INFORMATIONAL ASPECTS OF AUTOMATION

Thesis for the Degree of M. S.

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William K. Hilzinger

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This is to certify that the

thesis entitled

Informational Aspects
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has been accepted towards fulfillment
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James M. Apple
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INFORMATIONAL ASPECTS OF AUTOMATION

By

William K. Hilzinger

A THESIS

Submitted to the College of Engineering of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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AN ABSTRACT

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The development of automation has come about through isolated instances of automatic control, mechanized materials handling, coding techniques, programming, and the development of trends in the continuous processing industries. This development was slow at first, and as the individual concepts grew, they were more rapidly fitted into what can now be called automation--a philosophy of manufacturing.

Automatic control functions play an important role in automation, since they take the place of the human operator in the controlling functions of the system. With the introduction of control, concepts of open and closed loop systems, feedback, programming, and other terminology, are introduced to supply a working vocabulary for the developments to follow.

Automation developed from many isolated concepts, resulting in certain definite approaches to the subject, such as:

The Transfer Machine Concept
The General-Purpose Machine Concept
Assembly Concepts
Modular Production Production Concepts

The various types of equipment and systems used in automation can also be classified in certain groupings, ranging from relatively low orders of automaticity or levels of mechanization, to relatively high ones. These classifications vary with the area of application, and each one adds something of value to the subject. The classification may be one of terminology, automaticity, mechanization, or by industry, including either management or engineering approaches.

Information, coupled with energy, forms the basic parameters of operation of any device. As such, the devices used to obtain automation, as well as the overall system involved, may be classified according to the type of information they contain or use. Information may be immediate or stored; it may be supplied manually or by some other system; hence the opportunity to describe the components of automation by the informational function they perform.

Extending the information concept, its availability in the right amount and in the correct media constitute the basis for investigating storage and coding systems--the devices that supply or transmit the information upon demand.

Coupled with storage devices are the machines that process and handle the information. These devices--processing equipment and scientific sensing instruments--may vary from very simple indicating or manipulating instruments, to the complicated analog and digital computers. Both the analog and digital functions play an important role in the handling of their particular type of information.

Combined in the right proportions, systems which can process information automatically exist in three basic informational fields: factory control, paperwork data processing, and scientific data reduction. These systems overlap, but each performs a basic informational function. Automatizing these systems offers the key to automatizing and integrating complete factory operations.

The ultimate--the automatic factory--will result as a combination of these various manufacturing and informational systems; the one to control, and the other to physically produce the desired product.

The term "automation" has been applied loosely to many unrelated subjects, and has been a target for abuse or exageration. However, by grasping the nature of the relationships of automation's varied concepts, a better understanding of the subject is gained.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

PREFACE

In selecting a field of investigation for this thesis, careful consideration was given to the manner in which the material would be gathered, arranged, and presented. One of the greatest problems was that no unified collection of studies had been made of the entire field of automation from an engineering standpoint. Although a great many papers and articles have been written on the subject, each paper or article was concerned with what the author considered automation in his own particular field of interest. Books, also, have been prepared on automation and related topics, such as automatic control, the automatic factory, mathematical applications, etc., but few of them deal with the engineering aspects of automation, and the concepts that the engineer must be able to grasp in order to have a coherent understanding of the field in general.

Because knowledge of the subject encompasses so many fields of study and application, it was decided that an attempt would be made to assimilate and utilize material covering the broad general aspects of automation, as a basis for emphasis on a particular aspect. For this reason, investigations were made into several aspects of automation other than those included in the title of the thesis. This was necessary in order to form the basis for study of informational aspects of automation, and to relate these aspects to the entire field of study.

The informational aspect was selected for specific investigation because it more closely follows every branch of the broad subject than do some of the possible alternative topics. It is concerned with machine design, materials handling, systems design, method improvement techniques, data processing, and many of the other interrelated fields which are concerned with automation.

Although the subject of the thesis cuts across many related fields of study such as electronics, mathematics, business and management, the basic intent is to cover the subject from the viewpoint of industrial engineering and manufacturing. Therefore, illustrations and references are made to many techniques of related sciences concerning their relationship to automation, but no attempt is made through these references to describe in great detail the technique or the extent and limitations of its application to automation.

CHAPTER I

BACKGROUND OF THE AUTOMATION CONCEPT

Introduction

Historically, the development of automation was slow, beginning with unrelated bits of information and theories in the various scientific fields of study, and in isolated instances of practical application. These examples were not called "automation," because taken by themselves, they had little direct relationship to present-day concepts of automation, automatic control, and the automatic factory, often--but erroneously--used interchangeably.

"In the beginning"--that is--when these ideas and concepts began to crystalize in men's minds, they followed the particular inclination of the individual. As the world progressed in its knowledge and understanding of basic scientific principles, these various theories, relationships, and examples became interrelationships, much as many of the scientific theories of today may be related to the separate but interlocking fields of science. Practical examples, too, are related to these theories, since the example or experiment is necessary in order to verify the theory, and the theory is just as necessary to apply and expand the basic concept to useful daily application.

To illustrate the statement that isolated instances constituted the automation development, consider the example of the flyball governor, constructed in 1788 by James Watt.

This practical application, controlling the speed of the engine, incorporated through inertia forces and the speed of the engine, the basic concept to automatic control and feedback--fundamental concepts of automation--which will be discussed in greater detail in the further development of the thesis. Although James Watt may have been interested in the theory behind his application, his major concern was to control the speed of his engine, and the concept of automation, considering the state of industrialization of that period, would have seemed utterly fantastic.

Another historic example which has often been related to the origins of automation was the flour mill built by Oliver Evans in 1783-84, near Philadelphia. This mill was so constructed that the grain was unloaded at an upper level and passed through the various stages of grinding by means of powered conveyors of three basic types, to emerge at a lower level as flour. This example was not automation, but a method of continuous processing by using conveyor systems. It bears no direct historical relationship to automation as a developing chain of progressive steps, but stands as an isolated example of ingenuity in which the principle of mechanized materials handling, now incorportated in automation concepts, met a particular individual need.

Perhaps a more closely related example, historically speaking was the automatic loom produced by J. M. Jacquard of Paris, in 1801. These looms were controlled by a technique quite similar to the present-day punched cards used in business offices. The loom was not automatic in the sense that it was automatically controlled in its operation, but the product of the loom was regulated in pattern by the information entered upon the cards, in the form of holes. This was accomplished by raising or lowering the threads to change the pattern of the design, following the punched card pattern. In this manner, exactly identical material patterns could be obtained on separate looms or with different operators. It effectively introduced a degree of mass-production, since in France alone, over 11,000 Jacquard looms were in operation within a short time after introduction.

Other variations of the punched paper card technique to permit duplication of the original product were the player piano and the mechanical music box. The player piano made use of paper rolls, containing coded holes which, when run through the sensing mechanism, operated the hammers. The power to the piano was supplied through a foot bellows pumped by the operator. The mechanical music box uses a revolving drum and raised pins, striking or flexing metal strips, which give off musical notes in a prearranged order determined by the pin location on the drum. Here, too, these examples illustrate certain principles embodied in the automation concept, but they are not of themselves, examples of the automation development.

In 1812, the Englishman, Charles Babbage, envisioned what today we would call the analog computer.[1] Although

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[1]Charles Babbage, Economy of Machinery, John Murray, London, 1846.

his concept of what the machine should do was visionary, he had neither the practical mechanical understanding nor the refinement of machine tools to build into his machine the accuracy required. (This was a major problem of many of the early industrial inventors, including Watt.) Babbage's machine was designed to operate through long chains of gearing, which in practice would not have been feasable, because of the tremendous power which would have been required to overcome the friction generated in the gear trains. The minute measurements and movements required of his machine could never have been obtained in that day, and the machine was never completed. Nevertheless, his attempts stand as another isolated example of a concept incorporated in automation--the computer.

The development of the industrial revolution, with its increase in manufacturing and technology, as well as its problems, will not be discussed here, but from this point onward, an atmosphere concucive to the advancement of concepts pointing toward automation was created. An example is the following quotation from Gordon S. Brown and Donald P. Campbell, of the Massachusetts Institute of Technology, who state:[2]

> By 1900 the theorems of Laplace and Fourier, the studies of Routh in analytical dynamics, the work of Kirchhoff in circuit analysis, the physical studies of Lord Kelvin and Heaviside and others had laid the foundations for a theory of control. But not until the 1920's did the exploitation of theory by practice really get underway.

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[2]Gordon S. Brown and Donald P. Campbell, "Control Systems," Scientific American, 187, September 1952, 59.

Increased knowledge of metallurgy, physics, chemistry, and other fields focused the spotlight of interest on technical and manufacturing problems, allowing greater flexibility of application, and at the same time raising new problems of vast complexity.

Developments in automatic machines and mass production techniques were numerous in manufacturing from the time that Henry Ford established his assembly, based upon observations of the Chicago meat-packing industry. Technology increased during this period to the point of development in the 1930's of a political concept of "Technocracy," or rule by the technical class.[3]

In 1928 the A. 01 Smith Company built a factory for the purpose of automatically building auto frames. Actually this was an example of continuous processing, rather than automation.

In the petroleum and chemical industries, the concept of continous flow production was developed. Although the control function was performed manually, various instruments supplied information automatically concerning the substance being processed, allowing manual adjustments to be made in order to govern end-product. The petroleum and chemical industries have utilized concepts applied in automation (continuous flow, for example) but do not constitute in themselves what is considered as being automation. Here the product is generally of liquid or plastic form,

[3]Aaron Director, The Economics of Technocracy, The University of Chicago Press, Chicago, 1933.

while most physical manufacturing consists of discrete units.[4]

It was during World War II that many of the problems blocking the development of an automation concept were removed. Vast numbers of scientists, engineers, and other specialists were brought together to solve as quickly as possible the problems of design and construction of weapons, systems, and equipment. Specialists in many branches of science were able to exchange and relate their particular techniques to each other's work, solving many of the problems which had previously been confined to a narrow field of investigation.[5]

As early as 1946 J. J. Brown and Eric Leaver proposed a concept of automatic production, which was called "visionary" by industrialists at that time.[6] These two Canadians, who gained experience in the electronics field during the war, were attempting to relate their concepts to the field of manufacturing and mass production. Many of their ideas have been incorporated into what is now considered one form of automation. During this period, there was much speculation concerning the advantages and possibilities of the automatic factory.

Figure 1 illustrates the overall development of automation in a graphic manner. One particular point to be noted from this illustration is the fact that the automatic factory is considered to be a step beyond automation as it exists today. Perhaps the role of indirect labor should

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[4]Brown and Campbell, op. cit., 187.

[5]Loc. cit.

[6]Eric Leaver and J. J. Brown, "Machines Without Men," Fortune, 34, November 1956, 192.

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have been emphasized to a greater extent in the automation area, but on the whole, the figure illustrates quite satisfactorily the discussion presented here.

Automation--Its Definitions

The term, "Automation," was coined from the longer word, "automatization," by Del S. Harder, of the Ford Motor Company. His original definition was stated as "The automatic handling of parts between progressive production operations," and modified to include, ". . . a new philosophy of manufacturing," and "design of parts, methods for their manufacture, and production-tool control systems." The Ford Motor Company originally used the term to describe a special group set up to study and mechanize the loading and unloading of new equipment received by the company.[7]

First appearance of the word in print occurred in American Machinist (Oct. 21, 1948, p. 107-122). There automation was defined as ". . . the art of applying mechanical devices to manipulate workpieces into and out of equipment, turn parts between operations, remove scrap, and to perform these tasks in timed sequence with the production equipment so that the line can be put wholly or partially under pushbutton control at strategic stations."[8]

At approximately the same time John Diebold, then a student at Harvard University, used the term, but with

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[7]E. J. Tangerman, "New Tools, Automated, Make '55 Cars," American Machinist, 98, November 8, 1954, 119.

[8]Loc. cit.

a different connotation: "Automation is a new word denoting both automatic operation and the process of making things automatic."[9]

In a Harvard Business School report entitled, "Making the Automatic Factory a Reality,"[10] Diebold and the other members of his group stressed the concept of "rethinking" in designing for automatic production; that is, complete analysis of the problem through the steps of product design to completed manufacture. He carried the concept further than did Harder or the other automotive manufacturers, by including in his concept the use of automatic control. Diebold stressed the importance of the materials handling function, and that this would prove to be the biggest stumbling block to the implementation of automation.

Perhaps a broader, more complete definition of the term is given by W. E. Brainard, of Hughs Aircraft:[11]

> Automation is more than merely transferring. Nor is it a push-button factory. It may extend back to the design of the product. It is a new method of manufacture, not necessarily a new way of cutting metal, but a way of controlling the various processes. Automation is a philosophy of design, it is a manufacturing method, and it is control within a machine.

To these definitions should be added the fact that automation often includes the concept of "feedback." In the process of feedback (discussed more fully in the next chapter), information concerning the output at one stage of the process is returned, or few back, to an earlier stage,

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[9]Cleveland Public Library, Business Information Services, 24, July-December 1953, 13.

