I. B. M. CONFIDENTIAL

March 31, 1960

Subject: The Integrated System Project at General Electric

The enclosed material represents a reporter-like description of work that I was responsible for while employed at General Electric.

All the information contained has already been released, much of it at a System Development Corporation meeting in July, 1959. While it is realized that many details are lacking, this is necessarily so in order to avoid any implication of disclosing General Electric confidential information.

However, it is my feeling that the general area covered and certain of the techniques described are of value to designers of industrial processing systems.

Burton Grad

Burton Grad
Programming Systems
IBM Applied Programming

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THE INTEGRATED SYSTEMS PROJECT

AT GENERAL ELECTRIC

A summary of non-confidential information about the accomplishments and philosophy of a research activity directed at the design of an automatically operated business.

Burton Grad
Programming Systems
March 28, 1960

THE INTEGRATED SYSTEMS PROJECT AT GENERAL ELECTRIC

General Electric's Services' organizations have attempted to design an advanced automatic system, one that would be able to respond more efficiently and more economically to incoming customers' orders.

Certain general objectives were established in order to accomplish this task:

1. The new system was to be economically practical and technically feasible; it should be broadly applicable to many departments of General Electric.

2. The system should be multi-functionally integrated and provide a close linkage between the office and factory.

3. It was to be designed with bold innovation in order to break the historically accepted business systems patterns.

They hoped through research to develop new concepts and tools for use in designing such new systems. They hoped to develop new criteria for technically and economically sound approaches to automation that would help determine which particular new techniques should be used in specific businesses. They wanted to provide a foundation for future progress through research and development.

To pick an initial area for this exploration, they analyzed some of the current weaknesses of industrial systems.

1. Typically, delivery cycles are quite long when compared to the product's cost. This is particularly true of manufacturing cycles in relation to the actual processing time. Work-in-process inventories are correspondingly excessive.

2. Indirect labor costs are increasing steadily. Many factories even joke about the fact that they can't make a shipment until the paper weighs as much as the product.

3. A third area is the high redundancy of information used in factory paperwork. For example, on a line of shafts used by a successful motor manufacturing department, it was found that some three hundred different drawings had been prepared

> over the course of two years to take care of each minor variation. On each of these drawings, there was some sixty to seventy fields of information. Of these fields, better than 80% were completely fixed. For every shaft only 20% were truly variable.

With these and other significant problems in mind, they sought the areas of an industrial business system that would have the greatest impact in these areas of opportunity. This heart of the business process was called the Main Line System. This Main Line System included requisition editing, product engineering and drafting, manufacturing and quality planning, cost determination, production control and purchasing plus the actual shop operations.

Substantial amounts of money are involved in the Main Line System. Normally, 100% of the direct labor and 100% of the direct material is tied up in the Main Line System. At least 40% of the indirect manufacturing expenses are also in this area. All of the productive raw and in-process inventories are in this category as well as approximately 80% of the plant and equipment investment. In total, this area probably accounts for 75 to 80% of product costs and a similar percentage of investment.

To perform a research and development job on these multi-functional problems, a multi-functional team was organized representing the various business functions: Engineering, Accounting and Manufacturing. In this particular study, Marketing and Employee Relations were not included because the particular system defined did not require their extensive contribution.

In a decentralized company like General Electric, planning such a program is not uncomplicated. There are two types of problems that arise:

1. The integration of staff planning people into a closely knit team is complicated by the fact that there is no component in the organization responsible for multi-functional systems work. Therefore, effective work requires mutual participation of the functional services who have no common manager short of the Chairman of the Board, who is the Chief Executive Officer. Basic problems like leadership, budgets, relative functional roles, decision making, reporting, etc. were major problems which had to be overcome.

2. A second problem in a large decentralized company is developing concepts in a framework that will be both understandable and meaningful to the many operating components. Because they have such a variety of products, processes and markets, that generality is elusive.

They felt that an ivory tower approach would not provide an effective atmosphere for integrating systems design work nor would it particularly aid in selling any new concepts which were developed. What was needed was a real business -- a "living laboratory". This selected operation had to be representative of the breadth of businesses in which General Electric engages. Also in picking a business, they wished to select one where the existing information was in sufficiently clear form to be readily usable since they felt that "you can't automate a mess". They sought a well run business where they could concentrate on advanced development rather than having to devote time to cleaning up existing problems.

They also felt that by carrying on their research in a particular business, the systems team would have its attention focused on specific, clearly defined problems rather than the more vague, imaginary difficulties. In this way, the creative contributions were concentrated on the areas most needing improvement.

A business system has five elements:

1. It has information resources including the various decision criteria which are currently in the form of reference files.

2. It must have decision makers capable of taking the transaction inputs and matching them with the information resources to determine a course of action.

