lunch time, have a bus to take us to the Michigan League. Following the afternoon series of papers we will have an informal get-together with coffee at the conclusion of the meeting. This morning we are going to start the program with the Role of Computers in Production Scheduling. We have with us a speaker who is well qualified to speak on this subject. He received his education from the University of Nebraska, The University of Pittsburgh, and M.I.T. He worked for the Westinghouse Research Laboratories before joining the RCA Company. We are pleased to have Mr. W. E. Bahls, Manager of the Advanced Automation Systems Development of the RCA Electron Tube Division from Harrison, New Jersey, with us this morning. Mr. Bahls.

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN PRODUCTION SCHEDULING

W. E. Bahls

Manager of the Advanced
Automation Systems Development
RCA Electron Tube Division
Harrison, New Jersey

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN PRODUCTION SCHEDULING

This title contains two key words, namely computers and production. Undoubtedly these words conjure up a picture in the minds of all present. But I am not too sure that we all see the same picture, and so let us talk about each of these words just a little bit. I am going to talk about production first.

Many different companies are represented here. I do not know them all but I am sure that the nature of the production systems vary widely. Without attempting to limit myself to the production systems you represent, however, let us enumerate a few possible classes. We might start with a continuous flow production system where we have a single raw material and break it down or "crack" it into many products such as, for example, oil refining and similar chemical processes. Another type of continuous flow system might be one in which the reverse processing situation applies, where we start with numerous materials which come together and by heat, pressure, and so forth, cause a synthesis or combination to produce a desired material. In another industry the flow of material might not be so obvious and well defined but may involve more discrete steps in processing such as, for example, the production and processing of steel. Instead of processing a given material through many steps we might have an alternate situation in which we have the flow or assemblage of many materials and parts along a prescribed production line or assembly line producing, for example, automobiles. Or we may consider a much more general and less defined type of assembly line upon which many different kinds of products may be assembled. One product may be produced for a period and sent to "stores" after which another product may be scheduled and produced. And finally we have an accumulation of rather general-purpose machines which may be used for a wide variety of purposes to produce a wide variety of products to special order. Such is the case in many job-shop production and assembly units.

We could go on looking for further dissimilarities and breaking production down into categories but it is not my purpose to look for dissimilarities. Rather I am looking for the similarities. What is there similar about all the processes that I have mentioned? In the very broad sense we are dealing with materials which flow or move as an input to some sort of a process, either assembly or conversion to provide an output in the form of a material or product. But as we view the various production systems we find that the materials are apt to vary widely, their mobility differs, the processes or production methods vary widely, both in purpose and character, and there are many very widely differing degrees of mechanization; but we note that they all have a similarity, namely, materials flowing to a process to be converted into some other material.

Now, what do we do with the materials that we produce? Well, obviously we want to sell them. We think that there is a demand for our product. We do not produce just for inventory. We want to produce a product that will appeal to our customers and we want to have the product ready at the time that they want to buy it. This, then, introduces another aspect of our business, namely; the requirements, the scheduling, and the controlling of the production system. We note here that we are dealing not with the actual making of the product, but rather information about the product and the production system, namely, what should flow through the system and what are the capabilities of the system.

This, of course, leads us to our second important word of our title, the word computer. Now, I am sure that when this title was suggested to me the individual had in mind those large electronic computers and probably more specifically digital computers. However, before discussing hardware for information processing I would like to go into a little more detail as to the requirements for information processing in connection with the production system, irrespective of whether this information or data is handled by people or by machines.

The various steps in information handling for planning and scheduling might be briefly listed as follows: first, we must forecast product requirements. These then must be broken down or exploded into their various components or material requirements. Along with these we have to introduce the associated factors of production time, and procurement lead times. In addition, of course, we have such items as machine availability, machine efficiency, manpower availability, and so forth. Now various assumptions are implicit in this matter of scheduling. These are: 1) that we know our product and process and that we have adequate data about the factors listed; 2) that these data may reasonably be assumed to hold for the future; 3) that adequate data about actual performance can be obtained quickly; and 4) that the data available and to be obtained can be manipulated at an adequate rate to match and control the flow of materials.

Now how have we actually handled our production planning and scheduling in the past? Historically, data and information are taken by people, are processed by people, and are communicated by people, either verbally or in writing. People do not vary greatly in the amount of information that they can handle or process in a given time. Although I have not personally gathered the statistics in this area a figure that is often quoted says that an average person can read in the order of 25 characters per second. Accordingly, organization structures have been set up in such a way as to provide a kind of balance between the producing part of the system and the planning and scheduling part of the system. Such a balance, however, is always short-lived in an area of rapid technological progress. And so for several decades we have seen rapid progress in the handling and processing of materials resulting in substantial reductions in the production or processing time. But it is fundamental in any control system that the information handling cycle, that is the planning and scheduling, must keep pace with the production system. And so we have seen that the white-collar functions have been broken into smaller and smaller sub-functions with more and more people added to handle smaller areas of responsibility in order to process necessary data in the time allotted.

But there is a limit to this type of thing. It introduces other problems. In the last decade particularly, we have heard much about the lack of broadly trained people and the communication problem. During this period however, there have been other forces at work which are of major importance. I refer, of course, to the mechanization of data handling starting with small aids such as typewriters, adding and calculating machines, and progressing into the punch-card, electronic accounting machines. These were, of course, substantial aids to speeding up and handling the large amounts of data. But they were just not enough to keep pace readily with production developments, even though the data processing speeds were up by several decimal orders of magnitude. And then came the stored program electronic data processors or the computers which are able to handle large amounts of data according to long logic sequences and at speeds another 2 to 4 or more decimal orders of magnitude faster than the EAM equipment.

These then were hailed as a solution to all our problems. And so we ask: "Have they been?" I think at this point that the only answer that can be given is, "No." Well, what has been done with them and why have they not accomplished all that they seem to promise? What can be expected in the future?

I have gone to some length to point out that our historical organization structures are set up to process information by means of people with the aid of some machines and that a fairly fine balance has been drawn between the information handling requirements and the processing requirements. But rather precipitously we introduce a new machine having much greater data handling capability than any of our old machines, but we try to introduce it into our present organization structure. And so we put our nice, big machine to work processing data in small steps fast and sending it back and forth to groups or functions that were only broken down this way originally because data could not be produced or processed fast.

The problem of analysing, planning, and developing new systems to really use our new tools, the computers, as they should be, requires a knowledge and understanding of systems engineering and business that is not readily found in most operating organizations today. Accordingly, we find various staff groups building up that are trying, not only to learn how things can be done more efficiently, but also to convince management of the new techniques. Progress is indeed slow. Practices of many years which have become gospel cannot be changed overnight. There is much analysing, testing, and then convincing, to show that there is a better way. However, progress is being made in various degrees in various areas by different companies and industries, depending to a large extent upon the degree of technology and scientific discipline prevailing within the companies.

I am going to classify the work that is being done into four major areas as follows: 1) more detailed product definition; 2) more detailed and specific process system definition; 3) improved instrumentation for data collection and for data transmission. (The physical data handling system); and 4) the development and modification of systems logic and decision rules introducing more scientific analysis, improved efficiency, directed at optimizing of product mix, improved dynamic stability of the production system, etc.

I would like to discuss each of the areas briefly, giving a few examples as illustrations.

Product Definition

Normally, I think that most manufacturers believe that their specifications are complete and adequate. Within the scope of the system in which they are operating they are undoubtedly adequate. Everything taken together, the people doing the procurement and assembly are able to keep production going. However, almost invariably there are those things that are implied which are known to people involved through experience which are not explicitly defined. In this category we might include such items as the use of alternate materials, special engineering tests, and many others. Now when we substitute computers for people we find that if we want to operate efficiently all such alternates must be either eliminated or logical decision rules defined as to when each of the various alternates may be applied. Not only must the machine file be built which contains all such necessary information but provision must be made for very formal and rapid updating for product specification changes. There is nothing quite as frustrating as running schedule explosions against standards that are out of date.

Process Definition

The statements just made for product apply equally well for process only probably more so. I should qualify that statement and say, "in the electron tube-making industry," but it undoubtedly applies in many others. Very often the detailed process interrelationships are only defined in a general way and actual operational yields are determined as a result of individual operator judgements.

Of course such a situation is completely inadequate for computer process control. Moreover it even presents problems from the standpoint of scheduling because of variations in appropriate yield data or production standards. The accumulation of up-to-date production standards for production scheduling by computer demands much more formalized routines with fast updating for files.

Instrumentation, Data Collection, and Data Transmission

And so we come to the instrumentation, data collection, and data transmission. In the two foregoing sections you may have noticed a constant repetition about accurate and current data. People are able to act on relatively poor and incomplete information because they also have stores of information from other sources and have ability to reason, judge, and correct and to get additional information if they deem it necessary. But the development of computer programs is far from such a state and therefore the need for accurate, timely data.

Now a large portion of data gathering in industry is by visual observation and manual recording. The conversion of such data to machine language and the transmission to processing centers has been one of the most costly and inadequate parts of computer systems. Moreover, there is much work going on to remedy this situation and in this area we may certainly expect that the progress in the next few years will be as spectacular as computer development has been up to now. The attempts in this field are many and varied but mention of a few may be in order.

One of the early devices in the field used in connection with production scheduling and control was the Stromberg "Transactor" for gathering data from various locations about a factory and transmitting it automatically to a central location for computer storage and processing. By combining a quantity of these with a disk-file data processor Hughes Aircraft at ElSegunda, California, has been able to set up a real time production and scheduling control system that practically eliminates the flow of paper work through the factory.

Librascope has a similar set-up in their "LOCS" system at Glendale, California. Lockheed is going even a step farther in setting up RCA "EDGE" data gathering equipment at locations hundreds of miles from each other and feeding them over telephone lines directly to an RCA 304 computer with disk-file storage.

As a final example I must mention the Westinghouse plan which will employ a completely computer-controlled on-line communication center for message and data transmission with data directly available to the computer.

Improved System Logic and Decision Rules

Actually we have already touched on these when we talked about product definition and process definition. We indicated that we had to look at our system in much greater detail than before and actually determine what was being done and then state it in some language or way so that the machine could act accordingly. When we get down to the detailed digging, looking into how people actually do things we come across this factor of decision making or judgement. Let me hasten to point out that I am using the word decision not in its specialized sense of statistical decision theory but rather in its very broad general sense of choice-between-alternatives. And so as we analyze the work done by some individual he says he does this and then this, and then comes to a point where he employs his judgement and decides to do that. And now we try to find the decision rule. What was really necessary to make this choice? Why did the individual act the way he did? Did he really do some master feat of anlysis or introduce some new technique? Was a mental brilliance required to accomplish the results obtained? Examination of many different functions by many different analysts has shown that, for a large percentage of cases, the decision rules used by individuals in their jobs are often very simple.

Then where does this factor of judgement come in? Well, what is really meant is that the individual, through experience and training, and other functions of the business, or maybe only in his present function had built up a store of knowledge and data which, with the current incoming data, he combines to make a simple, logical choice and probably to update his store of data. It then becomes obvious that when the file of data which the individual has learned or stored is available in the form of a machine language the decision can be reduced to a straightforward, logical choice program which can be performed by machine. And so we see again the importance of those factors: adequacy of data, availability of data, and timeliness of data. Now we might ask, are these simple decisions the "best" decisions that could be made for the company, or could other, more sophisticated decision rules serve the overall purpose better? Again let us reason from the specific case to a more general conclusion.

As companies have grown and organization functions have developed it has become more or less common practice to set up objectives for each function along with an expense budget and then judge performance by how well these rules were met. But it is well known that on this basis so-called good performance by one function may seriously affect and lead to poor performance by another function. Thus, for example, the sales function usually wants to maximize sales and therefore asks manufacturing to produce against optimistic forecasts so as to be sure to have low stock-outs. Manufacturing does not mind this but it would like to keep a fairly steady load or at least long runs so that its start up and learning costs are low and it has a favorable manufacturing variance. But now comes inventory control with overall inventory objectives and says: "No! No!, if you do that you will exceed my inventory objectives." How are these conflicting individual desires to suboptimize be reconciled? One of the most common methods prevalent in industry today is the meeting technique. On a regular basis the individuals involved all get together and by means of some logic, a lot of persausion, force of personality, and what-have-you, come to an amicable agreement between themselves.

Now operations researchers or management scientists say that there must be a better way. And so they set up a good hypothesis relative to business variables and objectives, express them as mathematical relations or equations, solve and come up with an economic order quantity rule balancing expected sales against procurement or production costs and inventory carrying costs. And so we have a nice, neat EOQ (Economic Order Quantity) decision rule which we can program for our computers (if we have the provision to gather the data to put in it), and with some confidence we sit back and say that this little degree of sophistication will pay off. At this point let me hasten to add that the use of mathematical techniques such as this do not necessarily need a computer for their implementation. Many production scheduling and control people have their charts, slide rules, nomographs and so forth based upon this type of mathematical model which they manipulate manually. However the converse is true, namely if we wish to computerize effectively we do need the mathematical model.

At this point everything appears to be very neat and straightforward so we might easily be caught with our guard down, because there is a joker in the deck. The mathematical model that we set up for our EOQ formula is a static model, but our business situation is dynamic. Usage is not at a constant rate but fluctuates. We usually reconcile the situation by forecasting future sales or usage based upon past sales or usage and smoothing the variations by some such technique as straight running averages or exponential smoothing. This then is used in our EOQ formula. Now what we are actually doing is forecasting the future state of our business system in accordance with some decision rule (or transition matrix) based only upon the past states of our business system. Mathematically speaking we have a Markoff process. Now it has been shown that under the conditions of varying usage our EOQ rule actually acts as an amplifier of the statistical variance giving a greater variance to mean ratio in the output. If we call the amplification factor ϕ and we have a system in which this process is repeated "n" times in series as is very common the total amplification will be ϕ^n . This can result in a very high variance to mean ratio and many of you probably have seen it in connection with military orders that go many steps down the line.

Now does this mean that our EOQ formula is no good? This is not the point which I wish to convey. In many cases it will be perfectly adequate. Actually the most practical model is the simplest one that represents real life adequately. But we must be careful not to use some established computational routine just because it has been formalized and is readily available when the real life situation demands a more accurate model.

When we get into the subject of mathematical models that are useful in production scheduling we open up such a Pandora's box that it is hard to know where to stop. We could talk about such techniques as linear programming, critical path scheduling, sequencing queing models, to name only a few. But further discussion would really not strengthen the point I am trying to make. It might only show how little I really know about them. And so although I have tried to break down or classify into four areas the kind of work now going on in the production planning and scheduling area, I have really only been successful in showing that it is all one problem of systems analysis and development with at least four major facets. And now it is time to summarize my thesis.

1. Computers are wonderful devices that can be told to do logical manipulations and calculations at rates millions of times faster than people.

2. At present business organization structures or systems are not set up to utilize such tools effectively but business generally does not recognize this and is trying to fit computers into present structures with only nominal success.

3. Computers must have much more adequate, accurate, and timely data than is presently generally available in order to be really effective.

4. Probably the best way to get this would be to have an on-line or real-time computer controlling mechanized data gathering and electronic transmission.

5. Such a job as described in 3 and 4 cannot be done piecemeal and still be effective. It requires a high degree of systems engineering knowledge to arrive at a business structure of people and hardware that is capable of functioning as a unit. This business of systems engineering function must take a place of equal importance with product engineering and the bits and pieces of associated activities such as industrial engineering, time and motion studies, manufacturing standards and so forth, that are often scattered around. Many different organization functions must be brought together into one function to produce a coherent design unit.

6. It is possible to mechanize or automate much of the production, planning, scheduling, and procurement routines with substantial prospects for dollar savings and more uniform performance using relatively simple logic and decision criteria.

7. Systems highly mechanized become easier to change because the personal aspects are not present.

8. Because of the uniformity and continuity of machines more and more sophisticated programs can be introduced with prospects for economic gain.

9. Care must be exercized to be sure that the model introduced is a reasonable representation of real life.

And so in conclusion, I believe that computers for production scheduling and control are here to stay, but that, in the vernacular, we have not seen anything yet. At this point let me hasten to add a footnote. The opinions herein presented are purely my own and do not necessarily reflect the policies of my company.

QUESTIONS AND ANSWERS

QUESTION: I would like to raise one question. In relation to the amplification effect of a series of events. Would you give a simple example of this?

BAHLS: I think an example might be orders from customers to let us say a distributor. The forecasting and such that he has to do must account for a certain amount of pipeline filling, as well as the bunching of orders, etc. The result is that he amplifies some of the variations that go on. In passing his orders on to the next stage the same thing happens, and the next, and the next stage with the result that you get quite large variations.

QUESTION: It is a fudge factor?

BAHLS: Yes, that is one way of looking at it, as a fudge factor or uncertainty factor. It is this indeterminacy for which he has to make allowance. We have examples in such work as J. W. Forrester's work in industrial dynamics where he illustrates the type of oscillation build up that you get from such variations. The mathematics of this type of solution for the EOQ work was recently done and is not yet published by Herbert P. Galliher, M.I.T.

QUESTION: I would like to ask, how much benefit comes from the studying of your production and of your products as compared to the other. I find sometimes that the preparatory work one goes through in order to communicate with a computer gives one a better understanding of the total picture. Would you speak to that?

BAHLS: Yes, undoubtedly substantial gains can be made just from systems analysis studies and many reports to that effect have been made. This is probably merely stating that as the change in mechanization of material flow has gone on, the question of matching the information control cycle has not been perfect, and even a review of the control loop can show improvements that can be made. Very often, however, this is not the real gain that can be made with computer usage because we find that the time cycle of the information flow loop has not been substantially speeded up in many cases and if the material flow demands a faster control-flow loop it will be there somehow or other bypassing the computer control. We find that there are always these manual expediting flow decisions that are made even in the computer systems. This is just a recognition that we have not analyzed the control factor that is needed because we have our information flows through the computer system out of phase or lagging to such a degree that it cannot control and therefore we have to have the other part of the system. I do not mean to say that gains cannot be made by the study itself but I do contend that we do not nearly take advantage of the gains that are possible if we do not go through all the rest of the systems engineering of matching the rest of the flow cycle to the actual control requirements.

YORK: Do we have some more questions, comments? Would you identify yourself please?

QUESTION: I am Robert Cruzak from Chrysler Defense Engineering. I would like to ask how much of your operation is controlled similar to the way you described? Is every operation controlled by means of a computer or just partially or are you in the process of just initiating this control?

BAHLS: We are as human as the next company. And obviously I must say no, we do not have everything controlled that way. We are planning and taking things loop by loop, trying to build this type of control philosophy and I spend a good bit of time trying to initiate and doctrinate and convince people that this is what should be done. We have employed the procedure and are rapidly extending it at the present time, but it is far from perfect. I believe that it is always going to be far from perfect because as fast as we get one thing done we are going to find material mechanization flow improved. We have new matching processes and so this is going to be one of those continuing types of things.

QUESTION: What type of display do you use to convince your top management that this is a good system? It is difficult for the top management to understand the computer output. It is just a bunch of meaningless numbers to them. And you have to convert it to say it in English.

BAHLS: Truer words were never spoken. That would be a rather lengthy story to try to tell. I try to employ the best concepts of information and communication theory by reshuffling and structuring my presentation to the store of knowledge and the words that the people that I am speaking to understand. So very often I get into some very simple charts and building blocks but I continually try to introduce new words. If I do, I try to define them and show by simple diagrams and block-diagrams and logic-flow diagrams what I am trying to do and to be reasonably logical in what I am stating. Now many things do not get sold on logic because it is hard to convince people on logic. That is not necessarily the thing they want to hear. And so you use every technique possible such as going out and speaking at other symposia and have feedback.