[10]John T. Diebold and others, Making the Automatic Factory a Reality, Griffenhagen & Associates, 1951, 7.

[11]Tangerman, op. cit., 119.

as a control function influencing its actions and hence changing the output itself.[12]

Following the developments of the original automation concept by Harder and its variation by Diebold, a great amount of interest was generated in scientific circles and in manufacturing industries concerning the effect of automation upon them. The publishing companies in particular siezed upon this opportunity and many articles and technical papers on the automation subject followed. Diebold, using material from his Harvard report, wrote a book entitled Automation,[13] covering in more descriptive form some of the topics and adding more information about the control function and the social effects of automation.

The Ford Motor Company continued to use the term, automation, applying it first to their press lines and later to their engine block machining and other parts manufacturing processes. Other automotive companies were quick to follow Ford's lead to some extent, adapting the original automation concepts to their production lines. These applications did not--and of today--still do not fulfill the concept of complete automation, employing the feedback feature. Some of them preferred to call the new innovations "mechanization"[14]

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[12]Brown and Campbell, op. cit., 58.

[13]John T. Diebold, Automation, D. Van Nostrand, Inc., New York, 1952.

[14]Allan Ellenwood, Chief Methods Engineer, Oldsmobile Div. of General Motors Corp., oral communication.

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rather than automation, but the trend is toward the newer word.

Following the increasing interest in automation and related subjects, several publishing companies began to publish magazines which included the subject of automation as a substantial part of the issue.

The magazine, Computers and Automation (Edmund C. Berkley & Associates, New York) features articles and technical reports on automation and computer topics, with cumulative indexes of manufacturers and consumers of computers; technical papers on computers and computer techniques; and the relationship of computers to automation. It also includes comprehensive surveys of publications in the automation field.

McGraw-Hill Book Company brought out its first copy of Control Engineering on August 19, 1954. It has a paid subscription list rather than a controlled circulation audience, as do most of the other publications. With a goal of 15,000 subscribers by September 1957, it had already obtained 18,000 by the end of 1954, and was still rising.[15]

John Diebold became editor of a new magazine in July 1954 called Automatic Control, published by the Reinhold Publishing Corporation. His aim was to bridge the gap between management and technicians on the subject of automation, pointing out the contributions of each group.

In August 1954, Roger W. Bolz became editor of the magazine Automation, published by the Penton Publishing Company.

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[15]"Advertising & Marketing," New York Times, August 20, 22:2.

These periodicals gave wide publication to the field, and helped to stimulate and report the interest that many manufacturers showed concerning the automation subject.

Summary

In summary, it can be said that the development of automation was not through a series of closely related events but through the development of entirely separate concepts. These concepts were developed to the point where they could be utilized in varying degrees to furnish the concept of automation. This concept was evolutionary in the sense that that it was necessary for the various associated fields to advance to a usable level, and revolutionary in the sense that a new philosophy and quickened pace of manufacturing resulted.

The terminology and understanding of automation varies with the application and the individual. Different definitions have been applied, and it is important to understand which particular concept is implied when discussing the term.

The tremendous interest generated by automation is evidenced by the magazines, newspaper articles, and technical papers presented on the subject as well as programs and courses in related fields offered at colleges and universities.

CHAPTER II

THE IMPORTANCE OF CONTROL IN RELATION TO AUTOMATION

Introduction

In discussing the term "automatic control" with respect to automation, it is important to bear in mind the definitions stated in Chapter I. The first concept of automation did not include automatic control of the process, but merely automatic handling. As the concept grew, it came to include the linking of automatic control, or control by the machine itself, to the manufacturing process. There is a basic difference, however, between a process using automatic controls and an automatically controlled process.

In the case of a manufacturing operation, a machine may be so regulated that it will automatically turn out parts without constant operator observation. It may continue to cycle, however, regardless of the quality of the part, or without any stock being fed into the machine at all. In many of the more modern automatic machines, the introduction of material, malfunction of the machine, output exceeding specified limits, or several other possible factors, could cause the machine to shut down, with indication to an operator through lights, bells, or other warning devices, that the machine is not working. An example of this is the automatic sequencing of a plating process, in which there is no manual regulation once the process has been initiated. The product will continue through predetermined stages of the cycle, regardless of the quality or quantity of the output. No attempt is made to measure the performance and make corrections as the process continues production.

In these examples it may be seen that although the machine functions automatically, it has no system of automatic regulation of itself in order to regulate the product or process. This is the basic difference between an automatically controlled process, and one using automatic controls. Both systems are often incorporated into the automation concept, and it is important to realize the difference.

In order to better understand the concepts of control as related to automation, it will be necessary to define and discuss certain terms. These terms will be used throughout the various chapters of the thesis, and a definition at this point will prepare the reader for their future use.

Terminology Used in Automatic Control

Feedback. Feedback is the fundamental principle that underlies all self-regulating systems. In the use of the feedback principle, information about output at one stage of a process is sensed, returned or fed back to an earlier stage of the process, and the process at this earlier stage is then influenced in its action, changing its output in an effort to correct the discrepencies originally indicated. The system using this principle is called a closed-loop system, or feedback control system, as opposed to the open-loop type of system.

In the previous examples, the plating process and machining process would be considered to be controlled by open loop control systems. The control function was previously determined and unvarying in adjustment throughout the process.

The difference between open-loop and closed-loop systems is illustrated in Figures 2 and 3. In Figure 3, it may be seen that the closed-loop or feedback system is essentially the same as the open-loop system, but with the addition of further measuring and control elements, tending to give self-correction to the system.

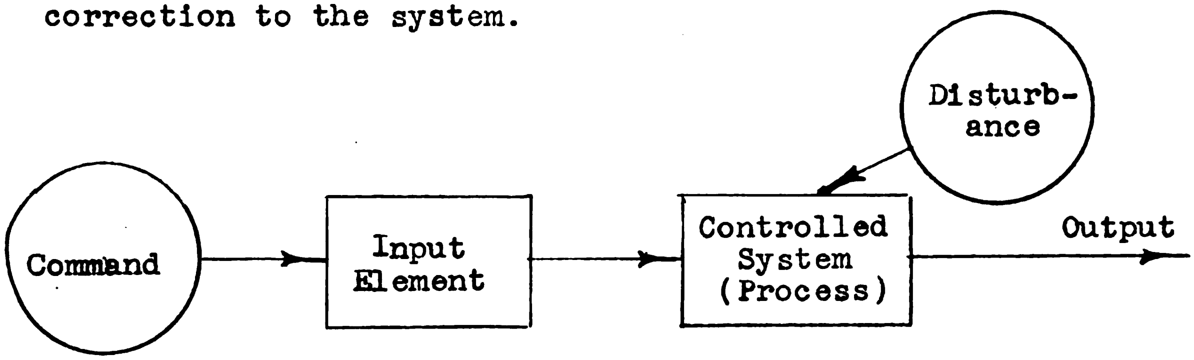

Figure 2
Open-Loop System

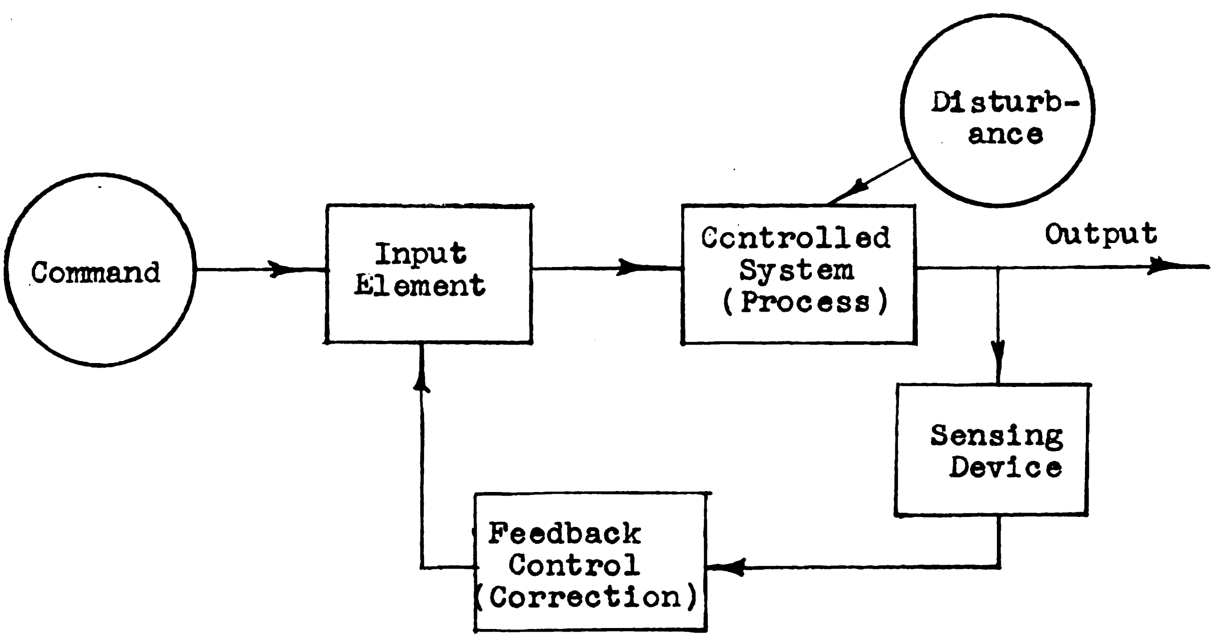

Figure 3
Closed-Loop or Feedback System

Error. It will be observed that there must be an error or deviation from the original or desired command, to be able to effect a correction. Otherwise the system would operate in essentially the same manner as the open-loop system. The error is kept to a practical minimum, of course, but often a certain degree of error is "built into" the system. The example of the thermostat on a heating system or home freezer unit illustrates this point. These systems are so designed that a change of temperature will actuate a switch, initiating the action of the heating (or cooling) system, in an attempt to maintain a constant temperature. However, it would be impractical to allow the system to become activiated at the exact point of desired temperature, only to shut off when that point were reached. The system would be continually starting and stopping with a very slight temperature change. Therefore, a range of temperatures is used. On the freezer, the motor might be started when the temperature rises above 10°F, and continue to run until the temperature dropped to 0°F, to remain off until the temperature had again risen to 10°F. The heating system would operate in a like manner, controlling the temperature over a range of values rather than a point.

Usually the disturbance causing an error is the result of some outside factor acting upon the system. It may be a change in load, or an upset condition acting on the system. In a manufacturing process, the error may result from a faulty or incorrectly sized part, in the process. If this is the

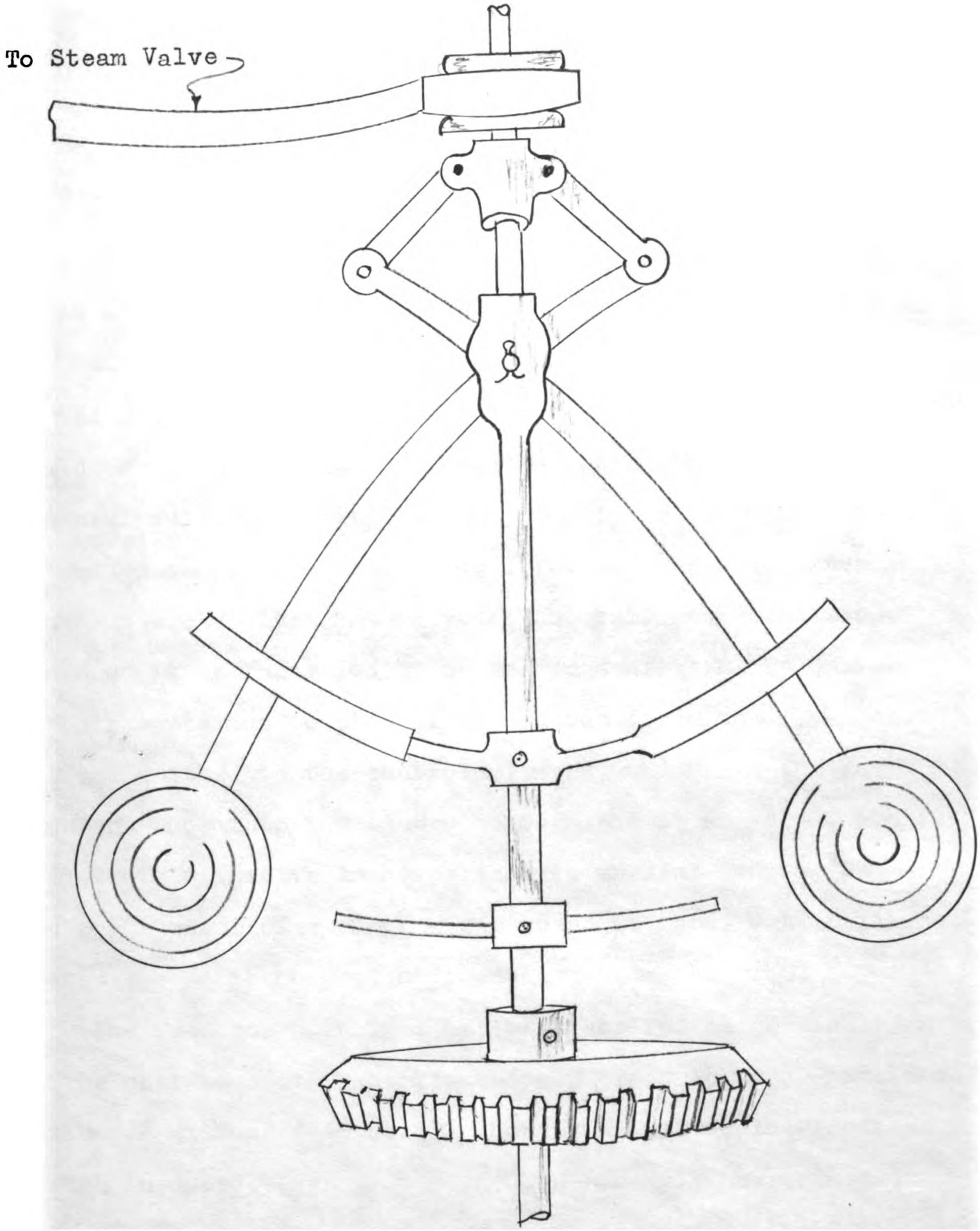

Figure 4
Watt's Engine Governor

case, the error detector will continue to observe the output of the machine, at the same time applying and altering the corrective force as required.