3. It must have communications channels enabling it to transmit its decisions and in turn to receive feedback information concerning operating performance.

4. It must have a physical processor which actually transforms material through the use of men, machines, and energy in accordance with the instructions given it.

5. The physical processor must have access to the physical resources of men, machines, materials and energy.

After the multi-functional organization was completed, a clear and specific design program was followed. The first stage was that of data gathering. This involved getting all the facts concerning present inputs and outputs, volume of devices, design variations, manufacturing facilities, historical performances, etc. This phase began in November 1958 and took approximately six months; it led directly into the second phase: problem analysis. During problem analysis, all the information gathered during the first phase was digested, reviewed and an effort made to determine clear cause and effect relationship between changing external conditions and changing internal performance.

The third phase of the program was that of preliminary systems design. This achieved a first specification of what might be called the basic system. This lasted approximately one month and brought into play the design efforts of not just the general systems designers but all the specialists in the various areas.

The fourth stage was that of detailed systems design. This refined the specifications in great detail. It clearly indicated those phases which needed to have their technological feasibility proven and those that had already been clearly demonstrated in previous work.

The fifth phase was that of construction of a prototype to demonstrate application of the new ideas. It was a bread board model, and not yet an actual operating model.

The sixth and final phase of the program was that of testing, training and evaluating. The bread board model has been tested against a variety of circumstances and found to be very satisfactory. The training objective was carried out during 1959 along with initial evaluations of potential savings.

While these are quite conventional steps, the important new concept was the application of the systems approach to business systems problems. With this systems approach, they treated the entire Main Line System as though it were a big black box with only one transaction input, the customer's order, and only a single basic output, the finished product. All that went on in between was subject to analysis and redesign. The systems approach was intended to design a new Main Line System and provide an opportunity to ignore present techniques and ignore all of the conventional organizational or functional divisions of work and to really concentrate, without inhibitions, on reconceiving the solution.

A review of the steps included in this Main Line System will give a clearer understanding of the particular scope of this project.

The present Main Line System starts with a customer's order. This specifies what the customer wants in functional terms, such as size, color, rating and other product requirements. A typical order then goes through certain conventional steps.

1. It is edited to eliminate ambiguities and to put the order into the proper, most usable, internal form.

2. Then this order is engineered and drafting prepares documents needed, namely blueprints, bills of material, etc.

3. Based upon this design information, the manufacturing engineers then perform the operational planning on how to make the product and what the time allowance should be for the various labor and machine operations.

4. In a similar manner, the quality control planning procedures are determined, establishing standards, methods and frequency of quality analysis.

5. And then, using the existing records and files, cost information is accumulated, compiled and analyzed.

6. Production control then takes over to determine when the parts are needed as well as how many are to be purchased and made. Typically, this includes the functions of customer promising, scheduling and inventory control.

7. Finally, instructions in the form of vouchers, purchase requests, etc., along with blueprints and other necessary papers are transmitted to the factory to direct the manufacture of internally made components or to purchasing for outside material procurement.

In each of these steps, information is taken from the previous function, typically in the form of written documents, and used to produce the next document or output with the aid of information reference files: material lists, blueprints, planning cards, quality records, cost cards, etc. In short, the Main Line System converts the customer's order into a finished product. Present systems are usually based on human-to-human communication with extensive file reference. The use of mechanical aids is generally still limited. The shop area is often characterized by job-shop type facilities, high buffer stocks between operations and long manufacturing cycle times.

The results of the work have indicated that a customer's order can now be automatically converted into parts of a specially designed product, performing all of the Main Line System's steps inside the computer. This automatically provides all of the factory's action documents: purchase orders, operator instructions, quality instructions, punched paper tapes to run numerically controlled machines, customer promises, bills of material, stock order recommendations, withdrawal notices, shipping papers, etc.

As a result of this Project, many new techniques were developed to help the various General Electric departments design integrated, automatic systems. For example, new techniques have been developed for decision analysis. New techniques have been conceived for part and product representation and identification. New ideas have been formulated for computer programming. All of these concepts taken together have changed the economic feasibility of installing integrated, automated business systems.

They feel that there are many benefits from these concepts. In order to clarify them, the nature of each function in the computer and some of the resultant benefits will be covered.

The determination of "What to Build" is the key role of engineering; the requisition engineering activities can now be computerized. The computer can translate a customer's wants into the specific details of the materials, parts and assemblies needed to satisfy those wants. In addition, this computerized process can avoid the necessity of having to create many of the documents and records with which we have become too familiar. Outstanding savings can be realized in the preparation of model lists, bills of material, blueprints, etc.

Included in the benefits from this engineering advance should be substantially reduced engineering time and cost through the elimination of many of the routine steps which humans now take. There should be less drafting expense through eliminating many of the tasks which drafting has historically performed. A clear, logical statement of the engineering scope of a product line should make it easier to obtain an optimal level of standardization. A properly designed computerized engineering system should be easier to change and be more flexible.