QUESTION: To what extent are there schools for managers to understand this? Are there a fairly good number of schools of this kind available to people who come in or does your own organization do this? This is something that I see the need for in industry. People are asking how can their managers learn these things. They are a little suspicious. They tell me that they are not sure that the computer people are always telling them the right story but they do not know enough to know whether it is right or not.

BAHLS: This is so true. It is like going to the doctor, is it not? Well, I think many schools are trying to do something in this area, and their business colleges, and I believe that this school is not any exception in that respect. I have been working with a number of schools on what should be the business education curricula for the future and I am cognizant of the fact that there is a great recognition of the possible change in education for business managers and, of course, as business managers get a broader technical training and understand their system concepts and how business is a coupled system and how it can behave, they will be in a better position to make decisions along this line and so it is one of those things that is going to have to build very gradually. I believe that with the tools that are available and the things that are being done it is not going to take very many actual illustrations of hardware systems before people begin to realize that, well, maybe they should be on the bandwagon.

QUESTION: There are probably a number of schools that the manager could go to in order to learn, but how do you get him to go there? I was thinking as well of the programs that are brought to the industry where he is on the job, where he cannot get away, so to speak. How much of this is being done, of having a one-, or a two-day, or a three-day workshop to give them some view?

BAHLS: Well, I really am not qualified to know how much is being done because I would be one of those small samples which would be subject to quite a wide variance but I do know from my contacts that a lot of people in the areas of operations research, management science, and computers are trying to hold meetings and symposia and get their management groups there. I think that there is this natural thing of which John Glenn spoke, the fear of the unknown, and it does take time to get this indoctrination across until people realize that it is not so complicated and some of the fears subside.

YORK: Other questions or comments?

QUESTION: Let me ask one in this same area. We have talked to you of the managers and the middle-managers. Would you care to comment from your experience as to what the relative aggressiveness in this area is between those two groups? This is a thing to measure the future because our next managers are going to come from the middle man.

BAHLS: Well, I will comment. I believe that probably the greatest area of difficulty is in the middle-management area. Although the operating people are affected very often at the clerical and performance level, many of the so-called middle-management functions have been built up because we have broken down our structure into such small units and have accordingly set up so-called managerial positions which are really supervisory positions, the supervising of people functions. If my thesis is correct, and computers are used to bring many of these functions together because they can be effectively done, some of these middle management supervisory positions are going to go. This, then produces fear and here is one of the problems. Now the obvious thing for the middle manager group to do is to learn about the new techniques. This is not always his reaction, however. Is that an adequate answer, with not too much equivocation?

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN RESEARCH SCHEDULING

William A. Gray

Mathematician
Union Carbide Company
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THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN RESEARCH SCHEDULING

My objective is to outline a resource leveling package and a method of scheduling a large number of parallel research and development projects. In attaining a complete schedule for such projects, the accuracy, memory, and speed of a large binary computer may be utilized. Hence, when I use the word "program," I am referring to the computer program which was developed for leveling and scheduling parallel projects.

Also, when I use the term "arrow diagram," I mean a figure in which each job in a project is represented by an arrow with the arrows joined to show the relationship which each job has with other jobs in the project. The arrow diagram shows the flow of a project.

In determining the relationship which each job has with other jobs in a project, it is necessary to know:

1. What job or jobs must be completed before this job may start?

2. What job or jobs may be worked on concurrently with this job?

3. What job or jobs cannot start until this job is completed?

With a job list and following these three rules, a project's arrow diagram can be constructed.

In assigning resources to each job, both manpower and equipment should be considered. If no equipment restrictions exist, the consideration should be given to manpower requirements. An example of an equipment restriction would be a crane. A crane may be required on a number of jobs and only one is available. Each job which requires a crane should have a crane allocated as one of its resources.

The resource assignment is based on the assumption that the resources assigned to a job will be used throughout the duration of the job.

One major problem in scheduling a research project is to reduce excessively high resource peaks. In general, great variation in a project's manpower pool will involve many problems and additional costs. Low utilization of equipment may also increase costs. In many circumstances, the use of a particular manpower craft or item of machinery may require the user to pay a minimum charge. Under circumstances such as these, it is desirable that management obtain a schedule which makes use of the resources available.

The objective of the resource-leveling feature of the program is to furnish a schedule with the resources used at any time as close as possible to the limits specified for that time, without exceeding those limits. This is accomplished by shifting certain jobs to later start times. The arrow diagram will have the same flow with various jobs delayed.

RESOURCE LEVELING

Each resource which is to be leveled must have an associated resource curve which limits the use of this resource throughout the project. These resource curves are step functions which bound the respective resources from above.

The program will fit the calculated resource curves as close as possible to the required resource curves, without exceeding the limits and without changing the sequencing of project arrows.

The leveling program is a stepping procedure. It is comprised of a series of time steps starting at time zero and continuing until the resources are leveled.

Let S_i, $i = 1, n$ be the sequence of merged Early Start Times (EST) and Early Finish Times (EFT) for a project P. This is a monotonic strictly increasing sequence where $S_1 = 0$ and S_n is the project's duration. The original sequence is obtained from the initial Early Start Times and Early Finish Times.

The first time interval considered is the interval bounded by S_1 and S_2. All jobs in a project with an $EST < S_2$ and $EFT > S_1$ are determined. These are the jobs in process during the interval. For each of the M jobs in progress a priority parameter, y, is calculated.

For $k = 1, M$

(1) $y_k = 0$ if $TF_k = 0$

(2) $y_k = TF_k - (S_2 - EST_k) + C$ if $TF_k \neq 0$

The constant C, at present set to 10,000 by the program, is used to make all y's defined by (2) positive. C does not change the algebraic order of the y's defined by (2) with respect to each other but it causes all y's defined by (2) to be greater than those defined by (1). The M jobs are sorted in ascending order on y. The jobs which are to be delayed are determined by comparing the RS (resource sums) with the RLF (resource limit functions).

This is done in the following way:

SET: $RS_j = 0$ $j = 1, q$ (q = number of resources in
SET: $k = 1$ project)

(a) Increment RS_j by R_{ik} where R_{ik} is the amount of the i resource of the k job, and RS_j is the sum associated with the i resource, i ranges over all resources associated with job k.

If $RS_j > RLF_j$ for any $j = 1, q$ job k is delayed to the end of the time interval being leveled. Restore the RS_j values to what they contained before the k job was checked by decrementing RS_j by R_{ik}. Go to step (b).

If $RS_j < RLF_j$ for all $j = 1, q$, job k is accepted as one of the jobs to be worked on during the time interval. Go to step (b).

(b) If $k < M$ increment k by 1 and go to step (a).

If $k = M$ all the jobs in the time interval being leveled have been considered. If any jobs were delayed, the EST and EFT from time S_2 on to the end of the project are recalculated and a new time sequence T_i is determined in the same manner the sequence S_i was determined.

The new time interval will be bounded below by $T_2 = S_2$ and above by T_3, where T_3 may or may not be equal to S_3.

The jobs which are in progress during the time interval T_2, T_3, are determined and the above procedure is repeated with one exception. There is a feature which allows the first $N (N < 25)$ jobs assigned to time step S_1, S_2 to have first priority in time step T_2, T_3. The y value assigned to these jobs, if they are not completed during the previous time step, is 0. The y value assigned to new jobs which are critical in time step T_2, T_3 is 1. Thus a maximum of 24 jobs from the previous time step may have priority over critical jobs in the following time step. If this feature is not used then the procedure for time step T_2, T_3, is the same as in time step S_1, S_2. The above procedures are repeated until the resources are leveled.

The feature allowing jobs from the previous time step to have first priority in the next time step is very useful.

It is possible for a job to be accepted for an interval i and then be rejected for interval i + 1 resulting in the start of the job being delayed until interval i + 2 or later and also in non-optimum leveling for interval i. The use of the priority feature prevents this from happening to the first N jobs of each time interval. Leveling is an empirical procedure, and it is expected that a "cut and try" approach will be used by the schedule.

The best results have been obtained by holding from four to eight jobs from one time step to the next.

Since the leveling feature does not allow the resource sums to exceed the resource limits, the leveled version of the arrow diagram may depend on how suited a resource limit may be in relation to the resource assignment. As an example, most jobs in a project involving a resource may have 10 units of the resource allocated to the job. To assign a limit of 18 to the resource would not be practical since the resource sum for a time interval would probably be a multiple of 10. It would be better to assign a limit of 10 or 20.

PARALLEL SCHEDULING

Let us assume that we wish to schedule a department which has a continually changing work load. The work load varies because new projects are being received, old projects are being completed and projects are being cancelled. Also, the projects may be independent but they become dependent as a result of competing for manpower allocations. Hence, a manpower leveling package is necessary.

The program is designed for departments which consist of a number of independent sections. As an example, a department may consist of sections such as engineering section A, engineering section B, engineering section C, engineering section D and engineering section E. Each section may consist of a number of sub-sections.

As an example, the section A could consist of a sub-section of engineers and a sub-section of draftsmen. The computer program is designed to schedule departments which consist of no more than twenty sub-sections.

When a new project is received by the department then the following procedures could be followed in scheduling the project.

The department supervisor evaluates the project and a coordinator is assigned to coordinate the project. The evaluation of a project consists of determining what sections in the department will participate in the project. Each section will then analyze their part of the project and determine how the sub-sections will function in doing the work assigned to the section. In addition, each section determines which phases of the project must be completed or can run concurrent with their phase of the project. It may be that a section will be required to work on their phase of the work at different periods during the project's completion time. As an example, a project may require work to be done by the engineering sections A, B, and C. The flow of the project will first require work by engineering section A, followed by section B and section C working concurrently. After sections B and C are completed, section A will complete the project. When each responsible section has evaluated their phase of the project, the coordinator constructs an arrow diagram of the project. Each arrow in the diagram represents a job which is a phase of the project which is assigned to a section or sub-section group. Associated with each arrow are the man days or hours required to do the job and the rate of work on some unit basis. Also, the information necessary to show the relationships which a job has with other jobs in the project and the alphabetic and/or numerical description of the arrow is determined. For each project the coordinator, work request and project identification is part of the necessary information.

The project is then reviewed by the department supervision and is approved or changes are made in the arrow diagram and the associated information. At the same time the department head assigns the project a priority number which designates the importance of the project relative to other projects assigned to the department.

The program will evaluate the new project relative to the current projects in the department and ascertain the project schedule. When evaluating a new project, the program considers the project's priority, the project's arrow diagram structure, float times and manpower availability. Also consideration is given to factors such as vacation, holiday week, cushion, transfer of manpower and delay conditions.

It is possible to add new projects to the system with a delay restriction. In other words, the project will be taken into consideration and scheduled after a fixed date. This delay may be due to outside factors which influence the start date of the project.

It is possible to transfer personnel within the department and keep a record of such transfers. As an example, the section A may have an overload of work which may have an effect on the schedule of other sections in the department and section D may have a light work load for a number of weeks. If the available personnel in section D were capable of performing work in section A, then a loan or transfer of personnel could take place for X weeks. At the end of X weeks, the personnel would automatically be returned to section D.

Also, it is necessary to consider the vacations for each group in determining the schedule. The program is designed to consider the vacation schedule for the entire department. This points out the impact that vacations play in determining the start and completion dates of a project.

Also, the scheduled holidays are taken into consideration in calculating the schedule. In considering scheduled holidays, the program is designed to reduce the rate of work on each job during a holiday week by a certain percentage. In other words, if a job was assigned manpower at the rate of ten man days per week, then during a holiday week the rate could become eight man days per week.

Factors such as these discussed above are very important in obtaining a realistic schedule.

The type A output shows the vacations scheduled for each sub-section, future changes in total manpower and cushion changes.

The type B output is a list of all projects in the department. For each project, the type B output shows the projects priority number, work order number, coordinator and identification. This output is very important to management in assigning priority numbers and knowing what projects make up the department's work load.

The type C output shows a list of all jobs which received manpower allocations for the given week. The type C output for each job shows the priority number, work order number, coordinator, the job's arrow diagram numbers, identification, estimated units of work to do the job, units of work remaining, resource group responsible for the job, rate of work and the number of manpower units assigned to the job for the given week. The type C output is a record of every job in the department which received resource assignments and the units of resources assigned to the jobs for the given week.

The type D output is designed for the coordinator. Each coordinator in the department receives a list of all the jobs and their associated information, for which the coordinator is directly responsible. In addition, the list shows all jobs which could have received manpower assignments if the manpower had been available. Thus, if a job is completed ahead of schedule then the type D output shows what job or jobs should receive the available manpower.

The type E output is designed for the section leaders. This output contains the same information as the type D output except that it is grouped by sections. Another type of output shows the complete information about each project in the department.

In other words, the arrow diagram structure is shown and the associated date about each job. In addition, the actual start and completion dates of each job is given; hence, the project's starting date and finish date is printed. This output answers many of the everyday questions which pass through the department.

The last type of output shows the workload summary for the department. For each section, the output list shows the manpower available, manpower loans, holiday quantities, vacation allowance, cushion factors, net manpower available, manpower scheduled, percentage scheduled and which weeks are involved. This output is listed for X weeks in the future and shows the overall picture of what is taking place in the department and forms the basis for decisions by management.

A very important part of the system is the procedures necessary to keep the schedule up to date. The section of the program which is designed to handle this feature allows the department being scheduled to have great flexibility in keeping the schedule up to date.

The information changes or additions which a department may wish to make are:

1. changes in any information about any job in a project,
2. adding or deleting jobs for any project in the system,
3. changing the total manpower available in any section in the department,
4. changing the coding symbols for a section or subsection in the department,
5. changing from a five-day week to a six-day week,
6. switching priority numbers on projects,
7. deleting projects from the schedule,
8. adding projects to the schedule,
9. add or delete manpower loans, vacations and holiday.

The coordinator must be able to perform operations such as those listed above very fast and efficiently if the scheduling system is to function properly.

The primary objective of the Multi-Project Scheduling method is to allow management to answer questions such as:

1. What projects make up the department work load?
2. What is the status of each project?
3. What is the present and predicted work load of the department, sections and sub-sections?
4. How will the department's schedule be influenced if a project is cancelled?
5. How will the department schedule be influenced if a project is added to the schedule?
6. How will the department schedule be influenced if a particular project receives a crash priority?
7. What is the predicted start and completion date of a new project if it is added to the schedule?

8. What is the predicted completion date of each project in the department?

9. What is the predicted start and completion date of any job in any project?

The answers to such questions are almost impossible under present methods of scheduling. By applying advanced scheduling techniques, such questions can be answered swiftly and accurately.

This gives a broad and very general outline of some of the features which are available in the above program.

In contrast to the conventional methods, many problems are solved and many questions answered readily under this system of scheduling.

Donald L. Katz:

Well, if we may come to order again please, we are going on to the first paper which is listed for this afternoon. We are going to look at engineering design. This comes a little closer to the sort of work which the students and the faculty at the University are looking at because we do teach our students some of the beginnings of engineering design. We are privileged to have with us a person who is working with and servicing groups in this area, Mr. Donald E. Hart. He comes from New York State, took his master's and bachelor's degree in electrical engineering at Rensselaer Polytechnic and he has been with General Motors since 1950. He is head of the Data Processing Department at General Motors Research Laboratories. We are pleased to have Don Hart with us; he will speak on The Future Role of Computers in Engineering Design.

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN ENGINEERING DESIGN

D. E. Hart

Head, Data Processing Department
GM Research Laboratories

THE PRESENT AND POSSIBLE FUTURE ROLES OF COMPUTERS IN ENGINEERING DESIGN

Engineers are now using digital computers for all kinds of calculations, related to all kinds of problems, and they are doing this on all shapes and sizes of computers. The problems that engineers are solving on computers range from simple mathematical formula evaluation at one extreme all the way to the study of complex systems such as automobiles and missiles at the other extreme. Now I've planned to describe briefly the various types of engineering calculations. I am sure that you are all aware of the various kinds of things that computers are used for. I will dwell at considerably more length on the impact of computers on the over-all engineering design process. In terms of types of problems, at one end, as I have indicated, we have formula evaluation such as table preparation, where we want to determine and tabulate relationships between some number of variables, usually as reference for the engineer at some future time. These are very small calculations. Included also at this relatively small end are things like data reduction where we want to reduce test data to some standard form and place it in meaningful terms which the engineer can understand. There are also a vast array of what might be called component design calculations. This is a natural place to start using a computer, of course. Usually for component design the design procedure is fairly well defined. It involves a combination of mathematics and the use of empirical relationships which may be in the form of tables and curves. These procedures maybe have already been carried out and are being carried out by hand. The computer simply provides a faster and more accurate way of doing the same thing. Examples of this are some types of spring design, gear design, design of solenoids, etc.

However, components usually cannot be designed out of context. The component is being designed as part of a system where a system is an assemblage of interrelated and interconnected components. The problem of the system designer is to attempt to predict how the system will perform -- how it will behave -- when a specific set of components are put together.

I would like to review with you the classical design process. Figure 1 is oversimplified, but assume an engineer has the problem of designing a new system to perform some function. He goes through a preliminary design process which includes making some sketches and some hand calculations, searching the literature, component testing, discussions with associates, etc.

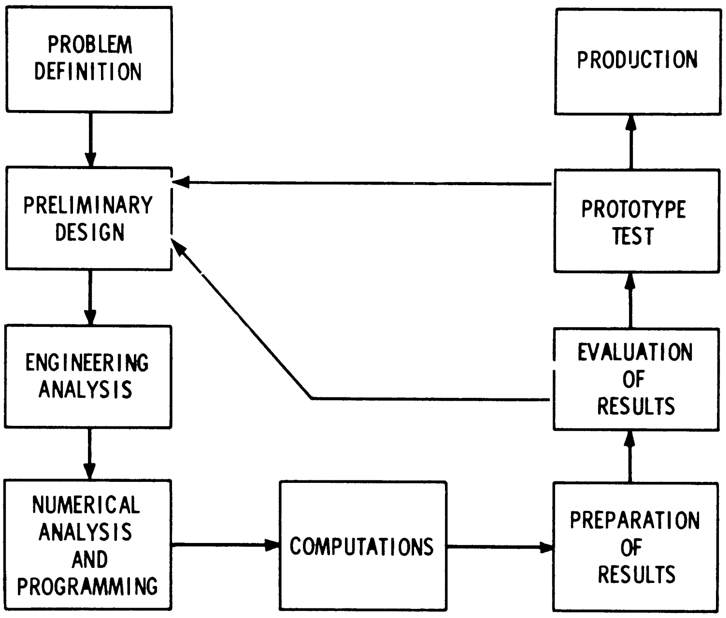


Figure 1

Before computers were available he usually couldn't follow the computational route so he spent a good deal of time in this preliminary design area because the only means he had for evaluating how the system was going to perform was to build one and try it. The process was to go from preliminary design to the construction of a prototype, test it on the basis of this, modify the design, and back and forth through this process until the design had finally reached the point where it was successful or proven to be poor and therefore abandoned. This build-and-test process is both time consuming and expensive. Computers fortunately became available and eliminated the bottlenecks which have previously existed in performing an analytical approach to the study of systems -- namely the computations themselves. Engineers for a long time have been taught in school how to formulate problems, to describe their problems in mathematical form. Unfortunately what you learn in school is how to carry out analytical calculations, and most of the real world is nonlinear and does not take well to analytic solutions. Numerical solutions are required. By hand, these become onerous, time-consuming or impossible. Computers eliminated this bottleneck -- the actual carrying out of the numerical computations. This created for us a new bottleneck which is called programming. This involves taking the problem description and converting it into a language which the computer can understand.