The classic example of feedback, of course, is James Watt's flyball governor, developed in 1788 (referred to in Chapter I). Watt needed a method of maintaining a constant speed with his steam engine. The speed varied with the load applied and the amount of steam allowed into the cylinder. By using two revolving balls suspended from linkage arms, he could control the amount of steam entering the cylinder. As the engine increased its speed, the weights would be thrown outward and upward by centrifugal force. The associated linkages would close the valve as the balls moved outward, and open it as the velocity decreased and the balls dropped. In this system, a portion of the output (from the flywheel) was transmitted to the control element, which fed the adjustment back into the system through the steam valve. This example is primitive in comparison to present sensing and control systems of a complex series of devices, but it illustrates the basic concept of feedback. (See Fig. 4.)

The feedback principle has been applied successfully in the past to control constant-speed electric motor-generator systems. Without feedback, a change in load could effect a change in speed, even though the power supply were constant (Fig. 5). With the use of a constant-speed regulator (Fig. 6) consisting of a tach-generator and a special DC exciter, the system may be made to perform as a closed loop.

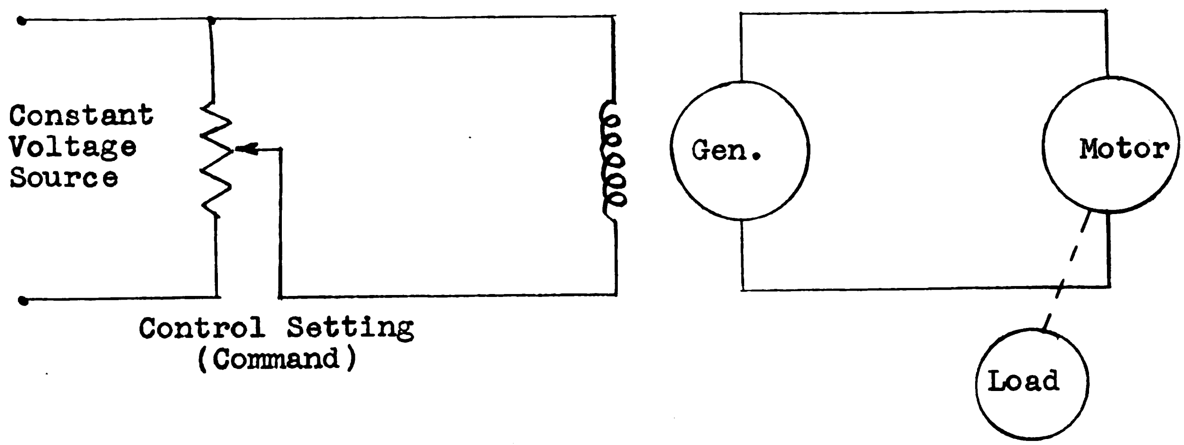

Figure 5

Open-Loop Control For Electric Motor-Generator System

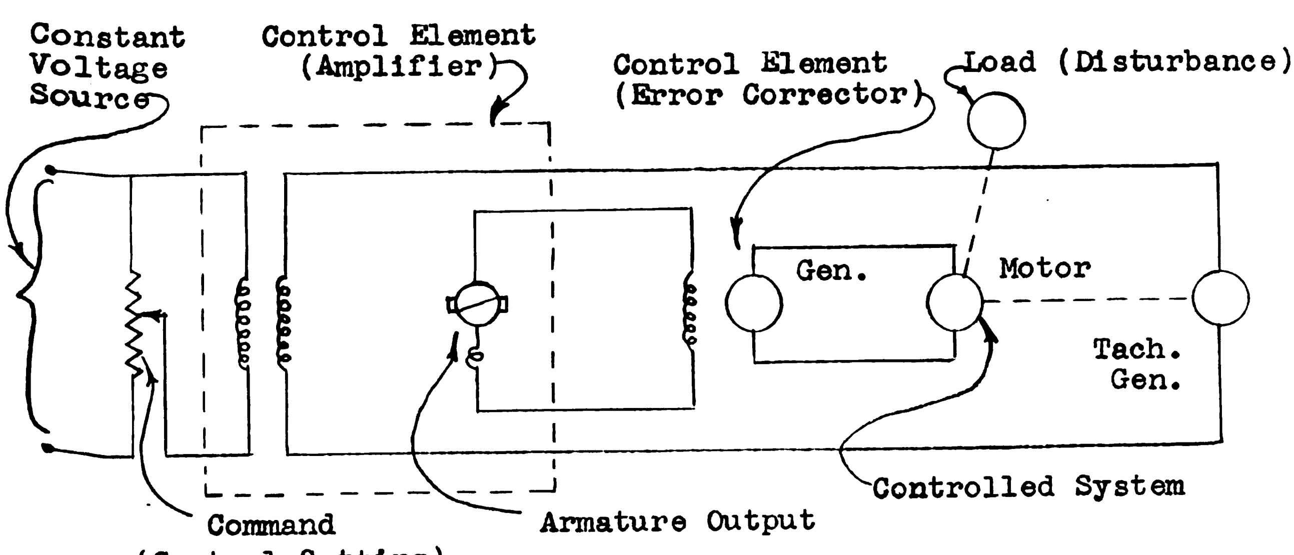

Figure 6
Feedback Control Using a Constant-Speed Regulator

Although the principle is the same, there is a vast difference in the complexity of regulation of a velocity and in controlling the production of discrete physical units.

Hunting. With the use of feedback control, the phenomenon of hunting or tendency toward self-oscillation is introduced. This may be caused by a mechanical or electrical time delay, or by overshooting the desired adjustment, due to either a physical limitation of the equipment or an inaccurate control command. This may be observed in Figure 7.

Figure 7a shows a series of feedback cycles, with corresponding cycles of output lagging the input. In Figure 7b the feedback is exactly equal and opposed to the error. This causes an equal amount of opposed feedback in the opposite direction on the next cycle. This problem of hunting is reduced as the delay in returning the feedback signal is reduced. The problem is critical in the design of control systems, since the feedback must be increased to make the system more accurate, while at the same time the increase may accentuate any small oscillation present. As the oscillation increases, the feedback ceases to function in a control manner and the system is useless (Fig. 7d).

To decrease the time lag, electronic tubes or quick-response DC generators may be used. A special phase-advancer, which introduces time-lead, may also be used. This device is based upon the capacitor principle, in which an alternating current in a capacitor circuit leads the voltage applied.

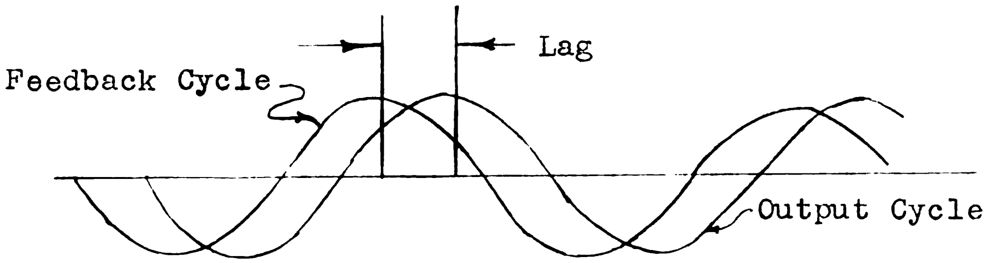

Figure 7a
Oscillatory Variation of a Feedback Cycle

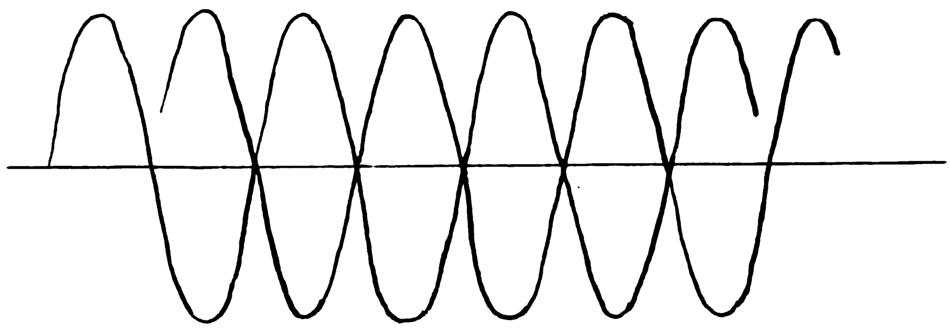

Figure 7b
Feedback Equal and Opposite to Error

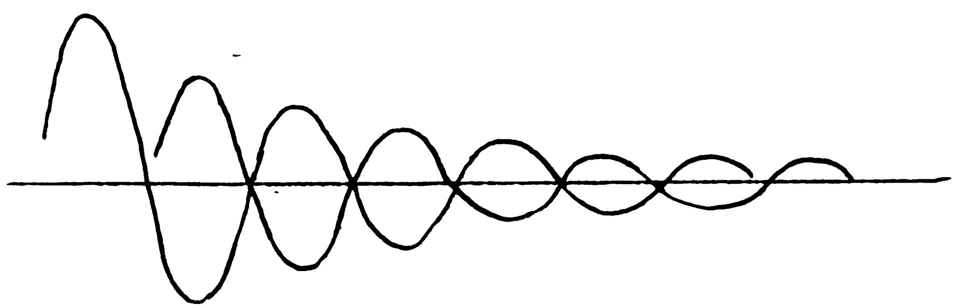

Figure 7c
Damped Feedback Oscillations

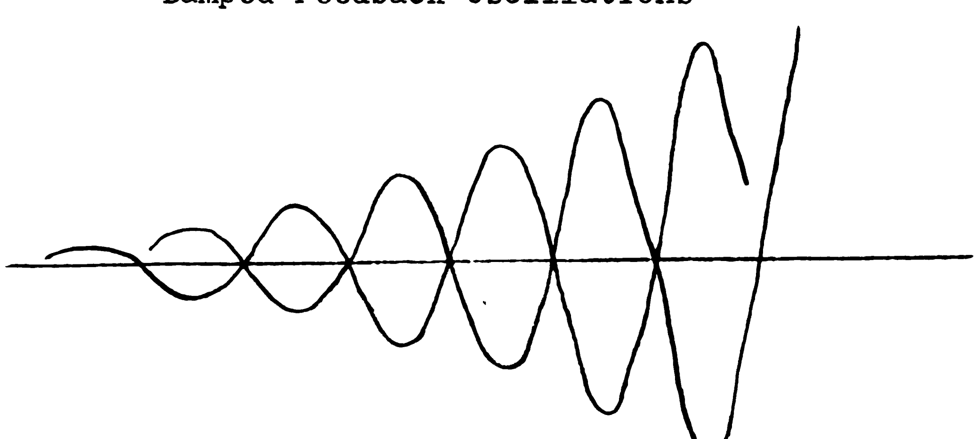

Figure 7d
Feedback System Out of Control

A third method is to introduce negative feedback, called damping. Usually a combination of these three methods is used in modern systems.

Damping. In a feedback control system, the object is to correct and eliminate the error. In order to prevent the occurrance illustrated in Figure 7b, successive feedback signals must be of a decreasing or damping nature (Fig. 7c). This arrangement tends to damp the disturbance in the system. An example of this occurance is the flight control of a guided missile. The missile receives a command to follow a particular course, which is constantly changing. As commands are given to the control surfaces, they tend to turn the missile into the correct path. Without damping control, however, the initial turn command would be such as to cause the missile to overshoot the correct path. By damping, the successive signals are reduced until the error is eliminated, for all practical purposes. In anti-hunting circuits the feedback is negative and proportional to the rate of change, rather than the change alone.

In a similar way, the concept of damping could be applied to the quality control function of an automatic process. Here the upper and lower limits would be the values which could not be overshot, such as tension in a paper roll, the speed of a machine, or the measurement of chemical deposition in a plating process.

In many manufacturing processes, the damping concept is not too important at the present time. The most urgent problem is that of simple feedback and error correction.