With knowledge of the product design details, manufacturing engineering is then in a position to determine the best routing, work methods and time standards. Much of this work on "How to Build" the product can also be completely taken over by the computer. The possibility of automatically preparing accurate operational descriptions coupled with correct time standards for every job certainly has considerable appeal.

Another intriguing area is in the communication of the computer with numerically controlled machine tools. Three new features should have wide application:

1. A single program tape controls an automatic machine for the entire day.

2. Machined parts are automatically identified as an integral part of the program.

3. Computers are used to automatically generate machine tool programs.

<u>"Tape-for-a-Day" Machine Tool Control.</u> Typically, users of numerically programmed machines have achieved repetitiveness in operations by cycling a loop of punched paper tape. Thus, if ten pieces are required, the operator glues the back-end of the tape to the front and allows the looped tape to run around ten times. In this system, the same objective is accomplished by providing ten machine tool control programs in a single length of tape. Further, the same length of tape also includes a program for all other pieces to be manufactured by the machine that day. Thus, one length of paper tape provides an integrated, sequenced control program for a numerically controlled machine tool for the entire day.

<u>Machined Parts Automatically Identified.</u> Parts processed on numerically controlled equipment are sometimes identified in a secondary manual operation. This can be avoided by introducing an identification step in the machine tool program. For example, parts can be identified with shop identification numbers by spotting a shallow blind hold in a code matrix stamped on the part itself:

	1	1A	2	6	51	62	64	75
identification hole →	●							

A more suitable, generalized version of this code matrix idea would be:

	0	1	2	3	4	5	6	7	8	9
(hundreds)										
(tens)										
(units)										

Computer Generated Machine Tool Programs. The generation of numerical machine tool programs was done on an electronic computer. This, of course, facilitates developing the "tape-for-a-day". While electronic computers are not essential, mechanizing the production of punched paper tapes (or cards) to run automatic machines improves accuracy and reduces cost.

Among the other benefits is reduced planning time since the computer takes over a former manual job. There would also be reduced planning costs since computers can do this job for less money than humans and probably, most important, the best method, more accurate planning and consistent time standards should result because of the computer's ability to follow the exact instructions that it has been given.

Quality Control: at what point to inspect or test, the quality evaluation method, appropriate time standards, frequency of evaluation, and criteria for acceptance or rejection. Here again it was found that a computer program can be prepared which will perform all of these tasks automatically. This would, in effect, determine how to evaluate the product and its components. Included in the benefits are fewer quality corrections through having the proper balance between quality failure and quality appraisal costs. There should be fewer complaints through a careful analysis of customers' needs and product characteristics. There should also be lower quality costs through the integrated planning of quality control along with engineering design and manufacturing operation planning.

Cost accounting offers another opportunity. The objective was to determine planned product costs for quotation work or for cost standards to be used for comparison with actual costs. They find again that cost standards can be automatically developed and that a computer properly programmed can also be used for establishing work-in-process inventory value.

Through this cost work, it should be possible to obtain better cost analyses by having all the facts at our finger tips when they are needed. It would be far easier to maintain up-to-date costs because of the potential simplicity in storing the cost information. There should be reduced cost determination expense through the use of a computer to replace human effort.

The next area of production control is particularly intriguing. Each of the previous steps in the computer portion of the integrated Main Line System have all dealt with tangible product characteristics: what to build from engineering, how to build from operation planning, etc. In contrast, production control, the final element of the computer portion of the Main Line System, develops a fourth dimension by determining the time and sequence in which main line activities take place.

Production control is interested in when things happen. It has the responsibility of actually carrying out at the right time the data processing and decision-making calculations necessary to support each function. Production control is concerned with the time inter-relationships of all customer orders. It is responsible for economically satisfying these customers' requirements considering the actual status of the shop.

Production control provides the scheduled release of the factory's action documents:

- purchase requests
- punched tape for automatic machine programs
- operator instructions to make and assemble products
- quality instructions for inspecting and testing
- shipping papers to deliver the customer's product

In this integrated system, the computer should daily schedule shop operations, specify operation release dates and due dates, specify specific order quantities, review inventory stock levels and issue customer promises. These orders should not be released prematurely. One key element in computerized manufacturing control is frequent feedback coupled with frequent scheduling for close shop control; using today's performance to guide tomorrow's shop decisions. In the past, a major obstacle to such tight shop control has been the mass of detailed data which had to be gathered and interpreted before any meaningful results could be obtained. Manual and even punched card techniques often sagged under this burden; but electronic computers offer the high speed, low cost calculating ability necessary to cope with this problem.