I would like to just quickly go through a series of slides showing the levels of language which are used for communicating with a computer. In Figure 2 we have the kind of language that a binary computer understands. Here are strings of binary ones and zeroes in which each line of information represents one computer word or one computer instruction. The first instruction says, "take a number from this memory location and clear out the contents of the accumulator and put the number in there." The second instruction says, "take another number from this location and add it to the first one," and the third instruction says, "take the number in the accumulator and put it back in the memory at the location." This is obviously a ridiculous way for human beings to have to describe how to solve a problem and if this were the only method that was available computers would not be used very much. Fortunately, we have gone through an evolutionary process of improving the language by which people can communicate with machines.

MACHINE LANGUAGE

```
0 0 0 1 0 1 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0
0 0 0 1 0 0 0 0 0 0 0 0 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 1
0 0 0 1 1 0 0 0 0 0 0 1 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0
```

Figure 2

SYMBOLIC LANGUAGE

```
CLA     TEMP

ADD      C1

STO     TEMP1
```

Figure 3

In Figure 3 we have the next step in the process which poses this same set of instructions in a mnemonic form which people could more readily learn and which involved writing down fewer symbols. CLA says "clear and add" a variable called temperature, then ADD to it a correction constant C-1, and STOre the results back in memory; this is now a corrected temperature. This begins to look like something the people could understand and work with. It still involves a great amount of detail and you notice that in this particular example there is a one-to-one correspondence between instructions that the human being can understand and instructions in binary form which the computer hardware can cope with.

Figure 4 shows the development of Fortran; it stands for formula translation. This was developed by IBM and it has been widely exploited by their customers. Now we can write down an algebraic expression. We can write down TEMP1 = TEMP + C1 and there is a computer program which translates from this into the ones and zeroes so that the computer hardware is able to carry out these operations. This is close enough to algebra so that engineers can learn this type of a language and use it for describing procedures for solving their problem and get answers on the computer in a reasonable length of time.

FORTRAN LANGUAGE

```
TEMP1 = TEMP + C1
```

Figure 4

Referring again to Figure 1, there has been a good deal of work in this area of improvement of the programming process, including the development of an increasing number of general-purpose subroutines. We don't have to worry any more about how to take square roots or do sines or cosines and we have black-box routines which will solve simultaneous equations and solve differential equations. These are reasonably foolproof, and can be plugged in as a part of a larger problem. Again we have shortened the programming time by building up a backlog of things that we already know how to do and incorporating them into our programs.

At the other end, in the area preparation of results, the engineer is not particularly accustomed to looking at columns of numbers and making decisions. Plotting devices are now available, both electromechanical devices and cathode-ray tube plotters, which will produce the output of the computation in the form of wiggley lines on a sheet of paper which the engineer can more readily understand.

There have also developed, during this period, things which we might refer to as general purpose programs. A procedure has been developed which solves this kind of problem. An example of this is gear design. This is a design procedure which has settled down to the point where the engineering analysis and the programming has been done in a general form, and to use this computation procedure it is only necessary for the engineer to fill out a data sheet and send it to key punch and thence to the computer to get the calculations performed. He begins to lose sight of the computations that are done. All he knows is that if he fills out the data sheet in the form prescribed he gets back answers which are correct and which are meaningful in the gear design area.

There are a number of these stereotyped procedures which have been mechanized in the form of general-purpose routines. These include, in addition to gear design, the design of solenoids, some motor and generator design, spring design, a number of design procedures in the gas turbine area, and so on. Now one comment I would like to make, which I will reiterate a couple of times, is that all of the techniques which are talked about, with the possible exception of the so-called general-purpose routines, are procedure oriented. What it is necessary to do is to describe in complete detail the procedure that the machine will use in order to solve a particular problem. What the engineer would really like, of course, is to be able to work in the language of his own field. We now have an engineer who has specialized in a particular field of engineering. In order to use a computer, at the present time we force him to become somewhat of a specialist in the computer field. What he would like to do is to be able to describe his problem in the language of his field and have the computer understand this language. In other words, what we would like is to make computers into people-experts instead of making people into computer-experts.

This means that we would like to go through the preliminary design area and at this time we have in a sense a description of the problem in the language of the engineer. Everything that is done following the analytical route over to evaluation of results is a process of describing the mathematics of the problem, converting a physical problem into a mathematical problem - and developing a procedure for solving the problem so that you can get some results. All the engineer is really interested in is the results, so it would be nice if we could simply short-cut this process and go directly from the design area to the results for evaluation. The obvious advantages, if we can do this, are that it again eliminates time and cost to get answers to computations. This also makes the analytical approach to problem solving even more attractive than it is now. Now obviously I would not be talking about this if we had not done something in this area. I would like to describe a system (Figure 5) which we have developed which enables us to perform this short-cutting type of operation. This system is called Dyana and it is preceded by GMR - which is a little plug for General Motors Research. Dyana is another one of these acronyms which stands for Dynamics Analyzer. It is a programming system which was developed for the solution of a class of dynamics problems and the technique which we use here can best be described by an example.

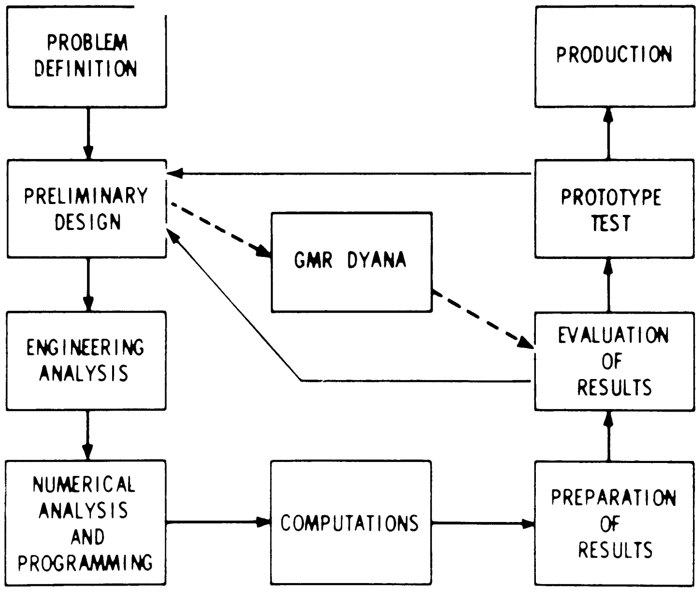
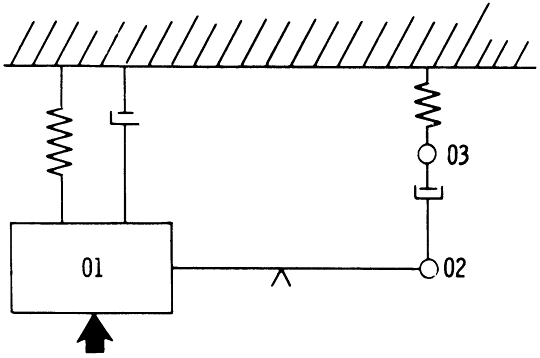


Figure 5

In Figure 6 we have a simple spring-mass-damper system. We have a ground reference, a spring and a damper connected to a mass labeled No. 1, a lever connecting that to point 2, another damper and another spring connected back to ground, and a forcing function acting on the mass. The classical approach to the solution of a problem of this sort is to write the differential equations which describe this system. Then, since analytical solutions are normally not so easy, or may even be impossible, a numerical solution is called for, requiring the use of a differential equation solving sub-routine and also the development of the surrounding programs (in FORTRAN) in order to use this subroutine and to get information into the computer and back out. Our approach here was to get the computer to do all of this for us. So we wanted to develop first a means by which we could describe this free body diagram in a form that the computer could understand, and we used the following scheme. We first put in a header card which says that that which follows will be the SYSTEM DESCRIPTION. We follow this by a series of phrases. Now we have said that there is an element K, which is a spring which is connected between points zero and one.

SCHEMATIC OF SYSTEM



DYANA REPRESENTATION

```
X    SYSTEM DESCRIPTION
         E00K01, E00C01, E00M01. E01N02,
         E02C03, E03K00, EF01
X    FORCE, EF01
         EF01 = 650.2*SINF (3.1415*TIME)
X    PLOT ANSWERS
         X01, DX02, DDX03, VS. TIME
```

Figure 6

Similarly, there is another element which is the damper, C, connected between points zero and one. There is a mass at point one. There is a lever, and we use the symbol N to designate the lever connecting points one and two. There is another damper between points two and three. There is another spring between points three and zero and there is a forcing function acting on point one. This then is a means of describing the structure of the free body diagram.

We also add to this the ability to describe algebraically any additional characteristics in the system. One of these is the character of the forcing function, and by means of another header card, we say that we now are going to describe the force, EF01 and we write down an equation which is now in the Fortran form, EF01 = 650.2 x sin (3.1415 x TIME). If there were other nonlinear elements in the system, nonlinear springs or dampers, we could describe their characteristics in a similar manner. We also indicate the answers which we want to see. We want to plot the following answers. We want the displacement, x, of point one, the velocity, dx, of point two and acceleration, ddx, of point three plotted versus time. This is a complete problem description. We have now described with this series of statements the structure of our problem, the algebraic character of any things which are nonlinear, and the type of answers we want to see. In the length of time that you have watched me I have programmed this problem for the computer. Now let us see what the computer does with it.

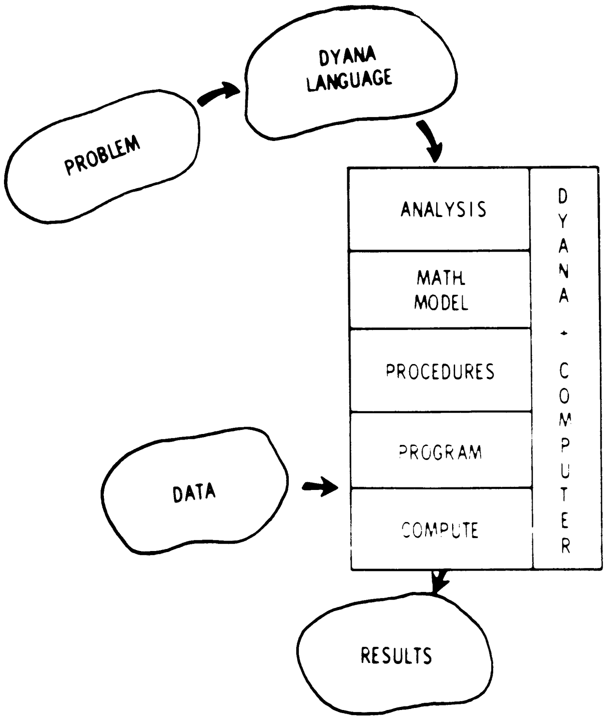


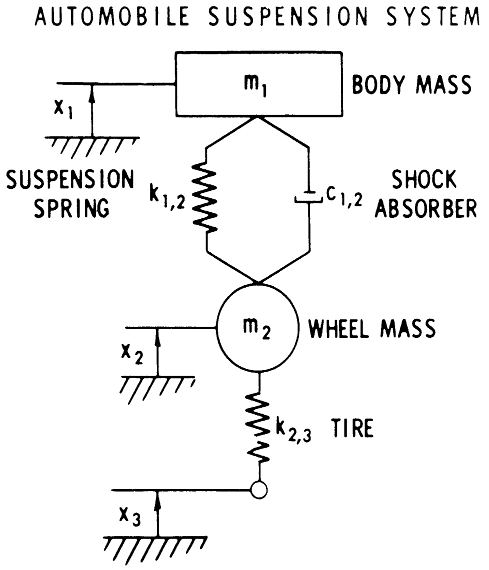
Figure 7

We started out with the problem and we described this problem in the Dyana language. Our present computer plus the Dyana processor, which is a computer program, does the following things. It inspects the information which describes the structure of the problem and performs the necessary analysis to prepare a mathematical model. In effect the computer writes the differential equations which describe the motions of the system. It then develops the procedures for the solution of these differential equations and produces as its output a computer program which is capable of solving individual numerical examples of that problem. So it has accepted a problem statement and has programmed itself, so to speak, to solve that problem. It also produces as output a data sheet which tells what data this program requires and in what form it requires it. This includes not only the values of the spring constants, damping factors, and masses but also what initial conditions are required to start the solution.

If we now prepare data for a specific example of the problem that we want to solve with numerical values of the mass, the spring constants, the damping factors, etc. and feed it back to the computer, the computer carries out the computations called for and produces the results in graphical form. I have a couple of examples which will illustrate this in just a little more detail. There is one point I would like to make, however, I commented before that in using a computer to solve a problem in a language such as Fortran it is necessary to describe in complete detail the procedure that the computer will use to solve the problem. In the case of Dyana we simply described to the computer what the problem was. We told it the form of the problem -- the computer then figured out how to solve the problem and did the necessary programming in order to solve the problem. We did not prescribe the procedure for problem solution. We only described what the problem was.

In Figure 8 we have an example of a somewhat simplified automobile suspension system which includes the ground, which is a displacement forcing function, a tire spring, a wheel mass, a suspension spring, a shock absorber, and a body mass. In this example we assumed that the spring and the shock absorber were linear. This is not necessary but it keeps me from talking quite so long. The forcing function, $x3$, is shown in the figure. It is a half a cosine wave between 0 and ℓ. Outside of this range the displacement is 0.

Figure 9 gives us the Dyana description of that problem which starts out again with a system description of the masses, springs, and dampers which are connected. We now have two displacement equations which are the Fortran equivalents of the equations on the previous side. The Range Functions are simply a mechanism for describing the inequalities which were used on the previous figure. Similar methods can be used to describe nonlinearities or discontinuities in the system.



CONSTRAINTS

$$x_3 = A\left(1-\cos\frac{2\pi v t}{\ell}\right); \quad 0 \le \text{dist} \le \ell$$
$$= 0 \qquad \ell < \text{dist}$$

Figure 8

DYANA REPRESENTATION

X SYSTEM DESCRIPTION
E00M01, E01K02, E01C02, E00M02, E02K03, EX03

X DISPLACEMENT, EX03, RFN(1)
EX03 = A (1.0 - COSF (6.28 * V * TIME/L))

X DISPLACEMENT, EX03, RFN(2)
EX03 = 0.0

X RANGE FUNCTIONS
DIST = V * TIME
RFN(1) = L-DIST
RFN(2) = DIST-L

X INPUT VARIABLES
A, V, L

X PLOT ANSWERS
EX03, X02, VS. DIST

Figure 9

There are certain variables that we want to have as parameters at the time we carry out a specific solution. These are the A, the V, and the L which appear in the previous expressions. We want to plot the following answers. We want to plot the displacement, EX03, and the displacement of point 2 versus distance.

Having gone through this two-phase process, first feeding the series of expressions to the computer, getting back a program and feeding a specific set of data to that program, namely that A = 3 inches, L = 4.4 feet, and V = 30 mph, we got back the following plotted answers which are EX03 and X02 plotted versus distance, properly scaled and labeled. (Figure 10) All the information which you see on this plot was produced on the cathode-ray tube plotter on the 704 computer including labeling the graph and properly keying which of those curves is X02.

The engineer who required a solution for a specific problem essentially had to know nothing about a computer. The only piece of computer information that was necessary for him to feed in at the time that he gave the data to this particular program was the increment which must be used for the numerical solution of the differential equations and how many points he wanted to use in plotting the answers.

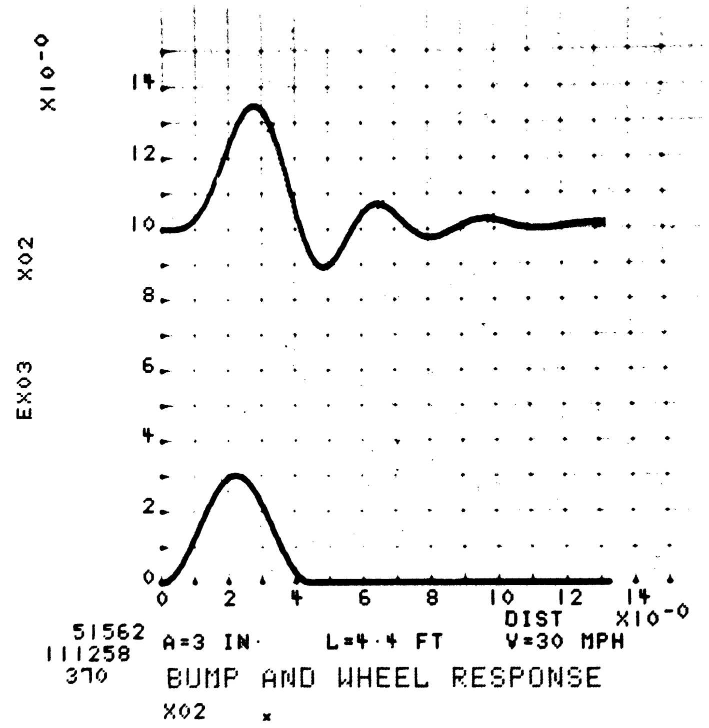
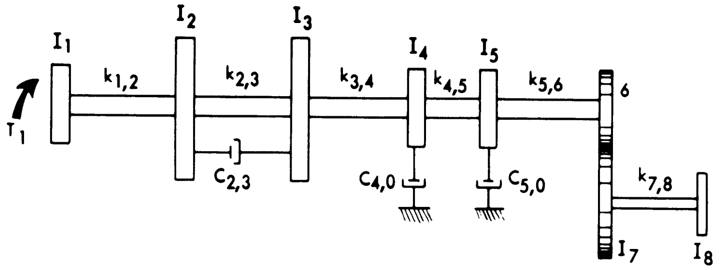


Figure 10

Some statistics on this are somewhat interesting. The programming time, this is the time from when an engineer came in the door with that particular problem until it had been programmed in the Dyana language, was about one hour. The time that the computer took, and this was on the 704 computer which we don't have any more; the time it took to translate from the Dyana language into the Fortran program for the solution of the problem, was three minutes. The time for translating from Fortran into machine language was 4.7 minutes. The time per solution, the time for reading a set of data and producing this plotted output, is 2.2 minutes. The elapsed time from "problem in the door" to "hard copy graph out" was about six hours. The cost of this amounted to $15.00 worth of programming time, about $40.00 worth of computer time for the development of the program, about $15.00 per answer. So about $50.00 worth of set-up cost, $15.00 per answer, and one-day service.

There are two versions of this Dyana system. One is transient response and the other is frequency response. Figure 11 shows a torsional equivalent of the frequency response system in which again we describe the system in terms of masses, and springs, and dampers and indicate that we want to see the following answers, which are the amplitude of point 1 and the amplitude of point 2 plotted versus frequency.