Servomechanisms. In order to physically effect feedback control in an automatic process, a system must be utilized that contains the proper mechanical devices. The standard terminology given by the AIEE for a feedback control system and a servomechanism follows:[1]

1. A feedback control system is a control system which tends to maintain a prescribed relationship of system variable to another by comparing functions of the variables and using the difference as a means of control.

2. A servomechanism is a feedback control system in which the controlled variable is mechanical position.

A servomechanism is a system, not a device. This definition distinguishes a position-controlled situation (often encountered in a manufacturing process) from that situation in which the control system attempts to match a fixed reference quantity such as constant voltage. A servomechanism could convert electrical energy or an electrical signal into a physical or mechanical response, or the reverse could be true. The system could also be entirely mechanical or pneumatic, or a combination of the three. A hydraulic valve actuated by air pressure, which is released by an electromagnetic coil, composes a part of a servomechanism. The function that the servomechanism plays in the automatic control of manufacturing processes is important, because the control information or signal must be translated into an effective position or motion response.

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[1]Paul Lindholm, "Feedback Control Systems," Automation, 1, September 1954, 59.

Programming. With respect to computing machines, a program is a precise sequence of coded instructions or directions to a computer for solving a problem, or (2) a plan for the solution of a problem. A complete program would include plans for transcription of data, coding for the computer, and plans for the effective use of the results. A programmer is a person who prepares sequences of instructions for a computer, without necessarily converting them into the detailed codes devised for utilizing the information.[2]

When speaking of programming for non-computer types of machines, such as those used mainly for manufacturing, the term "programming" takes on a different significance. Here the program function of control is often quite simple, compared with that of the computer. It may be defined as the direction of a mechanism through the desired operating cycle. On non-automatic types of machines, the programming function is performed by the human operator. In the use of a higher order of automatic machine tools, programming is often "built into" the machine, and is a fixed, inflexible, repetitive arrangement to control the part from start to finish of the manufacturing process. In transfer-type machines, the program functions much like a reflex action; advancing the part, performing operations on it, gaging or inspecting it--all through limit switches, relays, interlocks, and other mechanical, hydraulic, and electrical devices. The plan is

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[2]"Glossary of Terms in the Field of Computers and Automation," Computers and Automation, 3, December 1954, 8.

or "message" being the same, as each piece of work passes a particular point or station.

In certain automatically contolled machines, programming is more flexible, obtained through the use of information supplied from a source external to the basic machine tool itself. By changing the input information (the program), different parts or products could be manufactured within the designed capabilities of the machine. In this instance, the program more closely approximates a computer program--a sequence of coded instructions for solving a problem; the problem in this case being the steps of the machining or assembling operation.

For certain types of machining, the programming procedure uses mathematical analysis or synthesis of equations to establish the series of steps required. If a lathe were required to machine a taper or conical shaft, application of mathematics to determine progressive data that could be used by the lathe controls might be necessary.

The degree or complexity of programming would vary with the particular application of automation. All programming, however, involves the determination of a plan for the solution of a problem; and generally a sequence of instructions or information to be applied is included in the concept.

Coding. As programming consists of determining the plan or sequence, coding is the procedure of expressing the necessary information in a language or medium acceptable to the particular system. In the case where programming is "built-into" the system, coding is simple or non-existent.

It may consist of setting a dial or pushing a start or stop button. In a more flexible system where the program is fed in from an outside source, it must be presented in some form of a code. This might consist of punched paper or plastic tape, cards, magnetic tape, cams, gears, master patterns, or mathematical systems. A coder is a person who translates the sequence of instructions in the program into the code acceptable to the machine. If the procedure is office-type data processing, the coder would use a coding machine containing a typewriter keyboard. As the information is typed, the machine would perform the coding functions by punching the required code.

Programming and coding have been presented here to illustrate the part they play in the control concept of automation. In later chapters they will be discussed in greater detail and illustrated by specific examples of application.

Summary

The concept of control in automation has been discussed in this chapter, along with related terms and subtopics. Whether or not the process incorporates feedback in its operation determines whether or not the process is automatically controlled, or is simply a process which uses automatic controls. Introducing feedback, or the closed-loop control system, introduces other complexities of error, hunting, and damping. Since feedback operates on the principle of detecting a difference between output and input, and attempts to correct it, the system goes through the procedure of hunting or oscillating about the desired value, which may be reduced through negative feedback, or damping; similar but opposite to the direction of the feedback command, and in proportion to the rate of change rather than the change itself.

The method of implementation of control in mechanical systems is through servomechanisms--feedback control systems in which the controlled variable is mechanical position. The components of a servomechanism may be electrical, mechanical, hydraulic, or a combination of these and other methods. They are the "muscles" of the control system, physically effecting the sequences.

Formulating the plan or sequence of coded instructions for directing the machine tool through the desired cycle is called programming. Programming may be built into the system and be of a relatively permanent nature, or it may be more flexible and interchangeable by supplying the program from some outside source.

Coding is the method if implementing the program, translating the program into a form usable by the machine tool or controlled process.

CHAPTER III

THE DEVELOPMENT OF BASIC AUTOMATION CONCEPTS

Introduction

As stated in Chapter II, several types of machines and processes have evolved which often have been loosely grouped under the title of automation. These machines either use automatic controls, or are controlled automatically in varying degrees. In this chapter the basic automation developments will be presented and discussed as an introduction to formal classification of these developments.

The Transfer Machine Concept

A transfer machine is a multiple-station machine in which a sequence of operations is performed upon a workpiece by tools located at the various stations. The workpiece indexes from one station to the next in a predetermined order.[1]

The transfer-type of machine can be divided into two broad classifications: (a) the unit (plain) transfer machine, and (b) the pallet transfer machine. In the unit transfer machine the workpiece moves from one station to the next, and is clamped individually at each work station. This allows the complete transfer machine to be arranged in an open-end type of layout, with loading station at one end and un-unloading station at the other. Figure 8 is an example of the plain type transfer machine (used for engine blocks).

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[1]Kurt O. Tech, Chief Engineer, The Cross Co., oral communication, March 28, 1955.

The pallet type of transfer machine uses a pallet-fixture upon which the workpiece is clamped. The pallet transfer machine is used when the part is irregular in shape or difficult to handle and clamp, as it moves from one station to the next. The pallet also allows positive location of the part since it is indexed to a particular location at each station. (The pallet is of such a shape that it is easily located, while the part may not be adaptable to several relocating operations.) Pallet transfer machines may also be used where it is frequently necessary to modify workpiece design without altering machine characteristics to any great degree.

Since it is necessary to return the pallets to the loading station after unloading, these machines are generally of the closed loop arrangement. Often the load and unload stations are combined, and the workpiece enters and leaves the machine at essentially the same location.

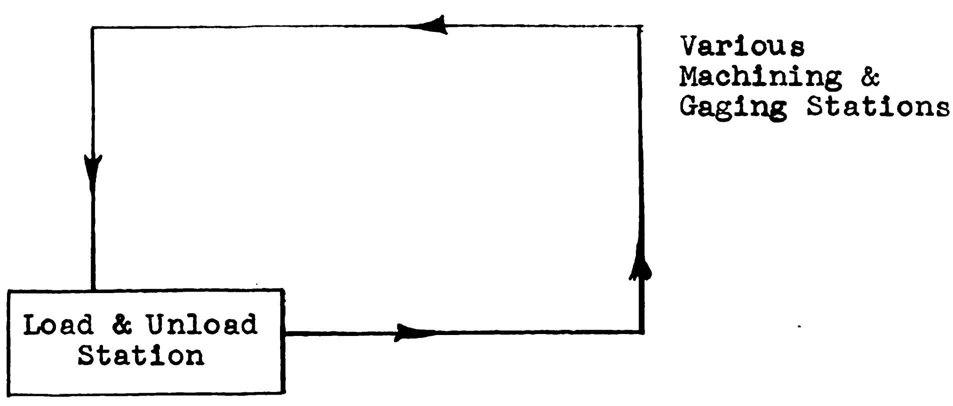

Figure 8

Method of Cycling Parts in a Pallet Transfer Machine

An example of the pallet transfer machine is the equipment used for machining rocker-arm shafts, by Oldsmobile Division of General Motors Corporation. This machine is constructed in rectangular pattern, with loading and unloading performed by an operator at one location. Pallet transfer machines are also used in machining irregular-shaped parts, such as refrigerator compressor housings.

Transfer machines have evolved from a particular need in the automotive industry. Originally parts were machined on single station equipment, such as standard production lathes, milling machines, broaches, and grinders. As the tempo of mass-production increased, a means of combining machining operations was sought.

The first such attempt resulted in a two-way multiple-spindle drilling machine. The workpiece was held in a single location (work station) while drills were advanced from either end of the machine toward the workpiece. The idea was later expanded to include a variety of tools and operations until the single-station multi-head machine reached a practical limit determined by the workpiece and machine.

The next logical step was a multiple-station machine that would allow a greater number of machine operations before requiring removal of the workpiece. The first attempt in this direction was to mount the machining equipment around the periphery of a turntable or indexing dial. One station was utilized for loading and unloading, while others were used for machining operations. (Figure 11 is an indexing dial machine used in assembly operations.) A similar arrangement was the trunion-type of multi-station machine, in which a movable trunion is used to transfer the part from one station to the next.

These machines were limited by the diameter of the work-table or the trunion. As the size of the table increased, the error in indexing became large; hence the need to keep the table diameter small, which in turn limited the number of possible work stations.

From these earlier machines the multiple-station transfer machines evolved. They allow high-speed transfer from one machining operation to the next, eliminating a great amount of manual handling between machine operations. They also eliminate much of the non-productive time and space between machines. (See Fig. 9a and 9b.)

Within the last five years, efforts have been made to integrate separate transfer machines into a complete processing system, with varying degrees of success. One example is the Ford Motor Company's Cleveland Engine Plant.[2] Here are used shuttles, turntables, roll-over devices, time-delay switches, loaders, unloaders, and a host of other non-machining special-purpose materials handling equipment.

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[2] Rupert LeGrand, "How Ford Automates Production Lines," American Machinist Special Report # 303, McGraw-Hill Publishing Company, New York, 1952.

Miles J. Rowan, "How Ford Extends Automaticity to Engine Handling," American Machinist Special Report # 312, McGraw-Hill Publishing Company, New York, 1952.