The Integrated Main Line System has daily feedback of completions for shop control. This information will be digested by the computer each night and recognized in the releases to be prepared for the following day. The parts to be started the next day will depend upon the exact status of each of the areas of the shop; whether they be behind schedule or ahead of schedule, what their status is on rush jobs and related information.

The result is a flexible system prepared to respond quickly and accurately to changes. Time delays in handling information are avoided and corrective actions can be initiated immediately throughout the Integrated Main Line System.

Developing production control rules presents some special difficulties. For example, product performance can be proven in the laboratory, operation time standards can be checked by a stopwatch, but how can you pretest a rule for customer promising? General Electric has been instrumental in applying simulation techniques to similar business problems involving many interdependent activities that change with time. The heart of shop simulation is a computer model which realistically duplicates the behavior of the shop as it processes customer orders, making allowances for set-up and processing times, absenteeism, machine breakdowns, and the like. The specific computer model developed for the Integrated Systems Project compressed four months of shop experience into a fifteen minute computer run. As a result, it was possible to test how well various proposed sets of production control rules would meet due dates and planned cycle times without actually trying them in the shop. In addition, inventory levels, employment stability and man-machine utilization could also be evaluated and compared.

Integrated production control offers several benefits. For example, it now seems quite practical to obtain a shorter main line information cycle -- actually less than one day. Similarly, electronic computers can be expected to lower paperwork costs. Shorter cycles in the office and factory, as well as improved scheduling techniques, will permit substantially lower inventories. These improvements should lead to shorter customer promises, improved service and potentially higher sales. Somewhat unexpectedly, indications are that these gains can be achieved while impr oving employment stability -- and without a sacrifice in promises kept and equipment utilization.

Of course, the only reason for all of this information is to procure the parts that are needed, on schedule, at optimum cost; and to direct the machines and operators in the factory to transform the raw materials into the right finished parts at the right time. This leads directly to the concept of flexible factory automation.

In the physical processing system, rather than visualizing automation as a long line of highly specialized machines and transfer devices, it may well be the important aspect of automation will be the ability of machines to switch from one task to another at little or no extra cost. The inherent flexibility of the individual machine or group of machines will be a determining factor in the effectiveness and usefulness of these automatic systems concepts. With numerically controlled machines, such as are now available, the set-up cost is generally reduced to practically zero. Hence, flexible factory automation permits direct response to the external, customer oriented requirements and not such heavy consideration to the internal shop.

This flexible factory automation will lower direct labor costs per unit through replacing human activities, where desirable, by machine operations. Machine accuracy and set-up flexibility will reduce both scrap and rework. Integrated planning and control with the right tempo will result in shorter manufacturing cycles.

The fundamental concept in carrying out this project was the idea of vertical integration. Integration is currently a by-word, but most new work has been concerned with automating common activities like payroll, inventory control or requisition processing across many product lines or the whole business. This might be called horizontal integration. However, true integration should probably follow lines of information flow; it should cut vertically through all functions in a product line. By having all the information processes linked together inside a computer, it is unnecessary for each function to duplicate the other's files. For example, cost will no longer have to maintain independent files of material lists, blueprints and planning records for every part and assembly. This elimination of file redundancy will be felt in many indirect labor activities.

Further, vertical integration of effort also has a major effect on reducing the information and physical processing time cycle. Since all of the decision-making logic needed to completely process an order is in the computer, it is reasonable to expect overnight data processing and, by having dynamic control of the whole physical process from purchasing through parts making and assembly, it is possible to reduce significantly the actual "make" cycle. This type of control should result in lower inventories, higher promises kept and better indirect labor efficiency.

A second principle is the need for discovering a logical structure or pattern which formally displays and relates the various decisions such as those in product design, facilities operation and factory scheduling. In manufacturing planning, for example, by focusing attention on each variation in method or elemental time standard, cause and effect relations can be spotlighted to aid in making improvements. By organizing the multitude of detail into a clear, easy-to-understand framework, it shows what design characteristics control the various manufacturing process elements making clear the simplification and standardization opportunities. The use of logical decision patterns in a business should reduce direct labor and direct material through the powerful analytical insights they make possible.

Another basic concept was to design the system with the computer in mind. Although computers and humans perform many of the same tasks, their relative efficiencies and economic advantages are quite different. To arbitrarily make the computer follow the same routines, the same steps, the same processes as humans is illogical. Rather, the basic system should be reconceived and redirected to obtain maximum performance from the electronic computing equipment.

It was also quite an insight to think about the system as being directed solely toward the ultimate user, ignoring all the intermediate functional outputs that have so commonly become identified with our data processing system. The only purpose of having any operating outputs from a system is to cause someone to take action, to cause a buyer to purchase materials, an operator to make parts, etc. The intermediate transformations and hence the intermediate outputs are not essential systems elements but are only a reflection of the particular data processing techniques currently in use.

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