SCHEMATIC OF SYSTEM



DYANA PROGRAM

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X   SYSTEM DESCRIPTION
       E00M01, E00M02, E00M03, E00M04, E00M05
       E00M07, E00M08, E01K02, E02K03, E03K04
       E04K05, E05K06, E07K08, E06N07
       E02C03, E00C04, E00C05, EF01
X   PRINT-PLOT ANSWERS
       AMPL01, AMPL02, _VS. FREQ
```

Figure 11

Figure 12 is the type of plotted answer which we get, again properly scaled and labeled. Similar statistics of this: the programming time is considerably less, about 15 minutes of human being time to perform the programming and five minutes of computer time to compile the machine language program and 3.8 minutes per set of answers. Elapsed time, again less than one day. Costs: $40.00 worth of set-up and $20.00 per answer.

Over-all, we have found that by employing the Dyana system for the kind of problem for which it works, which is in general any kind of a problem describable by a series of ordinary differential equations, we are achieving between five- and ten-to-one reduction over using the Fortran algebraic language for solving the same problem. Problems that once took us two weeks to do, we are now doing in a day or two.

Now, I would like to review what we have accomplished here. We have picked a fairly narrow area in the case of Dyana. However, we in the automobile business deal with a large number of vibration problems. For those problems where this particular approach works, we have greatly short-cut this process. We take the problem described in the language of the engineer and produce results for evaluation. The computer does all of this part of the task for us. As a result of shortening this cycle time, we can make some general comments. If it takes less time and costs less money to do this, the engineer is willing to take the analytical route more often, and he is able to be somewhat less conservative. He is more willing to follow his intuition and attempt to try more radical designs. This in effect, then speeds up the evolutionary design process. The design of a thing which goes into production is a continual evolutionary process. It is also an iterative process. We start out with the preliminary design and we end up with some results to evaluate. They are not as good as we would like so we get some new ideas, we make some changes and we go around this loop X number of times until finally we get something which is satisfactory and are ready to build and test it. So we build it, test it, gather data, analyze this data and find some shortcomings. We may then do more analytical work and modify the prototype until ultimately, either because we are done or production is ready, we stop. The evolutionary design process is a sort of an inch-worm process in which, if the expense of producing any stage in this is large, the engineer only reaches out a little ways from where he is, where he's real confident that he is going to be successful, and tries it. If it doesn't cost very much he is willing to reach out farther and try more radical designs and therefore hasten the development process.

Now let's look for a minute at the role of the engineer in all of this. I am not suggesting that we have about reached the point now

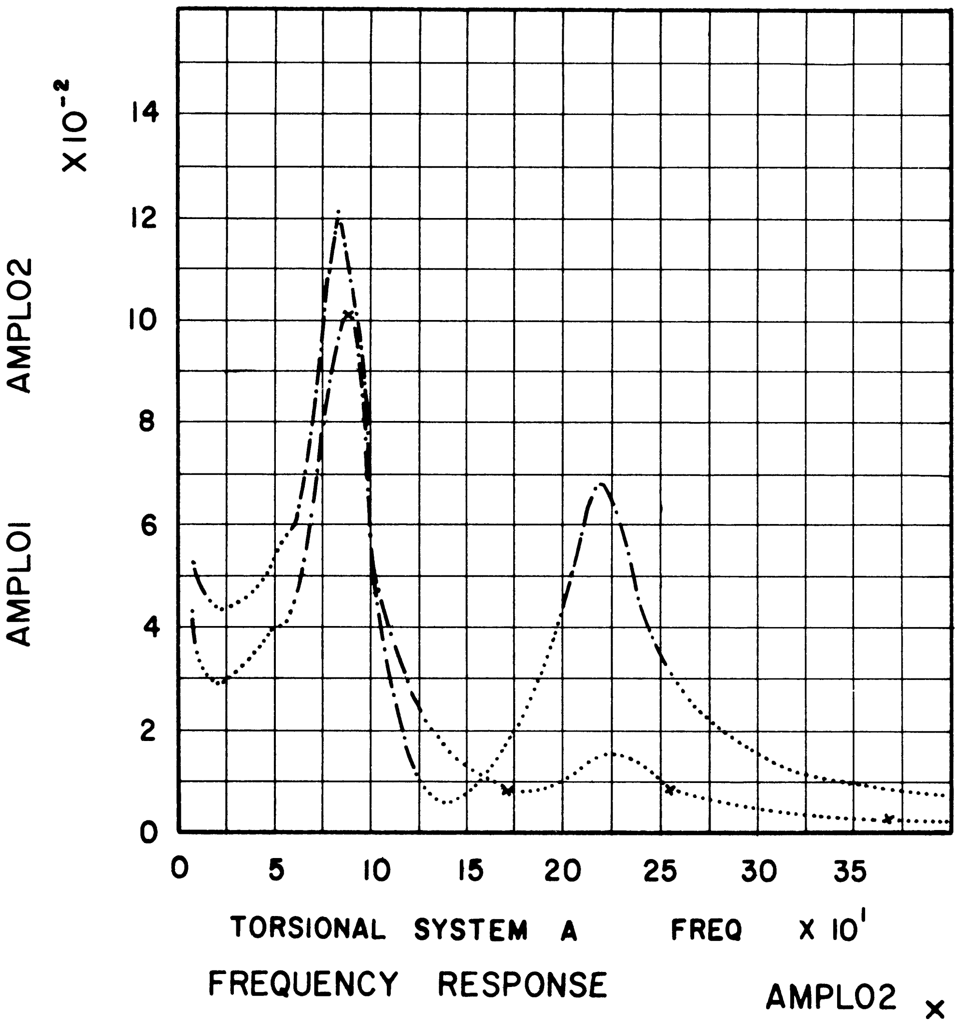
AMPLO1
AMPLO2
X 10^-2
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
TORSIONAL SYSTEM A
FREQ X 10^1
FREQUENCY RESPONSE
AMPLO2 ×

Figure 12

where we can perform complete synthesis and the engineer can sit at his desk and write down on a sheet of paper, "design automobile," and feed it to the computer.

For simple systems, we are able to do some kinds of synthesis. This is true in the case of gear design. The engineer now can, in effect, write down on a sheet of paper, "design me a pair of gears," and the computer program carries out the necessary iterations and adjustments in order to balance the life of the two gears in the gear set, in order to produce a gear pair which has maximum life, and which optimizes certain other characteristics. Most systems, however, are too complex for this and require a number of compromises. There are always certain side conditions which we have to consider. The conditions of size and shape, not to mention cost. Many of the compromises and side conditions, are not quantifiable in yes-no decisions. And this is the point which was made by the first speaker this morning; that if you can quantify these decisions in terms of a series of individual yes-no binary choices, then the computer can carry out the decision process for you. But in the design of a complex system which is either all or part of an automobile there are too many compromises involved and too many decisions that have to be made which are not quantifiable. So our objective then should be to use, rather than replace, the decision-making power of the human being. We want to take advantage of the engineer's know-how and intuition, all of what we loosely lump together and call experience. We want to take advantage of all of the experience of the human being and employ it and get the computer to do those things which are more mechanical. For the most part, we're not doing synthesis. Synthesis at the present time requires analysis plus human review. The human being looks at the results and says "What will I do next?" and on the basis of his experience and knowledge picks the next thing to try. In the cases where we have gone through this loop enough times perhaps we have begun to see the types of decisions that the human being makes - and this is what happened in the case of gear design. The human being was in the loop early in the game, but finally we were able to put down a set of rules that the human being used to decide a measure of goodness and which way to go in order to find something which is better. Once we had quantified these rules, we could put these into a computer program and take the human being out of the loop.

But this is, as I indicated before, being done only for very simple systems, so the computer is functioning mostly as an analysis tool. Dyana is another tool which makes it even easier to use the computer, but it still is only an analysis tool. The decisions about what to do, what to try, what to try next, are made by the human being. Other problem-oriented languages like Dyana are being developed and will be developed, and these will be developed whenever it is possible to set down the rules by which human beings perform their tasks.

Through this process we will continually extend the abilities of the computer. We started out early in the game extending the abilities only in little short steps, e.g., we taught the computer to take square roots. Some of my associates disagree with the terminology I use such as "teaching the computer" or "computer learning." I use these terms not to imply that the computer is taking on human characteristics but rather because these terms have meaning in the human context which we can relate to equivalent operations in the computer area. The computer, over a period of time, has gained an ability to do more and more things and if we applied the same terminology to a 10-year old boy we would say that he was learning. In effect, we in the computing business are in the process of attempting to educate a computer, to make it smarter, to make it possible for it to take on and carry out for us more complex tasks.

There is an advantage in teaching computers instead of people to do these things. The computer has a relatively perpetual memory. If we teach a man to do something and he does it well he gets promoted, and if he doesn't he gets fired, and so we lose the individual. If we use people to carry out operations, we must train successive generations of people. If we can train computers to do the same thing, hopefully we can perpetuate this capability.

The man plus the computer make a problem-solving team. The man has the decision-making capability, and the computer has the calculating and information processing capability. There is considerable effort which is needed in order to make this combination into the most effective team. There is the problem of inter-communication between the man with the problem and the computer. The technique which is now used is that the engineer, given a computer program which is already checked out, sits down and fills out a data sheet, gets it key punched, and sends it to the computer. The calculations are performed, the results are printed or plotted and are sent back to the engineer. The turn-around time to go through this system is 2, 3, 4 hours depending upon how much work load there is at that time and where the bottlenecks are. And it may take this 2, 3, or 4-hours of elapsed time in order to get 15 seconds of computer running - on the 7090 presently about half of our 200 runs per day take a minute or less.

Ideally, what we would like to do is to place the engineer at the computer and give him a console so that he can push some buttons and operate some keys in order to direct the course of the calculation, and give him a printer and maybe some kind of a graphical output device so that he can see his results almost immediately. But since big computers cost $10.00 a minute the human being is too slow to keep up with the speed of a computer with present techniques. In the future however, it will be possible for a central computer to service many such consoles without interference between them. In addition to this, through the communication channels which were mentioned earlier it may be possible to make these consoles remote from the computer itself. Work on the application of such consoles is going on at places like MIT and Carnegie Tech.

As we use a computer more and more we have moved the bottleneck in the design process. A new bottleneck is building the prototype to test. One thing which will ultimately help in this area is the technique of numerical control. At the point when the engineer finally says, "Yes, this is the design I like," we have existing in the computer memory a mathematical description or a numerical description of the component, part, or device which is to be built and tested. The computer is capable of preparing a control tape which can be fed into a numerically controlled machine tool in order to machine this part, perhaps with overnight service. From the biased view of the computer man we look upon the numerically controlled machine tool as just another kind of output device for a computer out of which come hard parts instead of printed pages. When we have a prototype which is successful, these same machine tool control tapes may ultimately be used in the production process itself. When this happens and where it happens will largely depend upon the volume of production. For short-run production this is feasible today, for building a million parts for automobiles it probably is not.

There is another bottleneck which is implicit. During the design iteration process a whale of a lot of paper work gets produced. Each time one goes around this iteration there are engineering records produced on what was tried, when it was tried, and what the results were. Records are kept on both the analytical and the experimental results. Drawings are produced. Shop orders are written to get things built, purchase orders are written, and invoices are received. Ultimately engineering releases are written in order to start production, and then there follow a succession of engineering change notices.

A tremendous amount of coordination and liaison is needed in order to keep track of what is going on, in order to keep design and production coordinated, and to coordinate the various phases of engineering. Some of the scheduling and planning techniques which were described by Mr. Gray hopefully will help as time goes on, but there is much which can be done through much more mundane application of computers. Hidden away in the design process is an enormous paper work overhead. Paper work represents information, and the computer is an excellent information processing machine. Unfortunately the world of computers has sort of been dichotomized. We talk about engineering doing design calculations -- solving mathematical equations, and the production area doing data processing -- keeping track of schedules and inventories, etc. Perhaps each of these groups is using the same computer, but they are using it in different ways and neither is much aware of what the other is doing. Communication between engineering and production is probably still carried out on forms which were designed before 1920. So, as a final message, I have a strong personal feeling that the design process can be improved as much by using the computer for data processing in the engineering paper work area as in the area of the more complex design calculations themselves.

Thank you. I'm sure you have some questions and comments.

DISCUSSION

Would you identify yourself please, for the record.

BLAIR:

QUESTION: I have two questions. One rather short one. Would you call this Dyana program a sort of a sophisticated compiler program?

ANSWER: Yes. It takes a description of a problem in a language which is somewhat more natural for the engineer. And it then performs a language translation, if you will, and develops a procedure and writes a program in another form which the computer is able to use for solving the problem.

QUESTION: All right. Now the main question then, is how much of the memory or how much of a memory does this routine take itself?

ANSWER: The Dyana processor (compiler) is about 20,000 instructions long.

QUESTION: You call them instructions?

ANSWER: Yes. Individual words in the machine memory. And it writes, actually a Fortran program which then requires the Fortran compiler for translation down to machine language. This was originally written for a 704 computer with 8,000 words of memory so there are several blocks in the program.

QUESTION: Does this require several passes then?

ANSWER: Yes. But actually the Dyana compiled time is faster than the Fortran compiled time. I was talking about minutes of machine time to carry out the Dyana compiling process.

QUESTION: What sort of limitations do you have as far as defining functions are concerned?

ANSWER: There is one limitation on the size of the system. We use two-digit numbers for describing the connection points so that this limits the system to 99 connection points between components. In terms of describing nonlinear springs or dampers or if you have a black box which you want to install in the system which has some sort of transfer characteristics these can be incorporated by describing their characteristics with a sequence of Fortran statements. Empirical curves or tables of measured points may also be used.

QUESTION: I presume you can keep adding to this program.

ANSWER: Yes. We designed it for mechanical problems. By analogy it has been employed for electrical network problems and heat-transfer problems. If somebody wanted really to work with electrical network problems, he should extend the program's dictionary so that it has L's and C's and R's as well as M's and C's and K's. Nobody has done this yet.

PROF. GALLER (U. of M)
QUESTION: You represent a class of industrial computer users. If you could tell the University people what engineers ought to know about computers, what would you say?

ANSWER: I feel that they should be imbued with the philosophy that a computer can solve problems and that there really isn't any mystery about how they do this. I think that perhaps what the computer offers in the University environment is an opportunity for the student to learn how to solve problems. Many students who come out of the University after 4 and 5 years have never really solved a problem. They have solved pieces of problems but they have never been faced with all of the details of planning and getting answers to a complete problem. The computer offers this possibility. The ability to code in a specific language is less important, I think, than the student having had the opportunity in the University to actually use the computer to solve problems and have an idea of how the computer works. This he does not get, obviously, from listening to people lecture about it. This he only gets by doing it. So I think experience in the use of a computer is very important.

PROF. YORK (U. of M)
QUESTION: In your diagram of the operation of the Dyana system, which essentially is a one-step description of the sequence of calculations from the engineering analysis to the evaluation of results, you talked about the possibility of having numerical control to build a prototype. Now the important step to the engineer is that we need

the feed-back from the prototype. Does this go to the engineering group which then tells you that your equations may be in need of modification or does it go to you, or do you both monitor the results?

ANSWER: As far as I am concerned, I'm running a computing center and what the engineer does on the computer is his business. He is for the most part doing the development of his problem descriptions and the method of solution. The data that he supplies to the computer is his data. He gets the answers back. So he is the man who gets the prototype built, performs the tests, and gets the answers. The computer is a tool which the engineer is using to solve his own problems.

QUESTION: As I understand it, the computer is selecting a problem attack and solution from a resolved approach so that all the elements does is to insert into it a description of the elements and the general pattern of the solution. What I'm after is, suppose the solution that you have put into the computer gives him an answer which the prototype doesn't check. This means really that your pre-solution needs modification. Does he just come back and pound on your desk or do you worry about this too?

ANSWER: We worry about this too. In the case of Dyana, he might get in trouble in either of two places. This is in describing his system which is the input to the Dyana process or in the solution of the differential equations. And he can get in trouble here if he has an unusual situation and he hasn't properly selected the step sizes. I couldn't conceive of the prototype being built until this other iteration had been completed several times. He is doing paper studies, and if he's got the normal engineering skepticism which he ought to have and knows there is nothing magic about a computer then he's looking at the plots of the results and he's correlating these with some other considerations such as energy balance and so on. Any normal engineering checks which he can incorporate, he is incorporating. If the results which he gets look doubtful, he is going to check more thoroughly. It is not until he is satisfied with the analytical results that he is going to go and get one built.