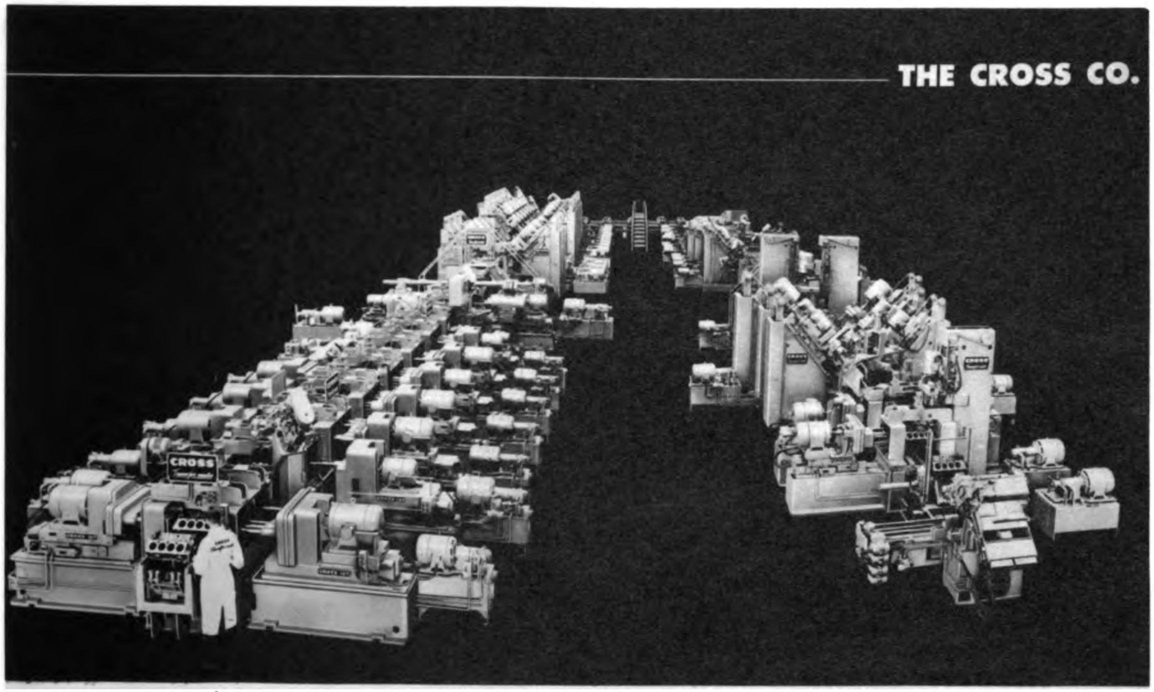

Figure 9a
Cross Transfer-Matic Engine Block Transfer Machine

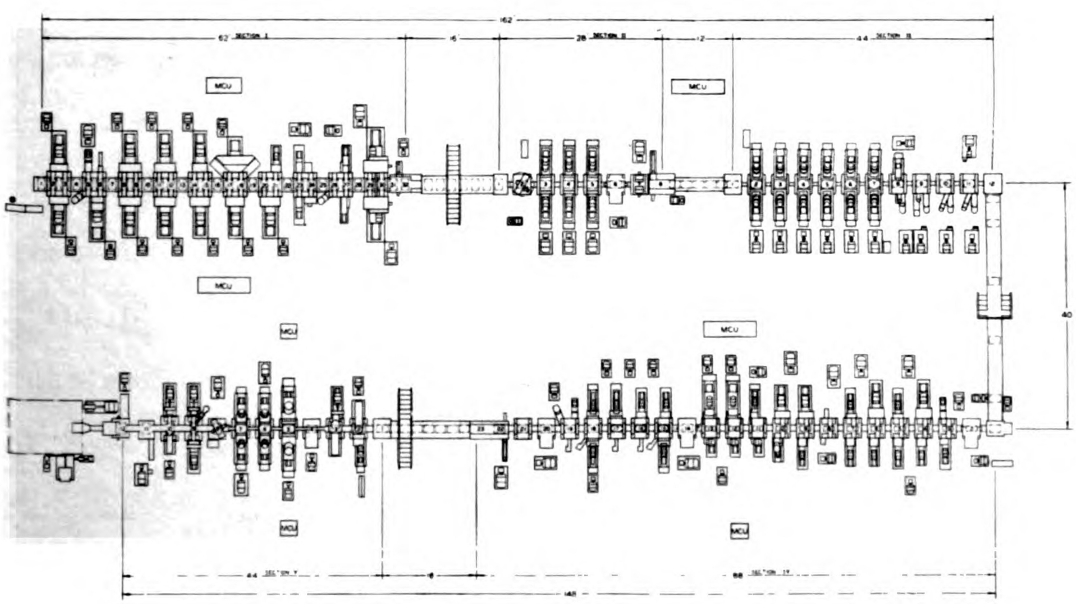

Figure 9b
Layout of Cross Transfer-Matic
Engine Block Machining Line

With the trend toward longer and more integrated machining processes using combinations of transfer machines, certain basic problems arise. Perhaps the most urgent is that of "down-time" caused by maintenance and tool replacement. Another problem is that of designing the process sequences so that the rate of production in the various machines is balanced and coincides with overall production rates.

The problem of machine down-time has been partially eliminated by a method which the Cross Company calls "sectionized automation" and which has been referred to as "segmented automation" at various automotive production plants.[3] This system uses banks of partially machined parts located adjacent to sections of the transfer machinery. Each section utilizes a primary and secondary transfer mechanism; the primary mechanism being used to cycle the part in unison with the overall system and the secondary mechanism functioning independently of the overall system cycling the workpiece through its individual transfer section. The purpose of the bank of spare parts is to keep all sections of the transfer machine operating except the one which is shut down for repair or tool change. For example, if Section 2 of a transfer machine is shut down, Section 1 will continue to operate, feeding its output into a bank of stored parts. In like manner, all sections following Section 2 will continue to

[3]Joseph Geschelin, "Segmented Automation Assures Uninterrupted Production of V-8 Cylinder Blocks and Heads," Automotive Industries, 112, January 15, 1954, 53.

operate, with Section 3 drawing its supply of parts from a bank located adjacent to Sections 2 and 3, which was built up previous to the shut-down. (Fig. 9c illustrates the sections of the machine in Fig. 9a and 9b.) It is important to realize that such a phase of operation is not automatic, since parts must be removed or supplied to the machines by hand at intermediate load and unload stations, and in the same manner, supplied to the bank. The use of banks of this type requires additional on-site storage space. It would probably be feasable to use an intermediate switching and transfer mechanism to shunt parts into or out of the transfer machine at banking points.

A similar arrangement is employed by the bumper plant of Oldsmobile Division of General Motors, Lansing, Michigan.[4] Here bumpers awaiting plating or polishing operations are stored on racks suspended from power-and-free conveyors (a type of overhead rail conveyor in which a powered conveyor pushes, as desired, units which are attached to a free conveyor located immediately below the power conveyor). The racks of bumpers are shunted onto non-powered (free) storage rails in an overhead storage area, while racks are removed from the opposite end of the storage area as needed. Here the term "float" is applied to the storage area, and this arrangement can be compared in design and operation to a railroad siding which is used for storage and switching.

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[4]Allan Ellenwood, Chief Methods Engineer, Oldsmobile Div. of General Motors, oral communication, March 24, 1955.

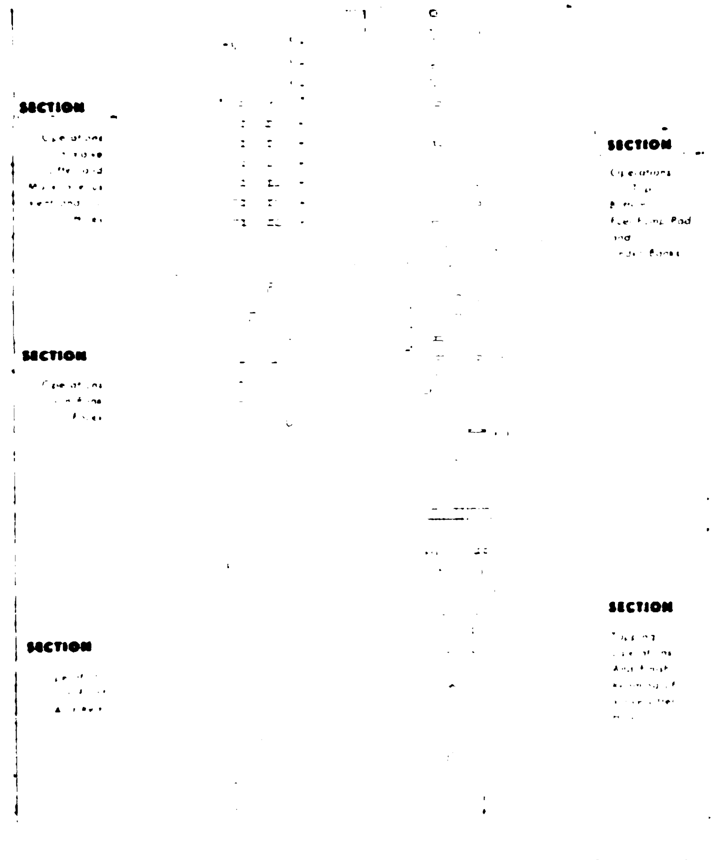

Figure 9c
Sectionized Automation
Applied to Cross Transfer-Matic

Much of the transfer equipment at the Ford-Cleveland plant had been designed and built by the Wilson Automation Company of Detroit, Michigan. Officials of this company state that their system utilizes the cushioning effect of alternately loaded and empty indexing stations.[5] Those stations located beyond a shut-down section would continue

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[5]C. E. Overstedt, Wilson Automation Company, oral communication, March 29, 1955.

to operate until all parts beyond this point (at time of shut-down) have been machined in the remaining operations. Those stations preceding the "down" station would continue to operate until all available indexing stations had been filled with parts, which in turn could not proceed beyond the shut-down station. This creates a wave type of effect in the production output, but eliminates a great amount of lost time which would result if complete shut-down were allowed. It also eliminates the need of semi-processed material banks as used in the Cross process. It has the disadvantages of longer overall down-time once the machine station capacity is saturated, and the inability to make maximum use of the work stations due to alternate or intermediate loaded and idle stations. This type of system would be feasable only where unit transfer machines were utilized and each work station operated independently of the next, shutting down only when limit switches indicated that the following station was full. In the pallet-type transfer machine, all pallets operate in a train (generally alternate stations are idle or gaging stations), and in such a system the entire section would shut down upon the signal of a malfunction from one station.

With the use of multi-tool and multi-station transfer machines, the problem of tool changing is also critical. This problem has been partially solved by the Cross Company by using a tool control unit which includes a device called the Toolometer. The Toolometer consists of an electro-mechanical tool cycle counter connected to each machine tool in question. As the machine operates, the Toolometer indicator indexes for each cycle, until it reaches a point of zero tool life (which has been arbitrarily deterined as a certain number of cycles--commonly 5,000, but varying according to type of tool, material of tool, type of operation, quality requirements, speed, feed, etc.) and shuts down the machine, or the affected section. An indicator light tells the operator which tool to change. The device has the added feature of indicating other tools which will require changing within a specified period--these also are generally changed at the same time. After tool replacement, the pointer of the Toolometer is reset and the machine operation is continued.[6]

Here again it should be noted that this system is automatic only in the sense that it will cease functioning of a predetermined limit is reached or exceeded. The Toolometer does not take into consideration excessive tool wear due to a particularly hard part or soft tool, and adjust the indicator accordingly. Neither does it change the output of the machine or install a new tool automatically. Therefore the tool changing process could be considered as one using automatic controls, but not as an automatically corrected process.

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[6]Kurt O. Tech, Chief Engineer, The Cross Company, oral communication, March 28, 1955.

Programming is present in transfer-type machinery but here the programming is essentially "built in." Since programming is incorporated into limit-switches, mechanical and electrical interlocks, relays, and switching devices, which are designed to perform a permanently fixed operation in indexing the part, the transfer machine is sometimes called "reflex-action" automation. These devices are designed to advance, actuate, and retract the tools, gauge and measure, and shut down the equipment if a malfunction is detected, at the same time giving indication of the malfunction through means of flashing lights or other warning signals. The transfer machine is essentially an open-loop control system, with a human operator completing the feedback loop.

To a limited extent, transfer equipment has designed into it a degree of flexibility. Power supply units, machine base units, and inter-machine transfer units could be interchanged in some instances. However, the degree of flexibility is slight and the equipment would require rebuilding by the manufacturer if the product were changed to any great extent. A certain amount of standardization has been accomplished in auxilliary equipment, however. Equipment working heights, lengths, drives, control units, and component parts have been standardized to some extent, but generally this equipment has been designed to fit a specific manufacturing process.[7]

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[7]J. B. Cunningham, "Small Shops Can Use Automation Too," American Machinist, 98, April 12, 1954, 179.

The major use of transfer-type of equipment has been in the mass-procuction industries--notably the automobile industry. Other industries however, have utilized transfer and similar-type equipment. One example is in the manufacture of artillery shells for the federal government.[8] Here special transfer-type equipment as well as standard machinery adapted to automatic handling, is used. From the formation of steel billets to the completely machined shell, the material is conveyed into machines, furnaces, treating ovens, etc., mechanically. The process is not completely automatic or automatically controlled, however, since approximately 80 per cent of the previously required work force is still utilized. Here the advantage of automatic handling is in freeing the operators from disagreeable or dangerous jobs, as well as uniformity of product. Note that the product is a mass-produced item, not requiring frequent product design changes which would complicate process changes.

A special type of transfer machinery has been developed in the food-processing industries. As the outgrowth of the need for sanitation and uniformity, machines for labeling, bottling, sealing, and tube and can manufacture have been developed. The programming is built into limit switches and mechanical cam and gearing devices.

Other examples could be stated which would parallel closely those of the automotive industry. The various

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[8]"Machining Shells," Automation, 2, January 1955, 50.

examples offered above all have certain characteristics in common. The machines are (a) built for special-purpose mass-production processes, (b) the programming is of the "built in" type, and (c) the control system is of the open-loop automatic type. Certain authors have decried the use of the term "automation" to transfer machines because they do not agree with the definition arbitrarily assigned to the word. However, it will later be shown in Chapter IV, the manner in which transfer machines may be considered as a particular part of automation systems.

The General-Purpose-Machine Concept

The concept of automation may be approached from an entirely different direction than that of the transfer machine, in which special-purpose, relatively inflexible machines are designed to perform a particular function or produce a specific product of limited design-change possibilities. This concept involves the use of general-purpose, standard-design machines, which may be rearranged, converted, or adjusted to produce a wide variety of products with a high degree of flexibility. The aim, of course, is to have automatic, controlled production, and to be able to adjust the emphasis of production from one product to another, or to make required product changes and improvements such as business, economic, and technological changes would deem necessary. This concept of automation was stressed by John Diebold as group leader of a Harvard Business School research

team, mentioned in Chapter I. At the time of writing of their report, little emphasis had been placed upon the concept of automation as a philosophy of manufacturing, although Leaver and Brown in 1946 had envisioned the concept of the automatic factory.[9] Diebold believed that the materials-handling of parts into standard-type machines would be the most difficult problem to solve, while the idea of using standard production-types of machines seemed perfectly natural.

Diebold's concept has merit, since there exist today many machine tools which are operationally acceptable although technologically outdated. In some industries, the concept has been partially utilized, although the element of overall computer control as proposed by Diebold is generally lacking. Most automotive body press lines now utilize such units as the "iron hand," which automatically pulls pressed parts out of the die and drops them onto a conveyor of one type or another, which in turn carries the part to a second-operation press, into which the part is loaded by an automatic loading device.[10] The presses used in these lines are generally of standard design. (Incidentially, this "iron hand" now employed on so many presses is in principle very similar to the mechanism used to unload offset printing presses for many years.)

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[9]Leaver and Brown, op. cit., 165.

[10]Rupert LeGrand, "Ford Handles by Automation," American Machinist Special Report, McGraw-Hill Publishing Co., New York, Ocutober 21, 1948.

Another example of the use of standard machines may be found in the manufacture of ball-bearing races at a Moscow bearing plant. The designer, V. A. Morozov, claims to have utilized 20-year-old standard production machines in an automation arrangement through the use of mechanically and hydraulically controlled materials-handling equipment.[11] Gravity chutes are used to a large extent in this arrangement and no attempt is made to utilize feedback or automatic control. This system is feasable because of the Russian policy of rigid standardization of equipment, and it points up the fallacy of expecting too high a degree of flexibility from such a system.

With a more critical interpretation of what constitutes standard equipment, the proposal takes on added meaning. If the general-purpose type of machinery is designed to include automatic positioning of workpiece and automatic control of the machining operations, and flexibile enough to allow its use for a range of products, then Diebold's proposals become meaningful. Several developments in the general-purpose, automatically-controlled machines of this type have been made over the past years, and recently the trend has been toward including them as one approach or one classification of automation. Although they do not by themselves constitute the complete automation concept, they serve as units which will be more extensively utilized in completely automatic processes of the future.

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[11] David Scott, "Russians Apply Automation to 20-Year-Old Machines," American Machinist, 98, October 11, 1954, 164.

These general-purpose machines (general-purpose in the sense that they are not specifically designed for only one product or process) may be roughly grouped into three catagories. There are (a) the cam-follower, tape-controlled, and punched card-controlled machines; (b) machines using "automatic programming" and playback; and (c) the MIT numerically controlled milling machine and similar developments (acutally an extension of the first classification).

The cam-controlled machine originated in early "copying lathes" and developed into what now is known as "cam-following" machines. The automatic screw machine is a modern example.[12] The programming required to control this type of machine is "built-into" the cam rather than the machine itself, and hence there exists a greater degree of flexibility than in the "reflex-action" type of machinery. The disadvantage of this system is that excessive cam wear results, because the force required to position the cutting tool is also transmitted by the cam along with the positioning information. This problem was solved when the Keller-type of machine was invented in 1921, in which a pattern of relatively soft material is traced by an electrical sensory device which in turn transfers the information to the cutting tool.[13]

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[12] William Pease, "An Automatic Machine Tool," Scientific American, 187, September 1952, 107.

[13] Ibid, 108.

Other variations include the hydraulically-controlled cam-follower machines and the tape-cam control devices. In the hydraulically-controlled machine, a stylus follows the shape of a pattern and transfers deflections of the stylus point to servos which in turn control machine movements.[14] The tape-cam arrangement is a variation of this method, except that a single dimensional characteristic is transferred to the machine controls by means of a stationary, deflectable follower, which traces the edge of a moving plastic tape pattern-strip which in turn passes over a series of rollers. By using a similar tape-pattern for each of the three spatial dimensions, a three-dimensional controlled machine is obtained.[15]

These developments were followed by the tape-controlled types of equipment such as lathes, milling machines, and boring machines. The programming concept here is the same--supplying directions to the machine through an externally originated source--in this case a punched plastic tape or paper card. Here the reference to the Jacquard loom in Chapter I is particularly important, because the same basic media--a card or tape with holes punched into it--is used to code the necessary machine control movements. However, the present-day system utilizes electric or electronic translating devices to convert the code into measured electrical

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[14]From information supplied by the Turchan Follower Machine Co., Detroit, Michigan.

[15]From information supplied by the Bridgwater Machine Tool Company, Akron, Ohio.

forces which in turn (through servo motors) control the position of the workpiece in relation to the tool.

The controls for these systems vary with the intended purpose of the machine. If a high rate of machining is desired, generally the individual machining steps taken will be relatively large and the control instructions will be fewer per measured distance of tool travel. However, if great flexibility is desired, the degree of complexity of the control mechanisms is greater. In the final decision, cost is the controlling element. The expense of making the machine more complex must be in line with the intended machine use.

Degree of complexity also depends upon the type of machine. Complicated lathe movements require a more complex control system than boring machines, but the boring machine usually requires more accurate locational controls. In most of the present-day tape-controlled machines, controls are of the open-loop type, since they automatically direct the movements necessary to complete the machining cycle, but make no provision for feeding back output results for correctional purposes.

A somewhat similar development in tape-controlled tools, yet one which goes a step further, is the "automatic programming" or record-playback method.[16] The machine being programmed (for example, a milling machine) is equipped with servo-control motors similar to the tape-controlled machines

[16] From information supplied by the General Electric Company, Schenectady, New York.

previously mentioned. In addition, it is also equipped with a tape-recording unit coupled through the servo motors, which in this case are selsyns. In the process of completing the first part, a skilled machinist operates the machine through the use of manual controls. At the same time, every machine movement is recorded on magnetic tape through use of the control units, which transfer the X, Y, and Z directional movements into codable signals. This system automatically programs the commands as the first part is made, compared with the usual manual systems of computing each increment of movement and recording it in code upon the tape. To reproduce any number of parts, the tape is simply run through the control units for each workpiece placed in the machine, and the original machinist's movements are reproduced upon the part.

Although mistakes may be erased as the machinist procedes from one step to the next, any unnecessary motions on his part which are left uncorrected will be repeated on each workpiece.[17] Of course, in programming a machine's motions on punched tape before actual operation the same criticism is true, but in this case the programmer is forced to analyze individually each machine movement, and generally a second person checks his program, which is not done in the case of playback control.[18] Maximum possible cutting rates

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[17] Frederick W. Cunnignham, "Controlling Machines With Tape," Automation, 1, August 1954, 79.

[18] D. D. McCracken, "Debugging Computer Programs," Computers and Automation, 4, February 1955, 27.

are not generally used by the operator, a disadvantage not encountered in an analyzed programming procedure.

The third type of general-purpose, automatically controlled machine is the numerically-controlled milling machine built by the Servomechanisms Laboratory of the Massachusetts Institute of Technology.[19] This machine is essentially the same as the tape-controlled machines, but with three important differences. The controls are much more complete, using numerical control of the binary system in conjunction with the necessary computing devices (to be discussed in greater detail under the subject of computers); the machine is correspondingly more flexible because of this type of control; and the machine utilizes feedback to control its output.

The machine used is a Cincinnati Hydrotel vertical-spindle milling machine, adapted to a numerical system of control. The servo motors operate to control the machine movement much the same as other tape- or cam-controlled machines. In coding on tape, however, it is necessary (after analyzing the part to be machined) to code only the length of travel which a cut must have, and the time to be used in completing the cut. The numerical computing devices of the machine will then calculate the number of machining steps to be taken and the size of these increments.[20] This

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[19] C. J. Jacoby, "Analysis of Developments in Automation," Mechanical Engineering, 74, October 1952, 810.

[20] Cunningham, F. W., op. cit., 81

removes from the manual calculations much of the tedious programming requirements, and at the same time allows the machine to calculate by mathematical means the optimum method of machining, giving a much greater degree of flexibility to the operation.

As the servo-motors position the part relative to the tool, servomechanisms read the output of the various directional feeds and speeds of the positioning mechanism, i.e. the actual amount of cross-feed or longitudinal table movement. This information is sent back to the servo-motors which in turn adjust to the corrected machine movement required. This feature is not generally found on other tape-controlled machines, because of rigid adherance to the programmed punched instructions.

In describing these general-purpose machines, detailed explanations of the programming functions and data-handling media have been omitted, because a logical presentation of these functions can best be made under the topic of information-handling systems. Such functions will be taken up in later chapters, since the purpose here is to give a general description of the various types of manufacturing generally included under the subject of automation.

Automation as Applied to Assembly

In describing the various types of automation, reference has been strictly to methods of manufacturing of component parts. Logically the next area to discuss would be that of assembly. Developments in automatic assembly have become prominent as a result of the underlying causes of automation itself--elimination of tedious, fatiguing, or monotonous jobs; the elimination of a great degree of human error; the elimination of costly human labor. But another factor--the tremendously increased pace of automatic manufacture--has demanded a method of assembly which could keep up with the manufacturing tempo. As a result, applications of automation to the field of assembly have been many.

Most of the automatic assembling devices are of the order of the transfer machine. Gearing, cams, limit switches, and relays play an important part in the programming and control of these mechanism. Generally the units to be assembled are small in relation to the equipment necessary to assemble them. Examples are small automotive sub-assemblies, toy assemblies, or electronic sub-assemblies. On occassion, however, automatic assembly has been applied to larger units such as aircraft engine crankshaft connecting rod groups or bulky pallet load assemblies.[21] Packaging and bottling machines (mentioned under the discussion of transfer machines) constitute a particular type of assembly. Usually

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[21] C. F. Hautau, "Automation Assures Precision Assemblies," _The Tool Engineer_, August 1953, (extracted).

these machines are controlled by physical mechanisms and/or electrical relays. Certain types of manufacturing in which assembly is an integral part, such as glass bulb manufacture, have been automatized to a high degree by transfer-types of machinery.[22] Cam and linkage devices are used extensively in this type of machine because of the required transmission of force as well as control information.

The materials handling industry has developed a method of automatically palletizing bulky packages (Fig. 10). This assembly system evolved from the need to handle more quickly the output of conveyor systems. Control is again by relays and limit switches. The system is programmed by "pattern cartridges" which select the proper pattern desired. Stepping switches count the packages as a layer is completed, and are reset to await the forming of the next or an alternate layer, depending upon the pattern preselected and regulated by relays. This system is closely integrated with the other conveyor systems in the manufacturing plant.[23]

In a great number of the small parts- or sub-assembly machines, the dial-type of turntable is quite popular. This machine has evolved to a certain extent from the use of simple hand-assembly turntables, in which a group of operators assembled components while working as a team. An

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[22]"Machine Automates Glass Bulb Manufacturing," Automation, 2, April 1955, 35.

[23]"Automatic Pallet Loading," Automation, 1, October 1954, 35.

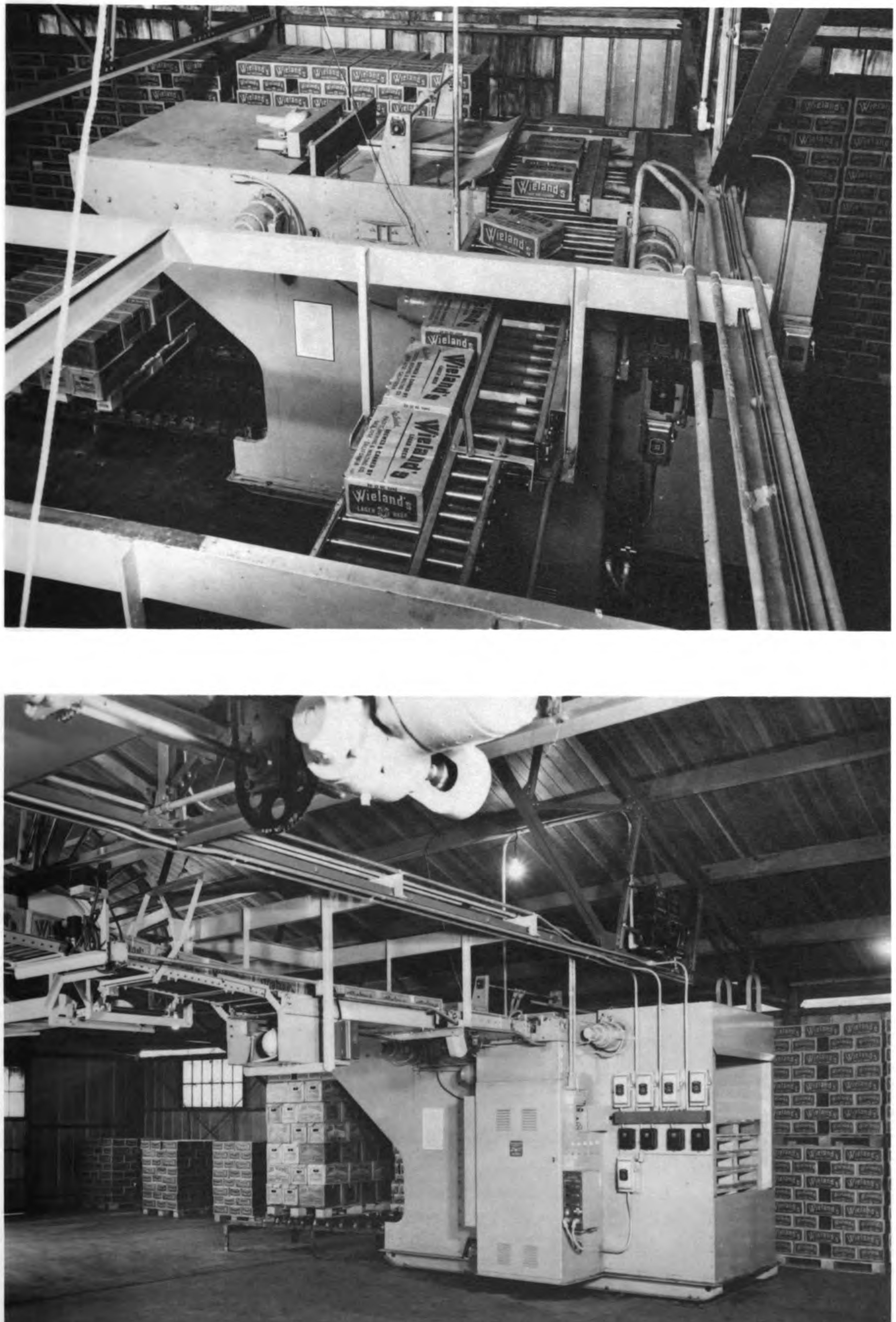

Figure 10
Automatic Pallet Loader

improvement was to substitute mechanized operations for hand assembly. (See Fig. 11.) These machines are flexible to the extent that assembly units placed about the turntable can be removed or relocated, or hand assembly can be substituted partially or entirely, using only the mechanization of the indexing turntable.[24] A variation of the common indexing dial is the ring-type turntable, in which the assembly machines are located in the center of an indexing, revolving ring. Supplimentary assembly operators may be seated around the outside of the ring with little machine interference. Indexing is more precise than with standard turntables since movement tends to approach a linear, rather than angular path. In these machines, control is of the open-loop type.[25]

Other major developments are the chain-link conveyors and the in-line transfer tables. Chain-link conveyors are an outgrowth of the conveyor belt assembly line in which workers assembled parts at tables or workbenches along each side of a slowly moving conveyor. Hand-operated assembly machines, such as staplers and riveters, were placed adjacent to the belt, and with the addition of automatic-type machines, chain-link conveyors were added to give positive indexing. The conveyor is either a vertical loop or a horizontal loop. Vertical-type loops (the return portion of the loop passing

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[24]George H. Kendall and Jerry A. Host, "Assembly by Automatic Machines," Automation, 2, May 1955, 29.