QUESTION: I would like to raise a question this way. Earlier in our work here at the University we had some abhorrence of what you call standardized or canned programs for classes of problems. We had begun to look back and see, well, there are programs for getting functions and handling certain mathematical procedures. Now we see here with the Dyana, a program for handling a class of problems. I had a recent visit with a man from Imperial Chemical from England and he told me that they now are operating on the basis that their computing groups are providing programs for all kinds of classes of problems. They only teach their engineers how to use the programs for classes of problems and how to combine them. They have a hundred or more classes of problems that they have the program set up for. The question is, as I gather it from what you're saying, that this is a feasible way in engineering. How much lack of understanding do you discern among the engineers as to how to use Dyana, for example, in a problem. How much don't they understand? Is it relatively foolproof so that say a new young man comes to you and you ask him to solve a problem, give him the material on Dyana, the kinds of information he can put in it and the kinds of results he can get out. How much of a problem is there for him to understand this and to actually have this short cut in the time that you're talking about. Is there a lot of problems or is it a relatively straightforward thing?

ANSWER: It is relatively straightforward. He can make errors of misinterpretation in reading the manual and here he can come back and get his questions answered. Let me answer this in a somewhat roundabout way. There is always a sort of a feeling deep down inside that you're getting the engineer to use the computer and eventually he's going to forget how to be an engineer. But this is no different than the way life has always been, even before computers. A procedure was developed, let's say for engine test data reduction. This was developed 10 years ago and the engineer got kind of tired of doing this so he assigned this task to the junior engineer who was just assigned to the department. Whenever a new junior engineer came into the department, it was unloaded on him. This got unloaded on a succession of generations of junior engineers until after 10 years had passed, the man who was now doing it didn't have the faintest notion of what he was doing. He was carrying out blindly a prescribed procedure. And I know this is true because we worked with one group trying to get a description of this procedure so we could put it on a computer, and it took about six months to figure out what the man was really doing. And the computer is causing the same thing, only more so. The advantage with the computer is that, assuming you lean on people hard enough, the procedure that the computer is using is documented and it remains invariant with time. It will give the same answer a year from now that it got today and you don't have the problem of the noise which is generated when a procedure is passed from one generation of people to the next. So I can't get terribly worked up about this problem of people forgetting what they are doing because the computer is doing it all for him. I think the computers are going to do the sort of thing people ought to forget how to do.

UNION CARBIDE CO.
QUESTION: I might say, just a comment on this one question. We are using Dyana which we got from SHARE (a computer users organization) with a very minimum of correspondence or communications with General Motors Research, with a fair amount of success. We also are doing almost what was indicated on the chart; using Dyana within our APT system (which is a program for numerically controlled machine tools) with a good deal of success. This is just to indicate that these things are actually being used. When they are developed, they are actually being used not only by us but by a great many other people who got similar programs out of SHARE and have their own people to use them.

ANSWER: Thank you. Yes.

QUESTION: Suppose a problem involved a solution, say of a differential equation. Would you be required to put the time into it or would it be variable or does this happen automatically?

ANSWER: With the present differential equation-solving technique which we're using, this time increment has to be specified externally.

QUESTION: You have to specify it? How do you know when you've got it right?

ANSWER: Well, here we are back again to the point that the engineer has to know something about what he is doing. There is somewhat of a tendency here to have complete blind faith in this electronic box. This is particularly true when you bring somebody in and fire them through a three-day Fortran course and give them the computer. This is dangerous. We do our best in the development of the various routines, such as differential equation routines and square root routines, etc., to build in checks and let the man know whenever something went wrong. The normal course of action in Fortran was that if you supplied a negative number to a square root routine, it took the square root of the positive value and continued blindly along. Now this may be all right, but it also may not. We have built into our process a means by which every time something unusual of this sort happens the engineer gets a print out on his answer sheet showing that something <u>may</u> be wrong, and the computation proceeds if possible. Similar types of checks can be put into the routine for differential equations. It is still possible of course to get wrong answers and additional external checks need to be made.

GALLER
QUESTION: You said you weren't too worried about the engineer forgetting what he knew. Now, again at the University, forgetting assumes that he knew it, and somewhere along the line he did have this understanding. As far as the University is concerned, I think, we should be concerned about going into the principles involved, and what is beyond the black box.

ANSWER: Yes, we might question, how you teach differential equations, for example. Perhaps, we ought to spend less time in how to get analytic solutions to differential equations and more time on how to get numerical solutions to differential equations. Because by the time the present freshmen get out of the University, most of them will have access to some kind of a computer somewhere. They won't even think in terms of getting analytic solutions. Now if a man is trained to be a mathematician, this is a different problem. If he is trained to be an engineer he is concerned with solving problems, and the numerical technique is the best one to learn because it is the one he's going to use. Obviously we can't train people who just know how to poke holes in cards and feed them to a machine. We might sort of loosely, perhaps, divide people into two kinds, and this is an oversimplification. I am not talking about male and female. These are going to be the procedure developers and the procedure users. A lot of engineers are now coming out of school who have learned how to use various tables and monograms and techniques and tools in order to solve problems. Others are more analytically oriented and are developing the new tools, the new tables and the new techniques which these problem-solving types are going to use. The computer really hasn't changed that, except in perhaps accelerating the process and providing better tools to the man who is going to be a problem solver. This is the kind of man that last year was using engineering tables, charts, and graphs. Next year he will be using black-box routines and a electronic computer. But this is still a tool which he is using to solve a problem. Now we still need the other kind of engineer, scientist, mathematician or combination thereof who are developing the tools, and these people obviously have to know what is going on down inside.

QUESTION: My question rather anticipates the next speaker on information retrieval. You have talked about building up a history of programming techniques. In other words, you are building up a history of information. Are you also building up a history of information on ports themselves? In other words, instead of starting out to redesign a component each time from scratch, do you automatically look back through the previous designs of similar components to see if there is something you can use? Are you setting up a master file of parts information, let's say for an automobile? This would be the basis of all paper work you've described. The systems design might then be looked on as merely being adjustments to previous systems rather than the whole problem all over again.

ANSWER: This is being done in the operating divisions of General Motors in which going through the design process is largely an iteration from last year. You salvage as much as you can out of last year and use it this year. So here files of information are using the large disk files, random access memory devices, in order to keep parts' histories. To a large extent we have not yet gone to the extent the military has gone where they're filing all drawings on aperture cards, properly coded, so that they are retrievable and the drawings can be reproduced.

QUESTION: Do you see any reduction in design time as the result of adjustment instead of the recalculation of the entire program?

ANSWER: The problem here is no different than it is in the retrieval of literature. It is a question of economic pay-off. Is it cheaper to find results of somebody else's experiment or to rerun the experiment? If the information is readily retrievable in a reliable manner then it is cheaper to retrieve the information than it is to do it over. I'm afraid at the present time for much of this, if you don't have an individual who remembers, then it is probably cheaper to do it over. Hopefully this will not always be true.

INFORMATION RETRIEVAL AS A DYNAMIC ENGINEERING TOOL

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INFORMATION RETRIEVAL AS A DYNAMIC ENGINEERING TOOL

Once-upon-a-time it was not too difficult to find nearly everything that had ever been written about any given subject. A scientist or engineer could keep reasonably up-to-date with all known significant work going on in his field. But, times have changed. Over the past few years, it has become increasingly apparent that our limited and rapidly diminishing ability to retrieve the pertinent recorded past and our inability to keep adequately informed of current work in even narrow areas of technology are taking a high toll in wasted talent, time, and resources. And, even though we are now awakening and beginning to do something about the information problem, this situation will undoubtedly grow considerably worse before it is improved.

It is not our purpose in this presentation to add more words to the huge volume already published about the much publicized technical information explosion. We will leave observing the global picture up to those in government and education who are equipped to do so. Ours is a "meanwhile, back at the ranch" story. We are concerned with the practical problems associated with implementing Information Retrieval as a useful engineering tool in industry. However, it has been an improved understanding of the nature and implications of the technical information problem in general that has stimulated the development of our Technical Information Center and our use of automation to cope with the problem more effectively and economically on a local level.

We believe that an information service in industry must take an active rather than the traditional, passive, part in the technical activities of its users. To be capable of performing information retrieval is not enough. The real value of information retrieval lies in its application to specific technical problems whose solutions are related to the technical and financial success of our user group, General Electric's Flight Propulsion Division. Therefore, we have attempted to develop an aggressive technical information program based on selective information retrieval and the automatic dissemination of useful information to those whom it will help.

A brief review of the FPD Technical Information Center, its capabilities, its Automatic Information Retrieval System, and its services is presented herein.

I. The FPD Technical Information Center

The technical information program of our Center is characterized by its pragmatism. Services are added and modified to meet the changing needs of the business and are dropped if no longer required. We are fully cognizant of the vital need for a "value received" approach to technical information services. Every effort is made to identify areas of maximum pay-off potential toward which to direct our efforts.

We provide technical information services for more than 2500 scientists and engineers engaged in the research and development, testing and production of aerospace propulsion and space power components, accessories and systems. Most of our clients perform applied research and development in a wide range of technologies related to the Division's products.

To provide our technical information services on a volume basis yet with a reasonable degree of selectivity and quality control, we have found that three different capabilities are required in our Center as indicated in Figure 1.

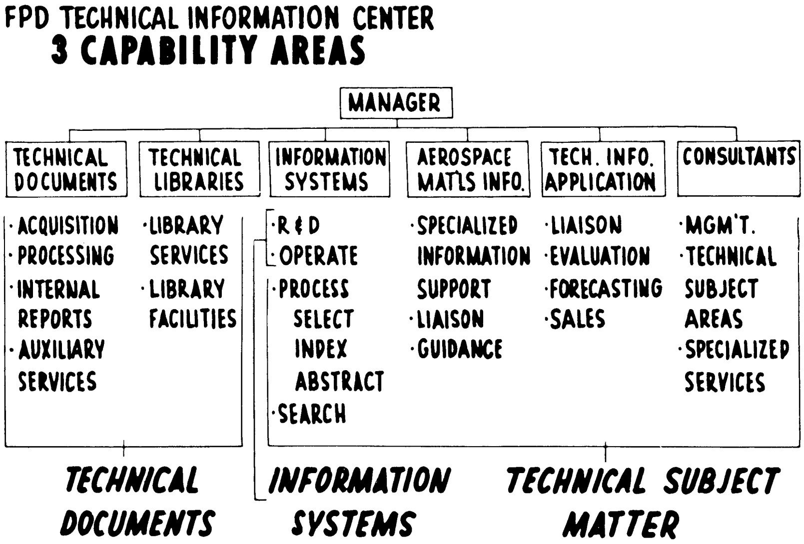


Figure 1

First, people skilled in library science are required to cope with the large flood of documents with which the Center is concerned and to provide conventional library and auxiliary services.

Secondly, technical people with educations and experience in appropriate areas of technology are required to perform technical information analysis, abstracting and indexing on a selective basis. This is an important key to effective and efficient information retrieval which appears to be overlooked by many people. We are convinced that careful selection of documents to be introduced into a retrieval system and their description by really significant index terms is prerequisite to a reasonable degree of retrieval selectivity, completeness, efficiency and usefulness.

Thirdly, technical people trained in information systems work and documentation are required to develop and operate the Center's systems and to perform the documentation and information systems research and development to improve and extend existing systems and to exploit new opportunities for service. Because of the extent to which we have automated the handling of technical information, machine programming and systems analysis capabilities are particularly essential to our Center's operation.

Our present staff of eleven professional and ten supporting personnel (Figure 2) includes all three capabilities. In addition, outside consultants are used to extend the Center's capabilities as required. These people, using our Automatic Information Retrieval System (AIRS) as a major tool, are now providing several services to meet a wide range of specific information needs.

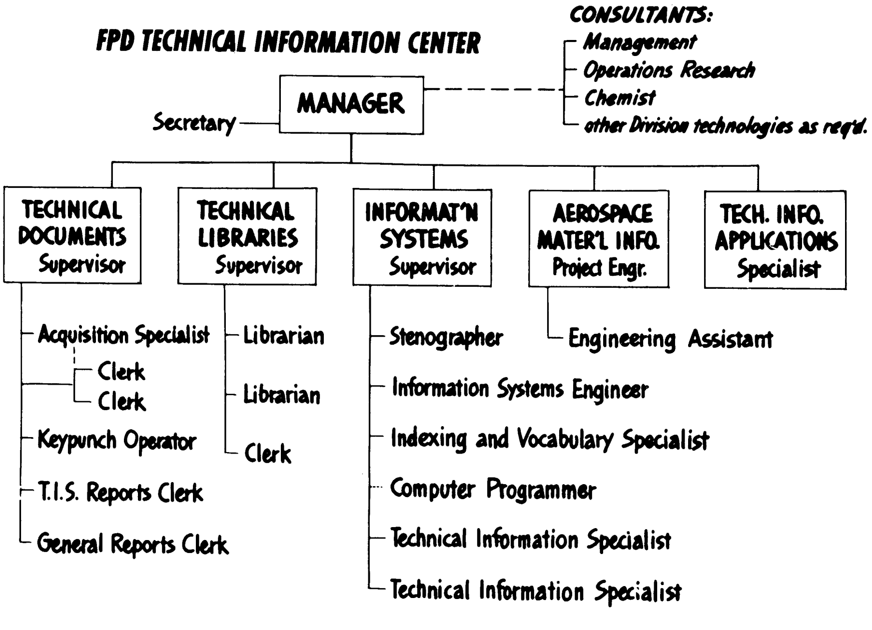


Figure 2

II. The Automatic Information Retrieval System

We do not intend to promote the present General Electric Automatic Information Retrieval System as the ultimate solution or a pattern for the solution of the IR problem, or as a fine example of the application of information theory. However, it is an operating system that is utilized and has been functioning with some success for five years.

AIRS operates on the GE Flight Propulsion Division's IBM 7090-1401 computer system. This is but one of the many applications currently running on these computers. The 1401 is utilized solely to load the punched card input on to magnetic tape for the 7090, and to print or punch the various output tapes generated by the 7090.

An inverted coordinate uniterm or keyword index and abstract tapes compose the recorded information for reference purposes for AIRS. The uniterm index presently occupies about one-half a reel, approximately 1200 feet, of magnetic tape. Of the present vocabulary of 7000 index terms, 5000 terms (majors) are contained on the index tape. Another 2000 terms (minors) have been used less than three times and are not yet included in the tape file. These terms are searched manually. Updating the index (Figure 3) is accomplished by posting new access or document serial numbers to the terms that were used to describe the documents.

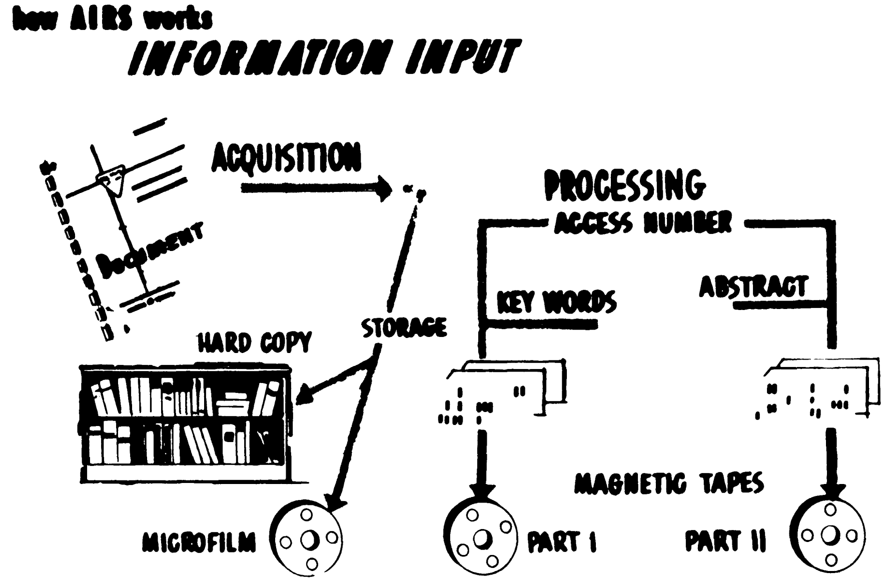


Figure 3

The abstract tapes contain indicative abstracts and source and security data for each document recorded in the system. Each abstract tape contains up to 10,000 abstracts posted serially by access number. There are now over 65,000 documents in the system with their abstracts on seven reels of magnetic tape.

Searching

The search programs are organized in two segments. Figure 4 illustrates the first segment, or Part I, of a search run. This is the keyword coordination or comparison part of the search system. Searching the index is done for many customers simultaneously. The search programs have the capacity, during a single run, to define 1300 simultaneous multiterm products and an unlimited ability to relate these questions. Figure 5 illustrates individual searches and their composites or sum. A typical search run may consist of 100-200 multiterm products and 50 or so sums. This would probably require from two to five minutes of 7090 main-frame time. Search output contains the search questions, customer identification and the resultant access numbers.

At the searcher's option a search may be terminated or temporarily held at the end of term coordination. For some purposes this result suffices (Figure 6). Also, a searcher may review the listing to see if it would be justified to continue into the second segment, or Part II. He may also elect to adjust the results to print the abstracts for only certain areas. Usually the two parts of the search are run consecutively through the 7090.

Part II of the AIRS is an abstract look-up program (Figure 7). During this segment of a search run abstracts identified by access numbers found during the index search are located and written on an output tape. A complete index and abstract search (Parts I and II) results in an output tape which contains access numbers, customer identification, and abstracts with their bibliographic and security data. Contents of the output tape are then printed by a 1401 computer. An abstract is shown in Figure 8.