[25]From information supplied by Dixon Automatic Tool, Inc., Rockford, Illinois.

underneath the working surface) are generally used where additional hand assembly operations are required. Horizontal-type loops (the conveyor path being in a horizontal plane) allow assembly on both the near and far sides, or use of machine components on one side and human operators on the other. Each type has its particular machine design and layout advantages and disadvantages, which will not be discussed here.

The in-line type of transfer mechanism more closely resembles the standard machining transfer equipment in design, since the transfer mechanism is less similar to chain links and more closely resembles transfer linkages, with integrated limit switches and indexing controls. All of the various types of equipment mentioned here are often referred to as mechanization equipment rather than automation equipment, because although they eliminate much of the manual assembly, the degree of control is primitive.

In discussing recent developments in the electronic component assembly industries (as well as other types of manufacturing assembly) the concept of redesign or "rethinking" as presented by Diebold and others becomes increasingly important. The degree to which this phase of automation has progressed has depended upon both technological improvement and the particular economic and social pressures present or developing in our society. In many instances the degree of redesign work accomplished in establishing a condition of automation is dependent not so much upon what is technologically possible but upon the degree of economic necessity and consumer acceptance involved. Many of the automatic (or mechanized) assembly systems now in use consist of assembling standard component parts such as washers, nuts, screws, rivets, and a host of conventional fastening, connecting, and operating components into a conventional or slightly modified unit. (See Fig. 11.) Despite the cries of the forward-planner that such systems tend to be archaic in method and design, a great amount of effort is directed into such channels. Until proven economically feasable,

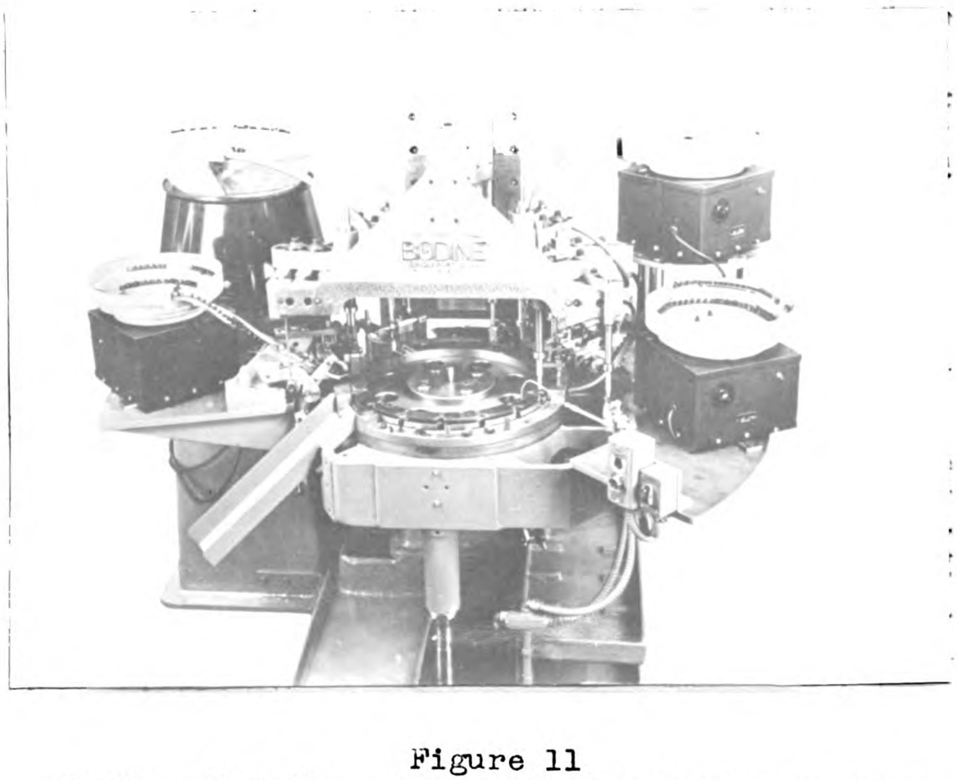

Figure 11
Bodine Dial-Type Automatic Assembling Machine
Using Syntron Vibrating Hoppers

manufacturers have been reluctant to change. As stated by James R. Bright of the Harvard Graduate School of Business at a recent symposium on automation, "It's often better to be a fast second, rather than first, in automation programs."[26]

There are instances, however, where, as a result of the pressure to mechanize assembly procedures, redesign becomes a necessity. In the electronics industry the mechanized manufacture of electronic components has long been standard policy. Assembly of these units was complicated by the demands of intricate hand-soldering and frequent circuitry changes and the use of hand methods of assembly was accepted as a necessary evil. With the increased demand for electronic equipment by the military (and by the electronic needs of automation, itself) a method was developed to produce circuitry upon which is fastened standard (or slightly modified) electronic components. The circuits are "printed" upon a laminated plastic board combined with a thin sheet of copper foil. The "wires" are obtained by etching away that portion of the foil not desired. Other methods of printing are possible, such as the printing of metal powder, which is later cintered in a furnace.

Detailed descriptions of the method of manufacture of these boards may be obtained from various technical writings and need not be discussed here. The process itself is not

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[26] James R. Bright, Automation Symposium, Michigan State College, May 13, 1955.

generally automatic but logically could be.[27] The aim at this point is to discuss the automation assembly technique specifically as applied to electronics. Several systems of assembly have been developed; a few of them will be mentioned here.

A system developed by Admiral Corporation utilizes punched, etched base-plates and standard electronic components.[28] The machine is similar to an in-line transfer machine. Parts are fed from a hopper at each work station while an attaching head bends the lead wires and inserts them in the pre-punched holes of the printed plastic card. Heads are provided for attaching jumper wires to complete the circuitry. As the base-plate panels are advanced along the machine from one work station to the next, they are held in position by an auxilliary-type pallet arrangement. The control of the machine is essentially that of most transfer machines, i.e., by interlocks, limit switchs, and relays.

General Mills has completed a similar assembly unit called "Autofab."[29] This unit was produced originally for IBM for the assembly of printed circuit electronic sub-assemblies for military-type computers. The photographs (Figures 12 through 15) illustrate the operation of this

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[27]"Fabricating Television Circuits," Automation, 2, February 1955, 32.

[28]Ibid, 34.

[29]From information supplied by General Mills, Inc., Minneapolis, Minnesota.

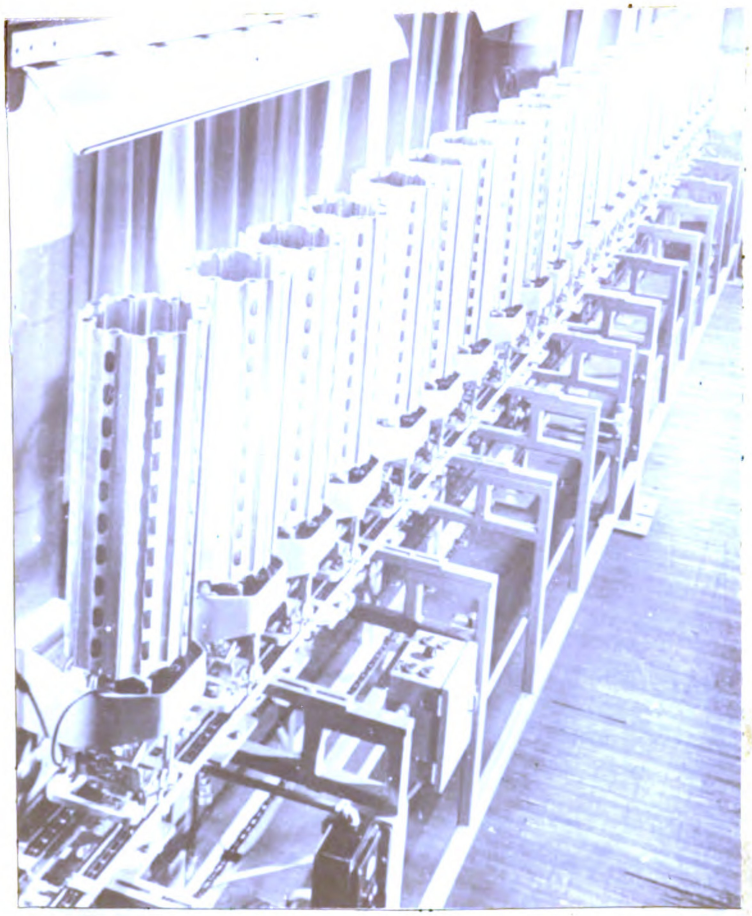

Figure 12
General Mills Automatic
Assembling Machine, "Autofab"

machine. As may be observed from the illustrations, this machine utilizes a chain-type indexing drive. Attaching heads have rotating hoppers which utilize magazine-loaded parts. Interlocks prevent continuation of machine operation if faulty parts or assembly occur at one of the work stations. According to company information, equipment for automatic loading of parts magazines is being constructed.

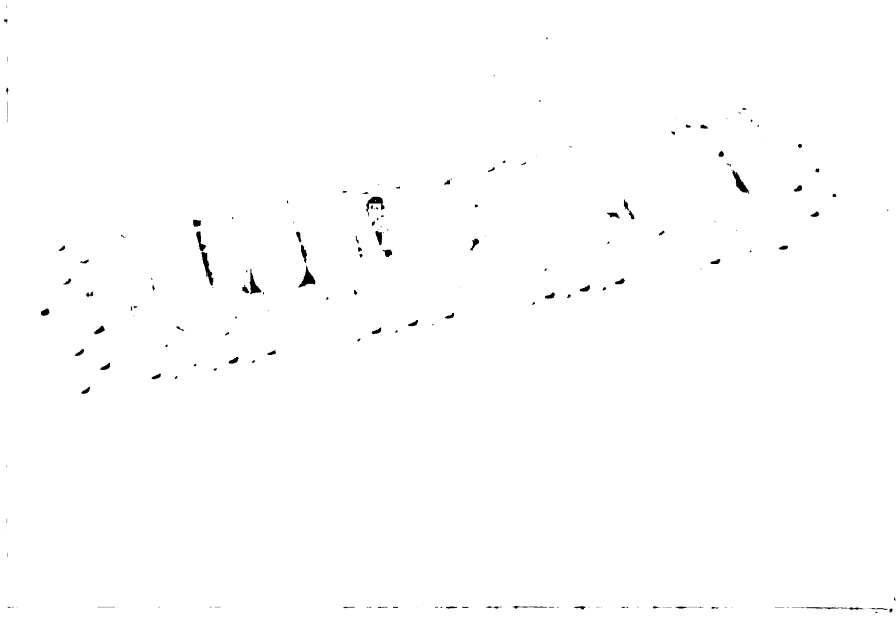

Figure 13
Completed Printed Circuit Board
With Components by General Mills Autofab

The methods of supplying and attaching parts to the printed circuit boards vary with the particular design of the machine and the requirements of the circuit. One machine, developed by the United Shoe Machinery Company, feeds taped-together parts into the machine in the manner of an ammunition belt. Other methods use special lead-bending arrangements and attaching clips, but the end result is essentially the same.