How AIRS appears from the customer's viewpoint is illustrated in Figure 9. The customer reviews his literature research problem with one of the TIC's literature researchers. The searcher will interpret the problem and will formulate the search questions by using index terms selected from the uniterm vocabulary which he groups in appropriate logical combinations. He will attempt to cover all the ramifications of the problem and to allow for specific-generic relationships as well as synonyms.

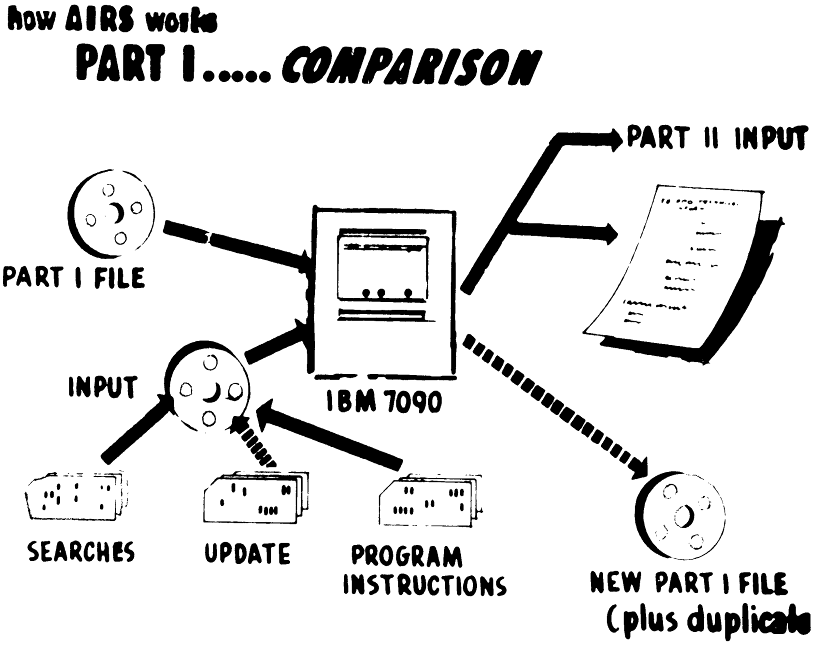


Figure 4

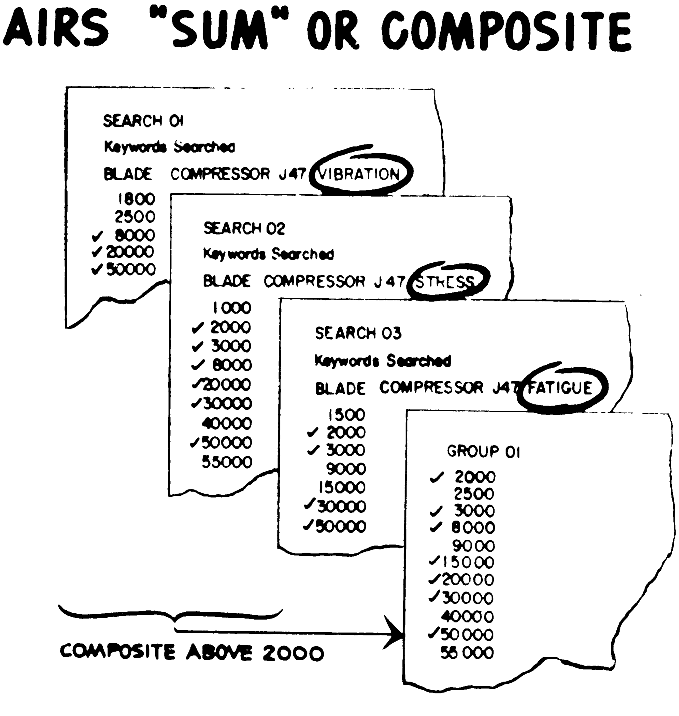
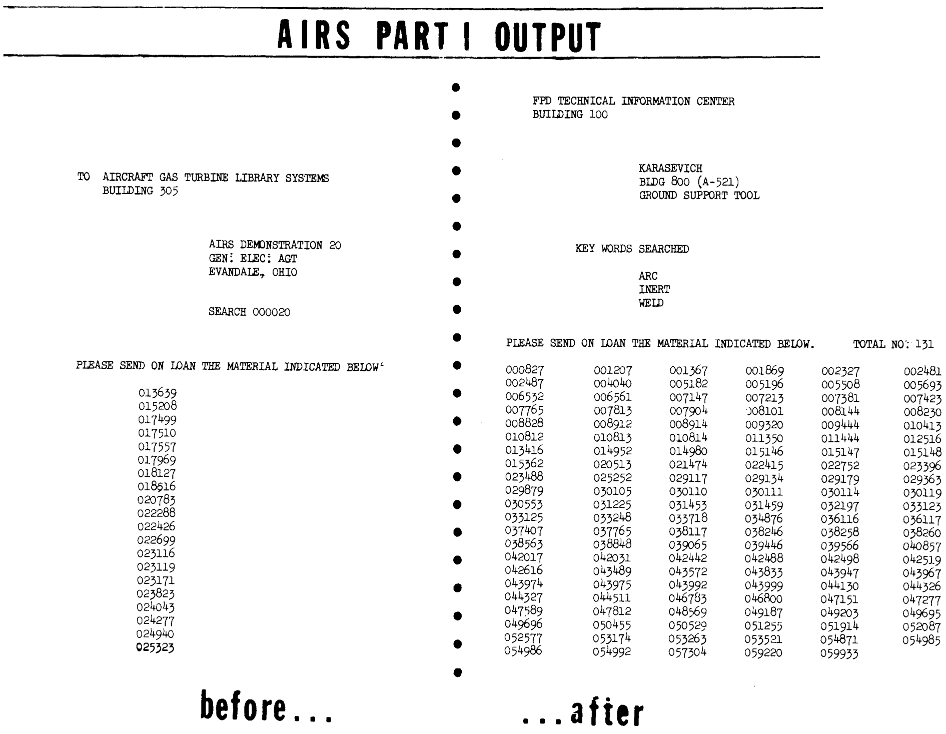


Figure 5



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TO  AIRCRAFT GAS TURBINE LIBRARY SYSTEMS
    BUILDING 305


                   AIRS DEMONSTRATION 20
                   GEN: ELEC: AGT
                   EVANDALE, OHIO


                   SEARCH 000020


PLEASE SEND ON LOAN THE MATERIAL INDICATED BELOW:

         013639
         015208
         017499
         017510
         017557
         017969
         018127
         018516
         020783
         022288
         022426
         022699
         023116
         023119
         023171
         023823
         024043
         024277
         024940
         025323
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    FPD TECHNICAL INFORMATION CENTER
    BUILDING 100


                KARASEVICH
                BLDG 800 (A-521)
                GROUND SUPPORT TOOL


         KEY WORDS SEARCHED

                ARC
                INERT
                WELD


PLEASE SEND ON LOAN THE MATERIAL INDICATED BELOW.      TOTAL NO: 131

000827      001207     001367     001869     002327      002481
002487      004040     005182     005196     005508      005693
006532      006561     007147     007213     007381      007423
007765      007813     007904     008101     008144      008230
008828      008912     008914     009320     009444      010413
010812      010813     010814     011350     011444      012516
013416      014952     014980     015146     015147      015148
015362      020513     021474     022415     022752      023396
023488      025252     029117     029134     029179      029363
029879      030105     030110     030111     030114      030119
030553      031225     031453     031459     032197      033123
033125      033248     033718     034876     036116      036117
037407      037765     038117     038246     038258      038260
038563      038848     039065     039446     039566      040857
042017      042031     042442     042488     042498      042519
042616      043489     043572     043833     043947      043967
043974      043975     043992     043999     044130      044326
044327      044511     046783     046800     047151      047277
047589      047812     048569     049187     049203      049695
049696      050455     050529     051255     051914      052087
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054986      054992     057304     059220     059933
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Figure 6

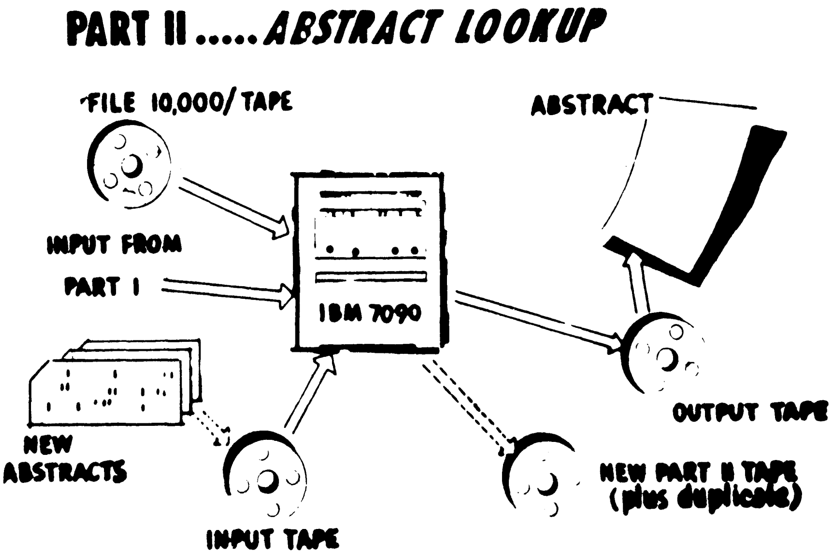
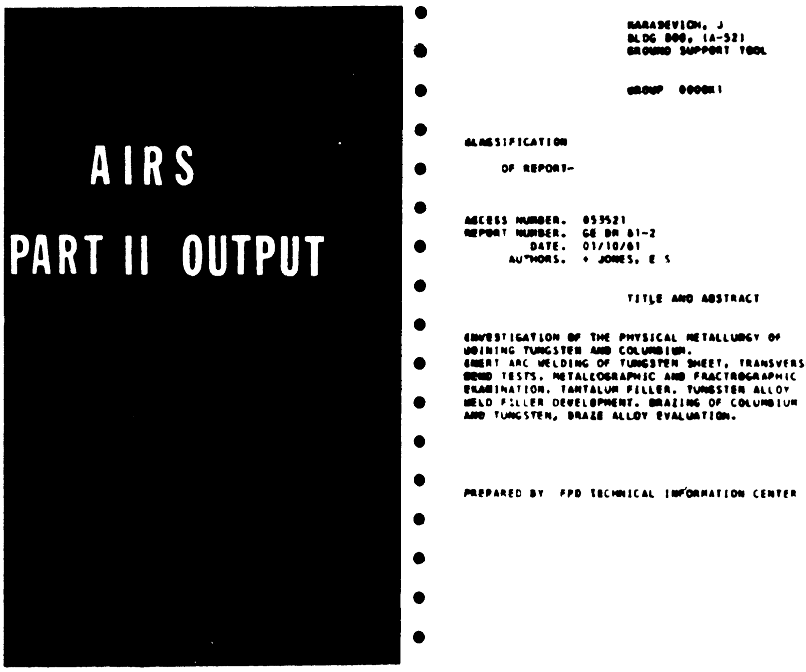


Figure 7



AIRS

PART II OUTPUT

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                              KARASEVICH, J
                              BLDG 800, IA-521
                              GROUND SUPPORT TOOL

                              GROUP  0000H1


CLASSIFICATION

     OF REPORT-


ACCESS NUMBER.  053521
REPORT NUMBER.  GE DM 61-2
         DATE.  01/10/61
      AUTHORS.  + JONES, E S

                              TITLE AND ABSTRACT

INVESTIGATION OF THE PHYSICAL METALLURGY OF
JOINING TUNGSTEN AND COLUMBIUM.
INERT ARC WELDING OF TUNGSTEN SHEET, TRANSVERSE
BEND TESTS, METALLOGRAPHIC AND FRACTROGRAPHIC
EXAMINATION. TANTALUM FILLER. TUNGSTEN ALLOY
WELD FILLER DEVELOPMENT. BRAZING OF COLUMBIUM
AND TUNGSTEN, BRAZE ALLOY EVALUATION.



PREPARED BY  FPD TECHNICAL INFORMATION CENTER
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Figure 8

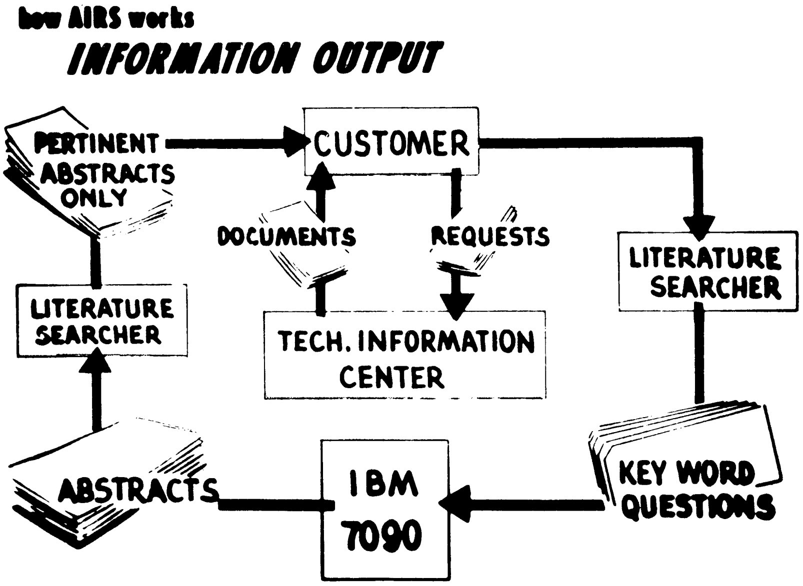


Figure 9

Because of the system's large simultaneous search capacity, the searcher may develop very elaborate search strategy to be as complete yet selective as possible in his search. Also, many different searches for several customers will be on the same run. Following the search run the literature searcher reviews the abstracts which have resulted and passes on only those abstracts he considers pertinent. The customer then makes his selection of those documents which he wishes to review in detail and requests them from the Center's Library. This cycle is usually completed within a twenty-four hour period.

Within the search system there are several options and controls which allow for a variety of types of searches and which prevent certain common and expensive errors. To avoid an unreasonably large output of abstracts on some particular question being run the searcher may exercise a quantity control on the number of abstracts. In which case only the more recent abstracts will be printed. Those in excess of the limit are deleted. Another important option is our ability to exercise an access number range control. Since there is a high correlation between access number and date of entry into the file, this control gives the searcher the ability to vary chronologically the output of the search. Also, it enables us to provide a Current Awareness Service for our clients.

In the event that a searcher has misspelled a search term the program will halt after the completion of all term coordinations. This forces the searcher to review the results before continuing to print the abstracts.

In the past year a considerable amount of reprogramming on the system has been done for the purposes of taking advantage of the 7090's capabilities, lowering operating costs, correcting certain problems, and increasing the capability of the retrieval system.

At present the system can define approximately 1300 simultaneous search questions. The previous limit of 99 was found to be inadequate for a large volume of customers on a single run. This situation occurs with Current Awareness type searches, where a great many individual profiles are screened against the recent acquisitions.

As the file steadily grew and with the increasing need to batch customers on a single run search failures or "tilts" as they were called, occurred with increasing frequency under the original logic. This situation was caused by heavily posted search terms filling the storage area and preventing the completion of a search.

The logic of the system was modified to select the smaller terms in an individual search and to use these as filters to the more dense terms. A secondary tape was incorporated for storage of terms rejected on the first pass of the file. This secondary tape is read up to five times in order to complete the search run. Since these modifications to the search program logic, the "tilt" situation has not re-occurred.

Under the original logic of the Abstract Look-Up Program (Part II) the abstract tapes were read serially. This program has been rewritten to allow the simultaneous searching of two abstract tapes, and it also incorporates buffering, packed output, and a print scheduler. These modifications have reduced the operating time for this program by as much as 50%.

Costs

Using a computer for IR has introduced a new and significant item of expense into the Technical Information Center's operating budget. It has also focused attention on the costs of information searching, both manual and with computers. Contrary to the popular misconception that information services are "free," only a cursory examination of any information service or library will reveal that literature or information searching involves considerable costs.

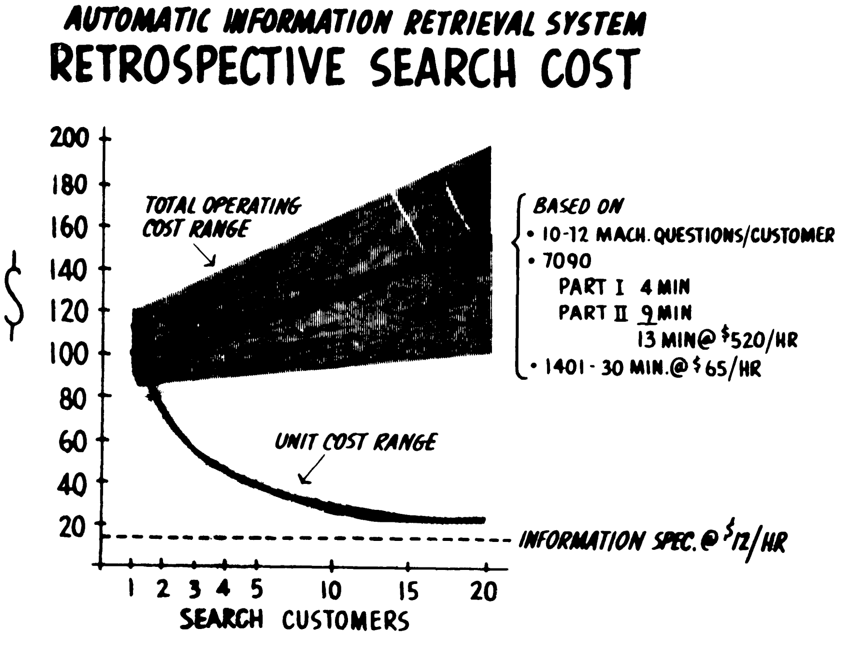
We have spent considerable money to develop, maintain and operate the Automatic Information Retrieval System. Our automation expenses for 1961 and those forecast for 1962 are shown in Figure 10. The 16% decrease in total automation costs forecast for 1962 is largely attributable to reduced programming requirements and to improved operating economies. These figures reflect not only those costs due to our Automatic Information Retrieval System, but also include several supporting services. It should be pointed out that 1962's automation expense forecast represents less than 10% of the Center's total operating costs.

Cost of performing retrospective searching is shown in Figure 11. This operating cost is based on today's file of over 65,000 documents. It is interesting to note that the search price range of $115 maximum to $22.50 for 10-12 machine questions for a customer (the price depending upon batching) compares with a range of $130 maximum to $20 minimum for eight machine questions per customer and a file less than half of today's in the early days of our 704 system.

AIRS AUTOMATION COSTS...

ITEM	1961 $ ACTUAL	1961 % TOTAL	1962 $ FORECAST	1962 % TOTAL
RETROSPECTIVE SEARCHES	7020	23	7000	28
CURRENT AWARENESS	820	3	2000	8
AIRS PROGRAM DEVELOPMENT	16,160	54	8500	34
PROGRAM MAINTENANCE	1000	3	1000	4
SPECIAL PROJECTS & PRINTOUTS	960	3	3000	12
AIRS KEYPUNCHING	1945	6	500	2
AIRS UPDATING	2195	7	3000	12
	$30,100		$25,000	

Figure 10



AUTOMATIC INFORMATION RETRIEVAL SYSTEM

RETROSPECTIVE SEARCH COST

BASED ON
- 10-12 MACH. QUESTIONS/CUSTOMER
- 7090
  - PART I 4 MIN
  - PART II 9 MIN
  - 13 MIN @ $520/HR
- 1401 - 30 MIN. @ $65/HR

INFORMATION SPEC. @ $12/HR

Figure 11

Search cost data is of particular concern to us because we sell our information services to our customers. There is an actual transfer of accounting dollars from a customer's operating expense budget into ours as a sales credit. Therefore, we must understand our costs well enough to competitively price our services.

III. IR and Dissemination Services

At the risk of oversimplifications, the ideal goal toward which our Technical Information Center strives is to identify and retrieve from the vast volume of technical information which is available throughout the world all that which is, or will become, useful to the scientists and engineers of the Flight Propulsion Division and to exclude all that which is not, or will not become, useful to our users; then to send to the man who needs it, only that information which will help him and to reach him when it will be most useful to him. Candidly speaking, we have no idea of how far we really miss the ideal. We know for a fact, however, that we err far more toward incompleteness than toward surplus. For nearly all of the information we select, process, and disseminate, is retrieved through one or more of our services at one time or another for our users. The information may be sent, on our initiative, to a Current Awareness Service subscriber, or it may be asked for by a user as a result of a retrospective search or because of some other special service. The following discussion highlights those services directly related to our ability to retrieve and disseminate technical information on a selective basis.

Current Awareness Program

A Current Awareness Program conducted by the Center attempts to keep specific individuals abreast of world-wide technology in subject areas of key importance to them. The Current Awareness Service principle is illustrated in Figure 12. The Technical Information Center's monthly input of potentially useful information is estimated to be between 15,000 and 20,000 items in the form of reports, books, memoranda, technical society papers, journal articles, patents, abstracts, etc. This input is in more than 20 broad subject areas, such as physical sciences, fluid mechanics, mathematics and computation, propulsion systems, management and administration, and materials and processes. At the Center's present level of operation, about 5,000 of these items are evaluated, and out of these, 1,000 are selected and indexed into the Automatic Information Retrieval System for dissemination and retrieval. By defining an individual's information needs and setting up his interest profile expressed in the retrieval systems language (keywords), he is periodically

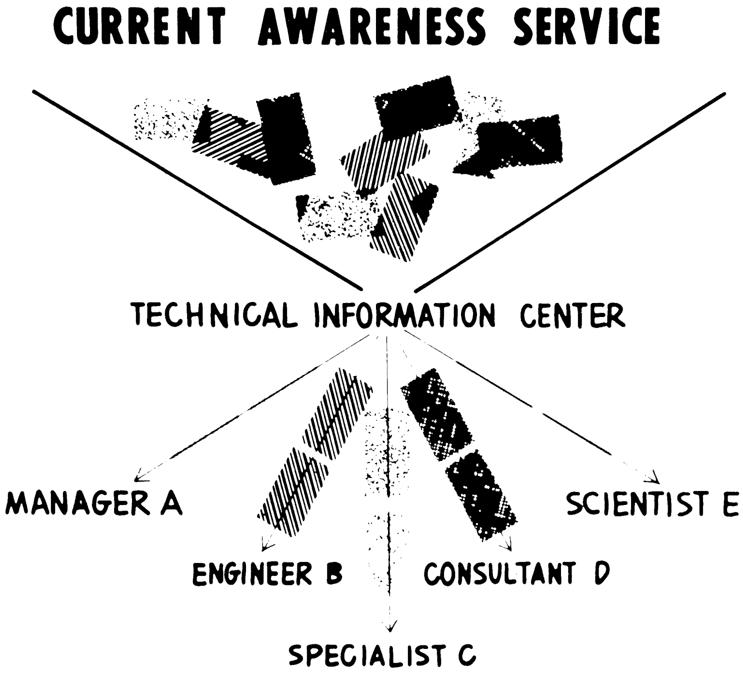


Figure 12

given a very selective look by the Automatic Information Retrieval System at the Center's indexed input of 1,000 documents per month and automatically receives abstracts of new material entered into the file since he was last contacted. Thus, in effect, in less than an hour's reading time per month, a Current Awareness Service client scans 5,000 new documents of potential value to him, carefully reviews the contents of 1,000 of them and then focuses his attention on only a few for detailed study.

Information Searching

Information searching is provided by the Center's two engineers who specialize in this field. Both specialists have been in the Division for ten years in various engineering activities and, as a consequence, are well acquainted with the Division's products and key technical personnel.

Through the use of technical people as information specialists the Center attempts to perform its information research on a more selective basis thereby assuring its scientific and engineering clients of more complete yet more carefully screened search results. The major tool of the searcher is the Automatic Information Retrieval System. But for exhaustive searches of world-wide technology AIRS serves only as a start. The Center's searchers use other sources as required. However, AIRS is the only approach by subject into GE internal reports and it is fairly complete in this respect.

Efforts of the Center's information specialists are augmented as required by outside technical information services and consultants. For example, a consulting chemist retained by the Center over the past several months has conducted a continuing survey of several sources on subjects having to do with the purification of Alkali Metals. His work is monitored by the Center's Aerospace Materials Engineer who disseminates survey results to several scientists and engineers throughout the Division who have need for the information.

Aerospace Materials Information Project

The AMI Project was established to better meet the information needs of about 125 materials scientists and engineers in six materials groups in the Flight Propulsion Division. The Project is staffed with an experienced metallurgical engineer and a chemical assistant. The AMI Project functions are illustrated in Figure 13. To accomplish its purposes, the Project serves as a continuing technical liaison between its materials clients and the Center. The Project has brought to the Center a far better understanding of its materials users' needs than ever before possible. This has resulted in a significant upgrading of the Technical Information Center's acquisition, information processing, retrieval and dissemination efforts in subject areas of direct concern to the Division's materials laboratory and engineering groups.

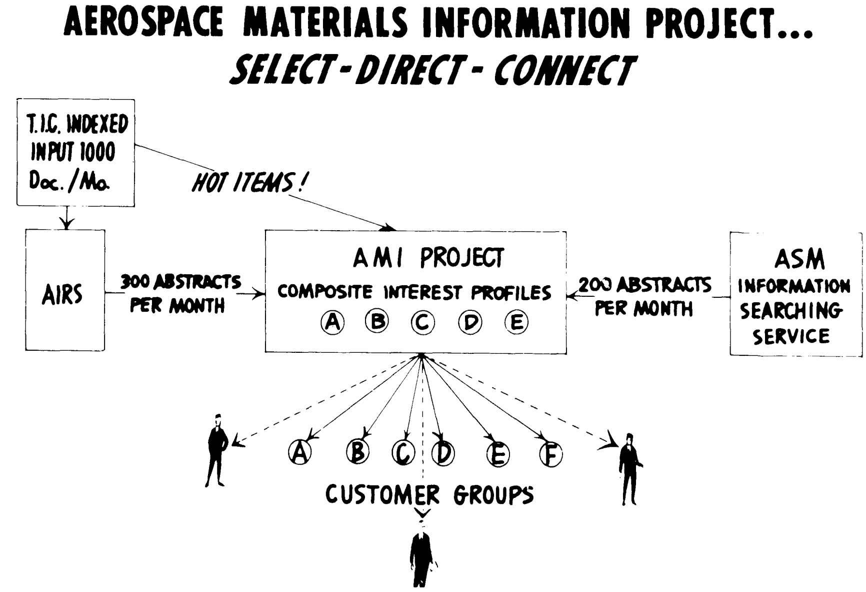
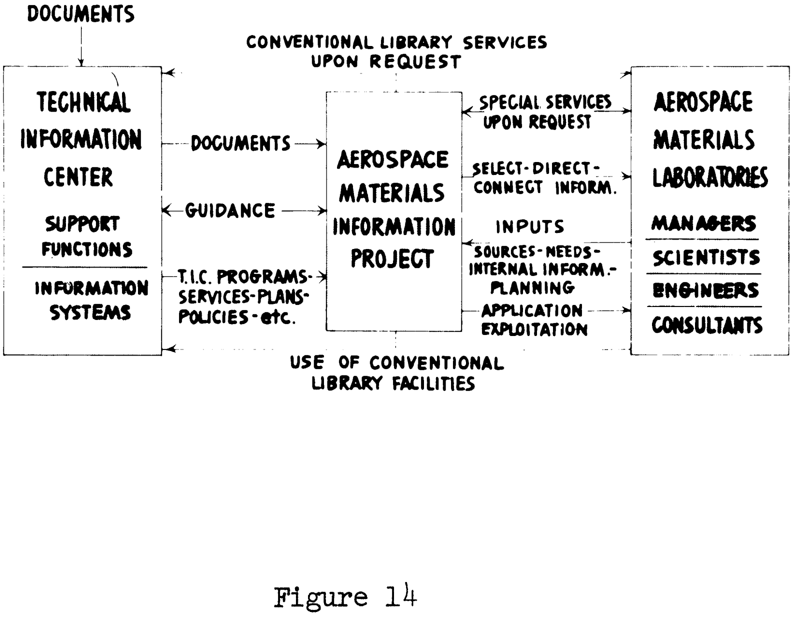


Figure 13

In addition to the alkali metals information survey referred to earlier, the AMI Project is currently engaged in a large scale current awareness effort (Figure 14). By correlating the information requirements of its clients, the AMI Project has established a bi-weekly input of abstracts from the American Society for Metals Documentation Service. As they are received, the abstracts are screened and distributed to appropriate materials clients. On a monthly basis, the Automatic Information Retrieval System is used for selectively disseminating its current input in the same subject areas to the same materials clients. Thus, the Division's aerospace materials scientists and engineers are now participating in a current awareness service of considerable scope and depth, yet in brief enough form for rapid assimilation.



AEROSPACE MATERIALS INFORMATION PROJECT...

Figure 14

FIND-X

FIND-X, a computer-produced manual version of the Automatic Information Retrieval System, is available for installation in areas geographically removed from the Technical Information Center. Contained in four search books and 25 abstract binders, FIND-X provides limited immediate manual access into the Automatic Information Retrieval System's file. For an exhaustive search of the file, an engineer may request a machine search. But while waiting for search results (usually within 24 hours) the engineer may "dig out" at least a few references on his own from FIND-X. Also, by browsing FIND-X, the engineer may estimate the fruitfulness to him of a machine search. One FIND-X is already in use in the Small Aircraft Engine Department's Library in Lynn, Massachusetts, and the Technical Information Center expects to lease the system to other groups within General Electric. Should demand justify the cost, FIND-X will be modified into a machine-printed manual uniterm system with an appropriate vocabulary and thesaurus.

Small Scale Retrieval Devices

Special purpose, small scale retrieval systems are set up and maintained by the Center for the use of specific engineering groups. The information indexed into these systems is also available in the Automatic Information Retrieval System. Consequently, a specific group of engineers can do its own retrieval work with its manual retrieval systems at their desks while at the same time the information is available to others via AIRS. A "Peek-a-boo" punched card system, a manual uniterm coordinate index and a keysort system are currently in use in three engineering areas in the Evendale Plant.

Abstract Bulletin

The Center's abstract bulletin, TIPS, is issued weekly, 50 times each year. Each issue contains 200 to 250 abstracts of new acquisitions. TIPS is a product of mechanization. It is one of four different products obtained from the punched cards prepared for a particular document. As shown in Figure 15, the Center derives the input for its Automatic Information Retrieval System, conventional catalog cards, library circulation cards, and TIPS items from the same packet of punched cards for a document. TIPS is a general dissemination tool and accounts for 75% of all loan requests received by the Center's two libraries.

AutoCom

An experimental technical information tool under development by the Center has been dubbed "AutoCom" for automatic communication. The system utilizes an electronic telephone answering device to collect input for the Automatic Information Retrieval System. By using his phone (as shown in Figure 16) -- inside or away from the Plant; day or night -- a scientist or engineer may call in information which he thinks may be of interest to others or which he may wish to refer to at some future date. In response to instructions he receives over the phone, the information contributor identifies himself and gives bibliographic data, an abstract, and his choice of index terms for each item he calls in.

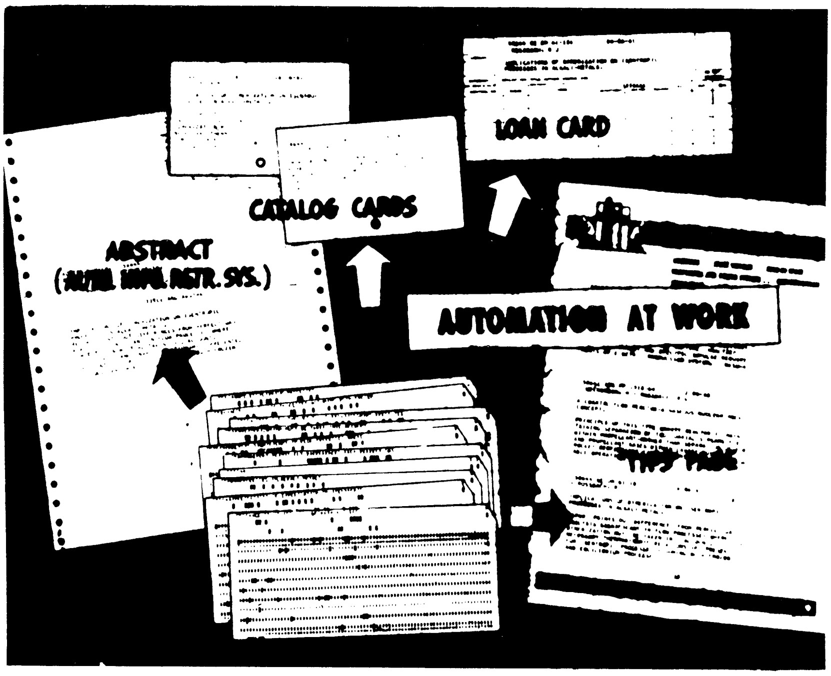


Figure 15

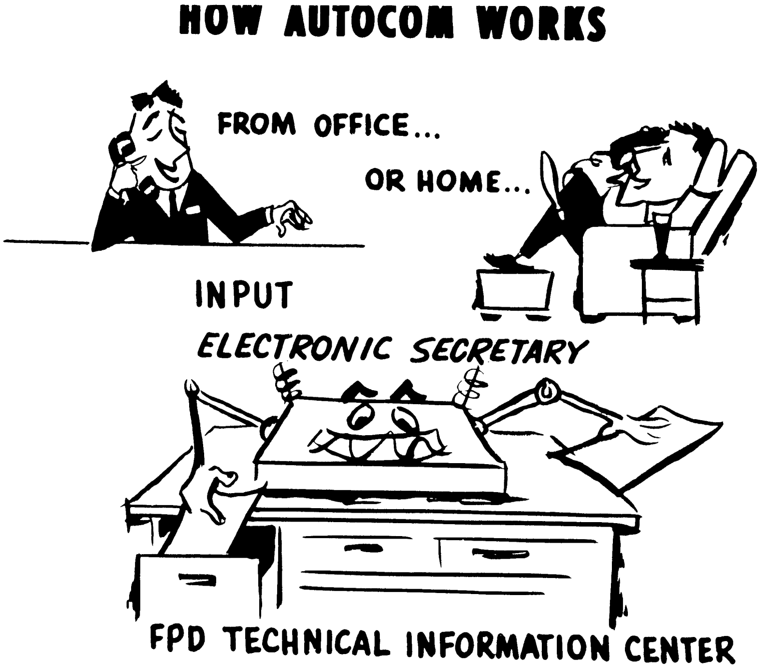


Figure 16

The key to Automatic Communication lies in the fact that when information is fed into the retrieval system, the contributor's identity is maintained in association with his contribution. Thus, when that information appears as machine output during either a retrospective search or a current awareness run, the recipient of that particular abstract bearing the contributor's name, title and extension may be fed to a person of related interest and experience or, perhaps, to one who even is actively engaged in related or overlapping research. Hence, "AutoCom" may correlate people as well as recorded information. And not to be overlooked is the information selection function served by such a device. With several hundred scientists and engineers using "AutoCom," the Technical Information Center's normal acquisition efforts may be greatly extended.

IV. Conclusion

Developing and implementing an aggressive IR program in an industrial R & D organization is not easy. The problems encountered in attempting to handle technical information on a selective basis are more complex than is generally realized. Progress toward their solution is expensive. Raising the caliber of our information service has been accomplished through the use of technically qualified personnel and automation. This has meant an increase in the level of financial support required by the Center of nearly 35% over the past five years. However, we are now providing far more information, more carefully screened and processed than ever before. Our acceptance as an aggressive engineering service function is on the rise. The scientists and engineers toward whom our efforts are directed are beginning to make effective use of our specialized services such as Current Awareness. Higher management is now gaining a better understanding of the information problem and of our role, and is taking a longer range view toward our work. But it was only after four years of continuing struggle through periods of widely fluctuating financial support that we achieved today's tentative status of stability. And, we are sure that until we can concretely demonstrate the real impact of our IR services on the technological and financial well being of the Flight Propulsion Division our continued acceptance by higher management will be tentative and will be largely dependent upon persuasion rather than visible results.

Therefore, not only are we concerned with the problems associated with IR and the use of computers but just as importantly, we need to learn how to measure the end results of IR, i.e., values gained from its application as an engineering tool. In our opinion, there is a real need for a practical study of this problem because we believe that herein lies the key to successful solutions for the many IR problems intensified by the technical information explosion.

Donald L. Katz:

The last paper is on the increasing competence of the engineering graduates in the use of computers. We have one of the men from the Computer Committee of the College of Engineering, Mr. Richard Wilson, who is going to speak to us. He is a graduate of Carnegie Tech, and took his graduate work at Lee High and his doctorate here at the University. He is an Assistant Professor of Industrial Engineering. He has, as I said, been on our computer committee since its organization and is active in the area, in fact, he has written the part of our project report on how computers are integrated into the educational process for industrial engineers. He is going to speak to us, in a general way, on increasing the competence of engineering graduates in the field of computers. I am pleased to present to you Professor Wilson.

THE INCREASING COMPETENCE OF ENGINEERING GRADUATES IN THE USE OF COMPUTERS

Richard Wilson

Assistant Professor
Industrial Engineering
The University of Michigan

THE INCREASING COMPETENCE OF ENGINEERING GRADUATES IN THE USE OF COMPUTERS

I would like to address myself to two questions this afternoon, the first, "What is the state of computer knowledge possessed by engineering graduates of today and the immediate future?" and second, "what are the implications of this knowledge for you, as people who will be employing these graduates?" I am indebted to the previous speakers here for two reasons: first, I think they have fairly well established the fact that computers are an essential, or if not essential, at least a vital tool for engineering and industry, and second, I am indebted to the previous speakers, in particular Mr. Hart, for giving part of my talk. So if you hear repetition, this will I hope strengthen my conclusions. If you hear some discrepancies you will then find points for later argument and discussion.

Let me begin, first of all, by describing the situation here at Michigan as best I can. We have been blessed for a number of years with a very liberal and I might add, particularly for Dr. Galler, a very effective computing center operation. The computing center has operated on the basis that students are essentially free, and I mean free in a literal sense of the word, to come and use the computer with relatively little control over the kinds of problems that they may wish to try or even over the practicality of these problems. So it has in this sense invited experimentation on the part of the student which I think at the educational level we will agree is probably desirable.

The computing center here has also made, I think, a marked contribution to the ability of students to communicate with the machine in their development of a Fortran type language which is easy to learn and utilize and therefore facilitates the student's learning to communicate with our current IBM 709. So, we have computing facilities which are readily available to the student. We have a language available which is easy to learn. We have auxiliary machines and equipment which are also available to the student, and in summary we have an environment which is very conducive to the student to turn to computers if he so desires.

Now, it is fairly apparent that the students are not going to turn to this equipment unless they have some initial guidance. For this purpose there are courses and planned opportunities for students to make use of the machine. To be specific, the computing center has offered optional, noncredit lectures in programming using the MAD language. The computing center is now offering, in conjunction with the engineering college, a one-credit course which is open to anyone at the sophmore level.

This is again directed toward the use of MAD language and hence the use of the computer with some additional orientation to the mathematical-numerical concepts involved. This is currently, I understand, being taken by roughly a thousand students. I do not know what percentage of these are engineers but I am sure it is quite large. The voluntary courses normally enroll, I would guess, somewhere in the order of 100+ students who receive no credit. Now it must also be obvious to you that there are a large number of other courses which are offered with various degrees of emphasis and various orientations toward computer work. In particular, it is obvious that the electrical engineering department is oriented toward design concepts of computers and in this area have a large number of courses, both digital and analog. It is also obvious that the industrial engineering department is interested in the application of computers to systems design and data-processing problems. The mathematics department is offering courses in numerical analysis as well as machine and compiler language development. We also have a master's, and doctorate, interdisciplinary program in communication sciences which is concerned with theoretical understanding of communication and processing of information.

These are all programs which are specific in their computer content. That is, they are oriented or directed toward the introduction to, or expansion of, knowledge in the computer field. In addition to this in the last several years the Engineering College has been fortunate enough to have a grant from the Ford Foundation with three primary objectives. The first of these was to look at and implement ways of training and updating faculty in the use of digital computers in their fields. Second, to study and look at ways of implementing and introducing computers into current engineering curricula and to determine what impact this will have upon the content of these programs. And third, to examine the implications toward education of various kinds and size of equipment. What is desirable and efficient for instructional use, or what is required to handle instructional loads which may be placed on computing facilities. Now the result of this over the several years has been that we have had the opportunity to educate, for periods of a semester or a full summer, some 75 faculty members from universities throughout the country. We have had symposia which have brought additional faculty here for periods of a week or less. We have published a group of brochures and publications, one of which Professor Katz spoke of in describing our attempts to introduce computers into various programs in the college. What are the results computer orientation in the educational environment?

Figure 1 is simply a listing of some of the general problem areas in which faculty members who have worked on the Ford Foundation project have prepared as useful problems for computer analysis and presentation to their students. These are chosen at random from the complete set of problems which were developed and my only purpose in selecting these is simply to show their diversity, and large number of different fields from which computer applications are possible. Those of you who are familiar with each field may be able to appreciate the potential of computer application.

TYPICAL SAMPLE PROBLEMS

OPTIMIZATION OF REACTOR OPERATION

HEAT BALANCE FOR AN IRON BLAST FURNACE

MOMENT DISTRIBUTION TABLE FOR CONTINUOUS BEAMS

VIBRATION OF BEAMS ON SPRING SUPPORTS

PROPAGATION PROPERTIES FOR ELECTRICAL TRANSMISSION LINE

QUEUEING DYNAMICS PROBLEM

EFFECT OF PRESSURE AND PROPELLANT RATIO ON HYDROGEN-OXYGEN ROCKET PERFORMANCE

Seventy-five or a hundred problems have been developed for computer usage in connection with specific courses. These courses are not computer courses; quite the contrary. These courses are traditional engineering courses such as kinematics, mechanical design, unit operations, and data processing. These are not all computer oriented but the attempt is being made to show how the computer has an impact and can be utilized effectively in these particular areas.

Next let me describe some of the computer work in a particular field of industrial engineering. We are requiring that all of our students take the one-hour course in programming so that when they hit our department we will find them confident to use the machine if they find it necessary. We are then requiring them to take an additional three-hour program which is essentially split into two areas: the study of data-processing systems and secondly the study of the application of simulation to manufacturing systems.

One of the ways we have approached this is to permit the student to work a problem which is of his own choosing. Something unique happens at this point. I am not sure how to explain this, but something happens when you turn a student loose with a computer in the sense that he suddenly has a completely new concept of the kinds of problems and the things which he can now handle. Let me substantiate this in several ways, first by listing or describing very briefly the kinds of problems which students choose to work on in connection with computers. Some of these are abstracted from their previous experience and others represent hopeful experience, I suppose. Let me explain that the course in which these students were enrolled is an undergraduate level course which is elected or required to be taken by junior, senior and a few graduate students. If a man comes in with military experience we find that he frequently wants to work on a problem from his field. For example, we have had a man from the artillery who wrote a computer program which would represent the data processing problems of an artillery captain in the field who is equipped with a certain mixture of tank, infantry, and artillery capability and faces an enemy of like or different, but known capability. He would like to process the known information about the capability of the enemy in order to determine which avenue of advance should be used, and furthermore, what his mixture of tank, artillery, and infantry ought to be in the face of the mixture of enemy concentration.

We have had another student who tackled a problem of simulating a interceptor-bomber raid in an attempt to evaluate the effectiveness of the interceptors against certain configurations of bombers given hypothetical parameters relative to the reliability of the radar, the reliability of the interceptor plane, and the reliability or probability of a hit, etc.

We have had a mechanical engineering student who took a belleville snap-spring problem, a straightforward problem in the mechanical engineering design sense.

Another student tackled a very messy combinatorial problem which can best be described as a pallet-loading problem, I suppose, in which you have a given area possibly 40 x 48 inches, and boxes of various configurations. You would like to load this pallet with the maximum number of boxes, or conversely with the minimum void spaces.

We have had students who have successfully flow-charted and programmed the personal income-tax computation on a somewhat restricted scale. In a sense they are doing the same job which the internal revenue department is trying to do except they are doing it for the individual tax-payer. Maybe the individual can make use of the internal revenue computer facilities eventually. Another student, a handsome young man, probably attractive to the young ladies, decided he would look at the problem of the sorority rushing selection procedure, which incidentally is not an easy problem. There are 25 or so sororities which, at the end of rushing period indicate first, second, or third preference of girls and up to 600 girls who also indicate first, second and third preference of sororities. And in some way you have to match these in order that you get some maximum satisfaction for both the girls and the sororities. Of course some of these girls do not get bids and some of the sororities do not get their quota either. We had another student who, indicative of his interest, attempted to simulate the game of tennis and the scoring process which goes on in the play of this game.

Now these programs, in part, are trivial in the sense of being practical tools. On the other hand they quickly demonstrate to the student a certain important thought process. Let us take the example of the tennis simulation. The man is forced to ask himself what are the parameters, or what are the factors which describe the game of tennis in terms of the simulation, and is this valid? He is mature enough to recognize that some of the things may turn out to be quite frivolous and merely an intellectual exercise. In any case, it is obvious that the instructor could never think up these problems. The students just explode with all sorts of ideas and the computer offers them a new way of thinking about these problems and the feeling of a tremendous amount of creative power.

There are lots of other probably more stimulating and more realistic efforts going on at higher graduate levels. This is the sort of thing, in any case, which is going on at the University of Michigan. We can fairly say that all engineering undergraduates at the University of Michigan will have at least a minimum of knowledge of how to program in a compiler language by the time they graduate. I am sure that most of them will have a far more sophisticated idea of the capabilities and the applications of computers in their field. Now, I would like to broaden our horizon here and look at the implications of what is going on in other schools, insofar as we can from this spot.

In Figure 2 is a preliminary compilation of the results of a survey which the Ford Foundation people under Dr. Katz have carried out. This survey was sent to all engineering colleges and this figure represents a summary of the responses tabulated in terms of the number of engineering students, enrolled at the undergraduate level in all of these colleges which were surveyed. At the time I made up this chart returns were incomplete. In any case, we had returns from colleges at which about 90,000 engineering students were enrolled. Out of these 90,000, 40,000 or almost a half, are required to be able to program at some level. Twenty-six thousand, or about a third, are required to program in some of their departmental programs. The remainder from which we have reports indicate that they are not required to program. Perhaps as a matter of prestige.

or maybe as recognition of the inevitable, in most cases, these colleges were studying this requirement and indicated that they expected to do something about it. This is a snapshot picture of what exists now.

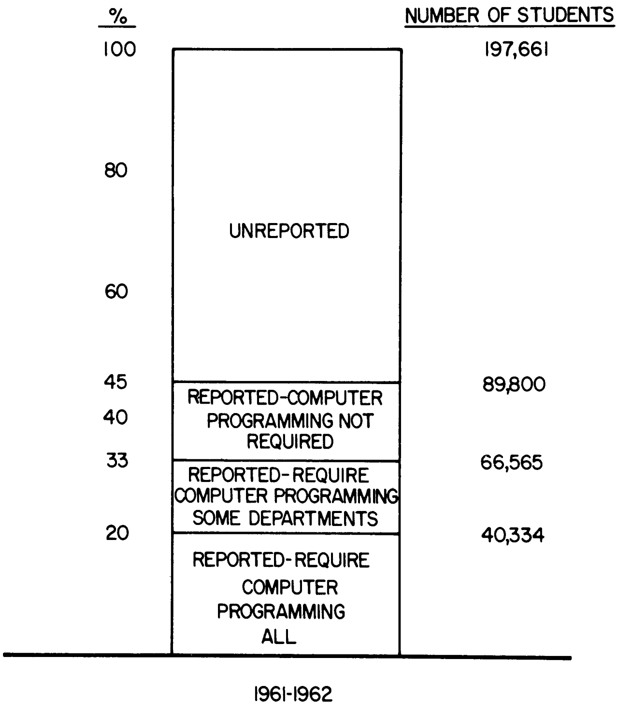


Figure 2

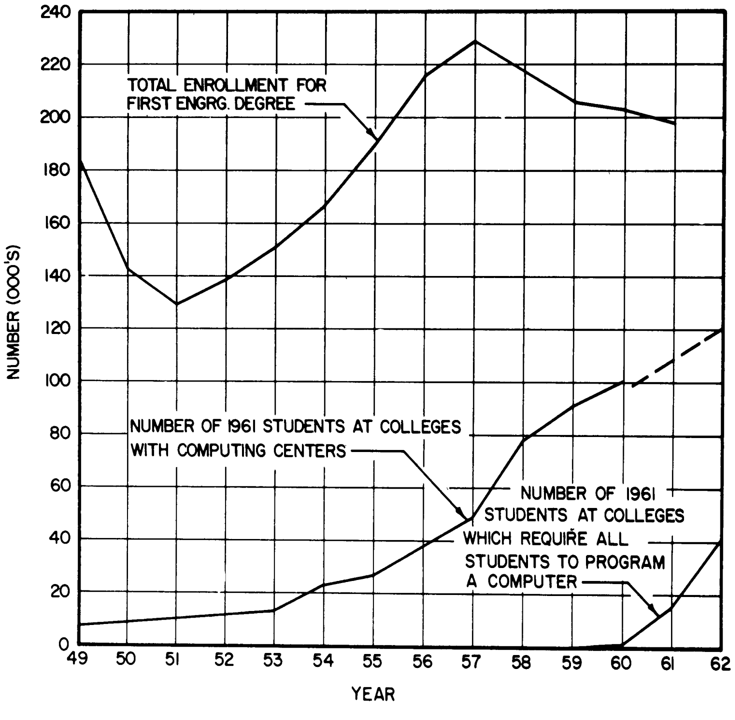


Figure 3

Let us look at Figure 3 for signs of the future. The top curve is an indication of the total number of students enrolled in engineering colleges for their first, or bachelor's degree. We see that this has had wide fluctuations the last 13 years. The University of Rochester has been making an annual summary of responses to a survey about the computing centers at various schools. This is a report covering only those schools which chose to respond. It does not by any means indicate all schools which have computers. But as a rough guess, the second curve is a conservative indication of the number of engineering students at colleges with computing centers. Now the interesting thing, in the light of today's symposium, is possibly the third curve which indicates the number of engineering students who must take programming or must use the computer at some phase of their undergraduate degree program. We can see that this has only really gotten off the ground in the last several years and it is moving at a fast clip.

Now the implication I think is fairly clear. I think we would be safe in saying that all engineering colleges will have access to, or will be using, computers in their educational work in a very few years if they currently are not already. Secondly we can extrapolate from the data and say that you can expect that practically all engineering undergraduates will have some knowledge of communication with computers.

All right, now, we can look at our second question in this light and ask ourselves what does this mean to you in industry who will be hiring these students. These are speculations about what may happen. But first, what characteristics will these students have which students ten years ago maybe did not have?

OBJECTIVES OF EDUCATION

A. FACTS
B. INTELLECTUAL SKILLS
    COMPREHENSION
    TRANSLATION
    INTERPRETATION
C. APPLICATION
D. ANALYSIS
E. SYNTHESIS
F. EVALUATION

Figure 4

Now, it is always good once in awhile to look at what we are trying to do in education. A group several years ago attempted to define the goals of education, particularly in the cognitive realm which is clearly the realm of engineering. These are the six basic goals of education which they felt fairly defined all levels or all of the ramifications of goals in cognitive education, Figure 4. The first and probably the simplest level is an accumulation of facts. Memorization, in a sense, files this information in your brain and knows how to get it back out when you want it. The second level is a development of intellectual skills, these including comprehension, that is, if you read a document do you understand it? Translation: can you then translate this problem in English, for example, into a mathematical model of the words; and thirdly, can you interpret what this then says? Could you translate it or interpret it back to someone else so that he would also understand it?

Next, we like to think that our students in various courses are learning to apply these intellectual skills to the solution of problems which may be not new, but may be characteristic problems of a type they have seen before. Fourth, we hope that they build some degree of confidence in the area of analysis, that is, given the characteristics of a system can they analyze it and describe how it will behave under other values of the parameters? Fifth, we hope they build confidence in synthesizing elements together into one comprehensive design, and sixth we hope that they build some element of judgement or evaluation, whether this be judgement of the desirability or judgement of the merits or contribution which their work is currently making.

Now tieing in with what Mr. Hart said earlier, I would like to look at the fifth goal, synthesis, in a little more detail. Figure 5 will define more carefully what synthesis is interpreted to mean or what the characteristics of a product of a synthetic or design process are.

CHARACTERISTICS OF SYNTHESIS

1. PRODUCT IS A UNIQUE COMMUNICATION
2. PRODUCT IS A PLAN OR PROPOSED SET OF OPERATIONS TO BE CARRIED OUT
3. PRODUCT IS A SET OF ABSTRACT RELATIONSHIPS

Figure 5

First of all, the result of such a synthesis effort is unique to the man or the group who made it. It is a unique communication. Secondly, it describes in some generality or detail what ought to be done, what the sequence of operations are, what the activities which ought to be engaged in, in order to carry out this plan are. And thirdly, we expect that it would be in general, describable, or maybe necessarily described in abstract terms.

In Figure 6 we see that this activity of synthesis involves a personal expression on the part of the designer or the person who is engaged in it. It involves independence of thought, since presumably the particular problem has not been solved before. It hence also involves creativity on the part of the individual engaged in it. Now, my contention is that these are the characteristics which students are discovering or these are the activities which students are engaging in in a new way when they tackle problems on the computer. They have discovered -- without our telling them since I guess maybe we did not even realize this ourselves, -- they have discovered that the process of going to the computer involves the student in these characteristics. In a sense, programming a computer -- even a trivial program -- requires the kinds of activities which are inherent in synthesis, at a micro-level.

If this is true, it helps to explain why students become so overly engrossed in many cases in the process of using the computer; they become overenthusiastic. They spend more time at this activity than probably is warrented and my assertion here is that they become

SYNTHESIS EMPHASIZES:

1. PERSONAL EXPRESSION
2. INDEPENDENCE OF THOUGHT
3. CREATIVITY

Figure 6

immersed and satisfied because they realize that this process is inherently creativity or synthesis. They therefore learn how to synthesize at a fairly early stage in their engineering program.

The result of course in new self-confidence. It is a new willingness to tackle problems which may really be beyond their capability. In any case, they have the world by the tail at this point.

I want to make a series of statements about what I think this augurs for those of you who will be receiving these young men. First of all, I think that these men will have an appreciation of the capabilities of computers in various possible applications, in particular in their own field. They will also have some understanding of the implications of computers for a broad class of applications.

Secondly, if they have had this kind of practice in programming computers, they think about problems differently. They have essentially been reinforced in this process at a micro-level of creative thinking. They have recognized the need for defining the problem quite carefully, for deciding what are the important variables or for choosing the variables they wish to look at, then relating these abstractly and analyzing their results.

Thirdly, chances are that a large proportion of these fellows will want to be involved in computer work. As a matter of fact, if they have some small exposure to computers, they will want to expand this type of experience until it has become tedium rather than learning. So it may well be that the first interest of many in approaching industry will be that they would like to flow-diagram and even program some of the problems which they would be working on. It is possible, and I see this happening in some cases, that these fellows will be selective about the companies they want to work for based upon whether they think they can get this kind of additional computer experience in that company. I think, also, that it is very likely that they will need some guidance from you to restrain them from attempting to use computers unwisely in some cases. And I think, finally, that the result of this will be that they will be able to handle, and they will be far more efficient in handling, a larger class of engineering problems than graduates of ten years ago or more. I think they will have a new conception, as Mr. Hart pointed out about how they will tackle many of their engineering problems They will no longer be concerned about the computational limitations because they will realize that somewhere the ability exists to do this computational job very quickly and rapidly.

Now, my general conclusion is that these fellows are going to be valuable, if they get the opportunity to use their new ideas and if they also get some guidance to keep them from going haywire in overenthusiasm. I think this is a picture of the kind of young man which all engineering schools will be sending you soon.

I would entertain questions at this point, whether it be details about the kinds of effort which is going on at the University or whether it be continuation of this subject of what this means to you.

DISCUSSION

QUESTION: You indicated that these computer courses are required in electrical engineering at the sophomore level. Are there other curricula in the University that require computer courses?

ANSWER: All but two of the engineering departments now require this same course and also at the sophomore level.

QUESTION: Outside of engineering, how many of the folks are using the computer in terms of education?

ANSWER: I don't think anybody is requiring the course. I find more and more people being couseled into it and the Mathematics Department is thinking of requiring it for certain programs in the department, like statistical and actuarial; I think the Engineering School so far is the only college requiring the course.

QUESTION: You mentioned the Ford Foundation report. Can you give me the name of it and is it available?

ANSWER: There are quite a number of such reports. One of them is available as you walk out of the room; there is one on the table out there which you can pick up. If you would like some of the others, such as annual reports in fields other than the one covered in this report you could write to the Ford Foundation Project of the Engineering College and ask for copies of our annual reports. There are documents on teaching analog and digital computers. Each of these reports includes a large number of sample problems which have been presented or developed by people in various disciplines of engineering.

QUESTION: What is being done in the area of business problems such as income tax computations and inventory control, and things like that?

ANSWER: Well, this falls into two areas as I see it. Our industrial engineering course in data processing devotes roughly half of the semester to data processing problems relative to the computer. There are other courses in various departments which approach the mathematics of these kinds of problems but not necessarily with computers. The Business School also offers a course in electronic data processing but possibly with more emphasis on financial controls as opposed to manufacturing control, scheduling, inventory, etc.

QUESTION: How do you get all these students on the machine?

ANSWER: I would be glad to say just a word about that. We had 60 courses in the College of Engineering last spring, I believe it was and presumably a similar number now, where the students have a number and are permitted to solve the problem on the computer. We have key punches scattered in the various engineering buildings and a couple of places where the students can throw their card decks. They are picked up, taken to the computing center and brought back with the results. We feel that a high percentage of our students will in the course of a year or two, all of them we think eventually, have had computer experience through this system. We have had experience in the analog field and I think most of our students are taking a laboratory course in which analog computers are used.

QUESTION: In this closed-shop technique you have, what advantage does a student have if he wants to trouble shoot his program? If this is all automatic what benefit does he get out of the program?

ANSWER: Well, it depends what you mean by trouble shooting. I think what you are asking is how does one correct his program with the restriction that he can't get to the machine itself. Well, we do our best to educate the student while he's writing his program to call for print-outs of the numbers that are going to make a difference to him as he goes along. Knowing which of these numbers comes out, which ones are printed out, he can diagnose what went wrong. I'd like to mention that we have simple format descriptions for use when we want to print something out. We have developed for the MAD translator very simple statements like "read data" for input "print results, a x + y b cos c," etc., for output, so that for getting intermediate numbers out for checking a program you simply write "print results" and a list of things you want to see. It's very easy for the student to get numbers out and we encourage people to do their coding this way, away from the machine.

QUESTION: Why do you start programming with sophomores? Why not freshmen for example?

ANSWER: Well, maybe you'd like to speak about the programming course itself. The reason we probably don't start with the freshmen is that our sophomore courses aren't geared to begin using the computer. We think there's no point in having a gap between the time students learn the basic material in programming and they begin using it in a course. I would recommend teaching it just before the semester in which you are going to have a problem course which uses the computer. You can speak to the teacher of the course, Dr. Galler.

QUESTION: Do you teach programming for the same reason that the students do their own keypunching? If you had a professional programming staff would that have made it unnecessary for students to program their own problems? In other words why do you teach programming?

ANSWER: Well, we don't think it would be adequate learning for the student if professionals wrote his programs. I think that there is an analogy to learning what the sine and cosine is before we turn to the computer. We can then go ahead and forget the details because this subroutine is now available as part of the library. In terms of what Mr. Hart said, we can learn something and then find it no longer necessary because we now are able to properly use it. I think that programming is the same kind of thing. Until a man has programmed, he doesn't fully appreciate what is the essential part of the machine, what are its limitations as well as its capabilities. We need people who are programming specialists in this area, but in general I think our philosophy is that we want the student to be able to program in order to understand computer capabilities. Then, if he is interested in pursuing this he may then go in this direction. Otherwise he may go in a different direction which may draw upon the programming specialists in this area when needed.

QUESTION: I wonder if it isn't partly a function of the phase of the operation at the University that each man has to do his own?

ANSWER: I'd like to speak to that. We believe that the people learn the logic of solving the problem by programming it. We think that's the way in which they are learning. Maybe they learn more about the logic of solving the problem by going through the programming process than they do in completing its solution. I think everybody, in order to really get an appreciation of the computer needs to face that moment of truth when he gets to the computer to find out whether the program is going to run or not. There's a lot of difference between a mathematical description of a problem and a description of the detailed procedure by which the problem is to be solved. These are interrelated. You learn the techniques of problem formulation and the approaches to the solution of a problem by dealing with the final procedures that a computer is able to cope with. This is part of the learning process in using the computer and there's a big, massive gap between a mathematical description of the problem and a procedure for solving that problem. The engineer needs to be aware of these procedures in order to gain a true appreciation of what a computer can do and what it cannot.

QUESTION: Is mathematics made easier?

ANSWER: Quite the contrary. I would say it's mathematics made more relevant. The use of the computer doesn't make mathematics easier. It now permits us to make problems easy and requires better mathematics.

QUESTION: You mean more precise answers?

ANSWER: Yes. But it also opens up to us the problems which have escaped solution either because of their computational difficulties or infeasibility or because they represent random processes for example, which perhaps cannot be described by mathematical formulations. You can't hope to have the people at the computing center knowledgeable enough so they can make decisions in all the areas which are coming to the computer these days. You've got to teach engineers what the computer can do so they are in the best position to decide how to use it in their own field.

Well, may we change the line of the discussion. Would you like to bring up the discussion of the previous topics?

QUESTION: What about this idea of the remote console attached to a computer?

ANSWER: Yes, I'm sure that this is one of the things of great interest. Well, maybe five years from now we will have remote access, a console for access to the big computer and we'll be able to carry on problems in the classroom that they would like to solve right then and there. I know that Professor Perlis at Carnegie hopes someday, maybe to have typewriters around his campus so that the student can go anywhere, go to the computer, solve his problem, call off the program, try some new solutions, get the answer back and go his way. This is the sort of remote control that he's thinking of. I'm sure that it will have a lot to do with educational process.

QUESTION: Could I ask a question on that one? Are engineers supposed to be such fast thinkers that they have to be in a console now? It's a different kind of engineer than I'm used to. That is, you've written a program and see the answers. Do you have to be there at the console to make the changes or should you go back to your desk and think about it a couple of days -- or is this again more gadgetry?

ANSWER: This would depend upon the type of problem you were concerned with. I think what we're talking about is making this available to people should they have problems which were adapted to this. Certainly you wouldn't be forced to using it. If we can adjust parameters on a digital computer the same way people do on analogs and it's useful, we'll do it. Other uses are for watching the path of a convergence of an iterative process to make sure that you catch it before it spends 10 hours computing and never worked at all. During debugging, where you feed-back right away that you've made a mistake, you can correct it, and so on. Remember that you don't have to be able to think fast because the machine will be fast enough to be able to go on and do somebody else's problem while you think about your adjustments.

CLOSING REMARKS

D. L. Katz

I would like to suggest that we conclude the final session. For those of you who are interested, Bryce Carnahan, Assistant Director of our project, as well as Dr. Galler and Professor Wilson, will be glad to discuss your questions with you. In concluding, I would like to thank Mr. Bahls, Mr. Gray, Don Hart, Mr. Hubbell and Professor Wilson for their presentations and all of you for your comments and questions, and we appreciate your being here for this industry-education program. We are very appreciative of your presence. We hope that you will stay around and have some coffee and have a little discussion in the halls afterwards.