To a certain extent these machines are more flexible than automotive-type transfer machines, because the parts to be assembled are to a degree modular, having approximately

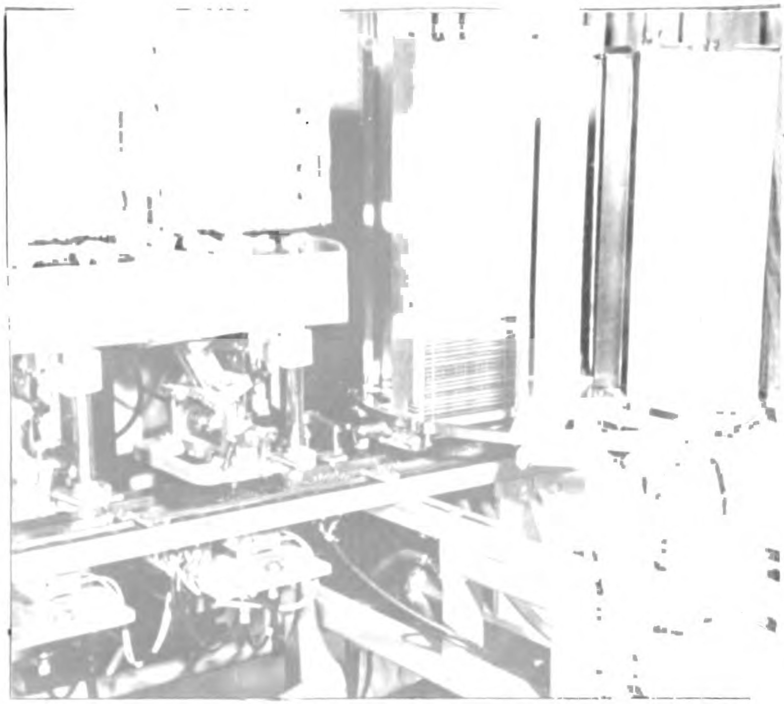

Figure 14
General Mills Autofab--Printed Circuit
Card Dispensing Hopper

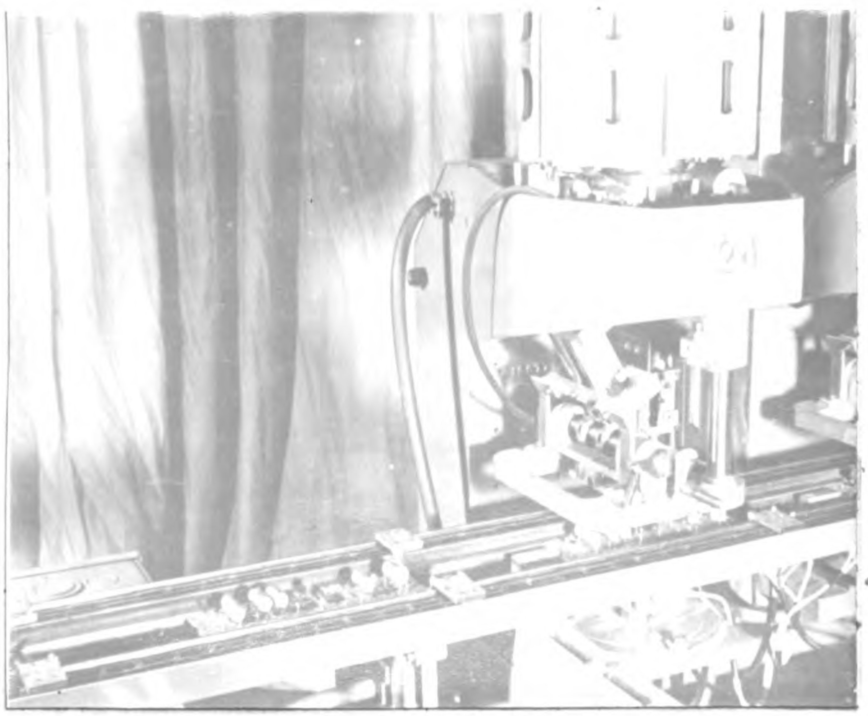

Figure 15
General Mills Autofab--Completed Assemblies
Rolling Off the End of Line

the same shape although differing in size. Different components could be added or changed by readjusting positioning devices and tooling. The relative size of parts and the amount of physical work performed upon them in assembling is small, and spacing readjustments of the machine are relatively simple.

An advanced degree of the control function of the assembly equipment is incorporated into a large machine being built by General Electric. It utilizes punched card programming to give a more versatile arrangement. Since the programming is external to the machine itself, short-run assemblies can be completed with only a short period devoted to changeover.[30]

The Modular Concept of Production--Project Tinkertoy

Although this portion of the chapter on basic automation concepts could have been included partially under the topic of assembly and partially under component manufacture, this concept in itself is far enough advanced technologically to be considered and discussed separately. Project Tinkertoy is the code name given to a program of manufacture and assembly of modular electronic products sponsored jointly by the U. S. Navy Bureau of Aeronautics and the National Bureau of Standards.

This project as devised by its creators was to include two phases: a design phase, Modular Design of Electronics;

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[30]Edmund L. Van Deusen, "Electronics Goes Modern," Fortune, 51, June 1955, 132.

and a production phase, Mechanized Production of Electronics, abbreviated MDE-MPE.[31] (Tinkertoy is a copywriter trade name of a toy manufacturer.) This project was originated as an aid to industrial preparedness and rapid mobilization in case of need in a national emergency. The original idea was to make possible a rapid conversion from civilian to military products and visa versa. It was designed to utilize non-critical unprocessed or bulk materials in the manufacturing sense, and to allow rapid and interchangeable assembly through the use of mechanized equipment.

While other types of mechanized assembly of electronic parts (the General Mills and Admiral assembly machines) utilize modularly designed parts to a degree (printed circuits and standardized electronic components) the MDE program keyed its entire development to the idea of modular components.

The module is composed of a notched ceramic wafer which is used as the base for all of the electronic components (Fig. 16). These components consist of capacitors, resistors, tube sockets, coils, basic circuitry wafers, and other common electronic parts. The wafer is used as the basis in the manufacture of these parts, however, rather than conventional components. The riser (support) wires also serve as circuitry, connecting various wafer units electrically. The wires may be clipped between wafers at various points to

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[31]"Project Tinkertoy," <u>NBS Technical News Bulletin</u>, 37, November 1953, 161.

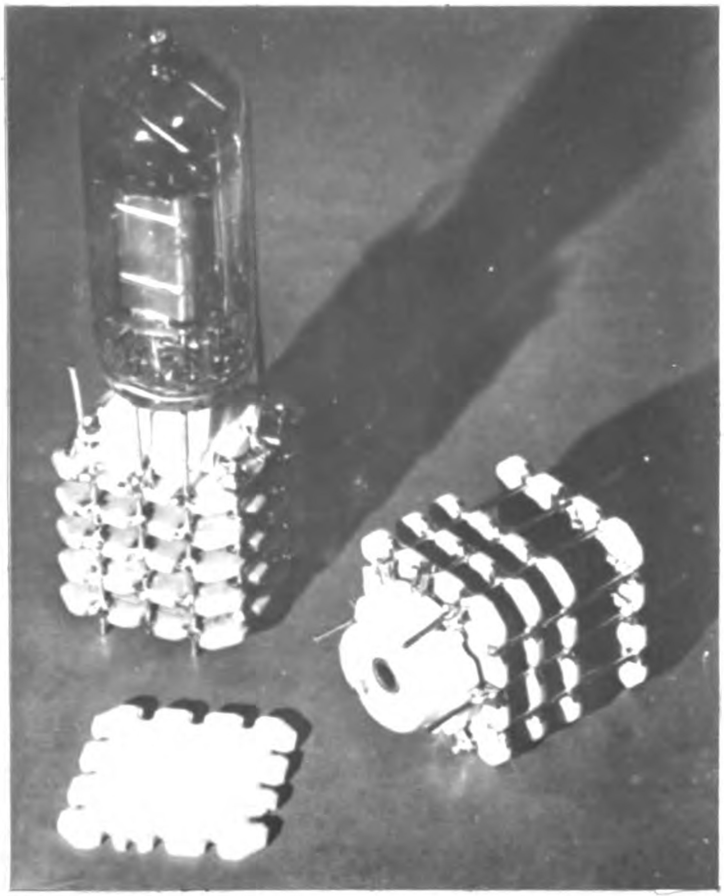

Figure 16
Wafer and Module Used in Project Tinkertoy

provide the necessary circuit breaks between elements. The wafer sandwich or module is composed of from four to six wafers which bear the necessary integrated components. These modules are often fastened to a printed circuit base plate, although this unit is not necessarily a part of the MDE program (Fig. 17).

In Figure 18 is shown the flow diagram of the entire MPE pilot plant. Conventional methods of manufacturing

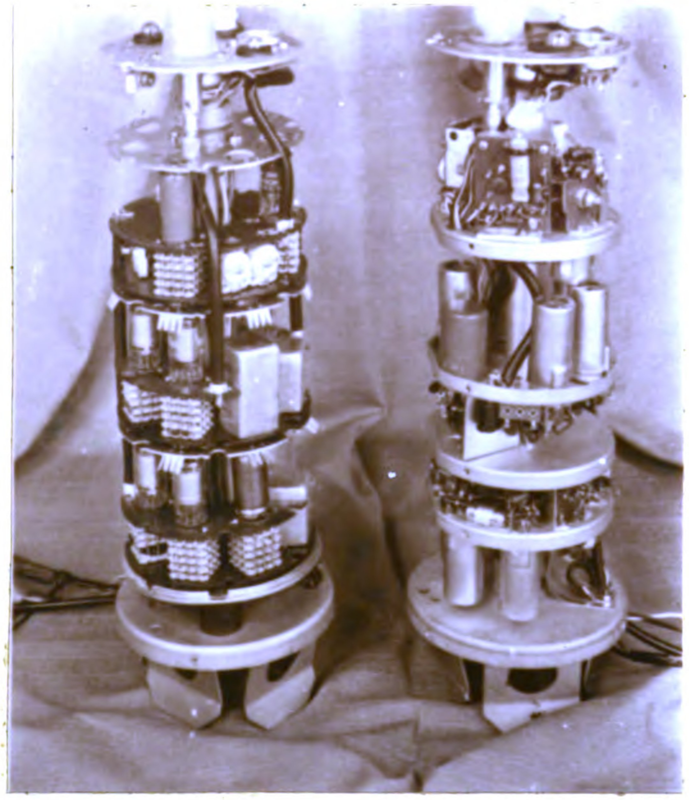

Figure 17
Modular and Conventional Assemblies

components were considered inadaquate for obtaining desired results, and an entirely differnet approach was tried. The diverse skills of normally unrelated industries were utilized. Much of the manufacturing equipment was designed and built by the Kaiser Electronics Division of Willys Motor Company.[32] (It is interesting to note that some special machines were designed and built by the Doughnut Corporation of America,

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[32]"Project Tinkertoy," op. cit., 170.

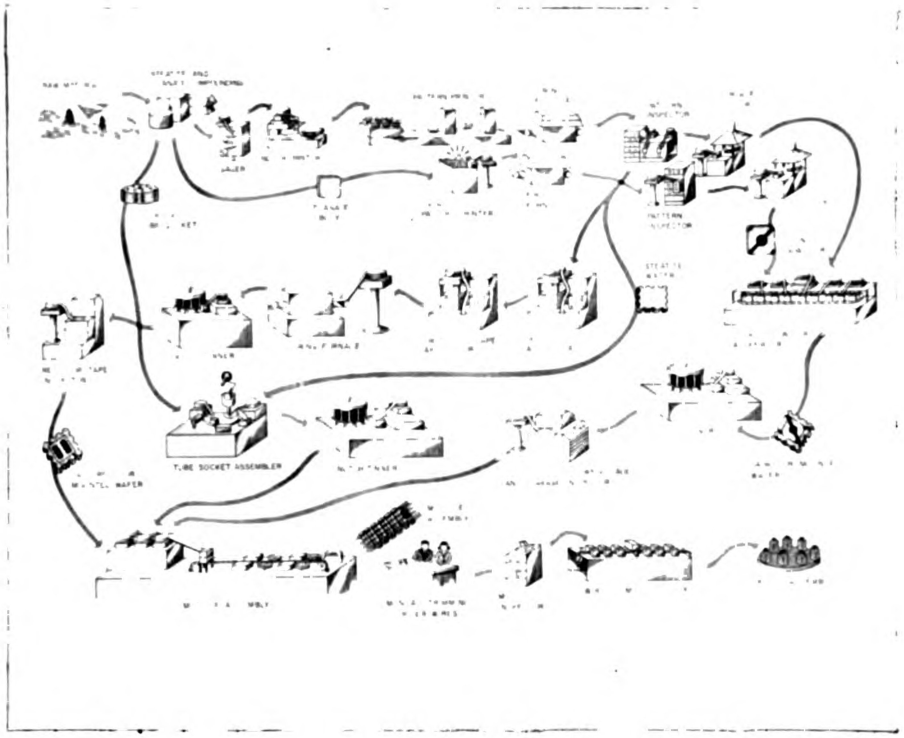

Figure 18
Flow Diagram of Project Tinkertoy Pilot Plant

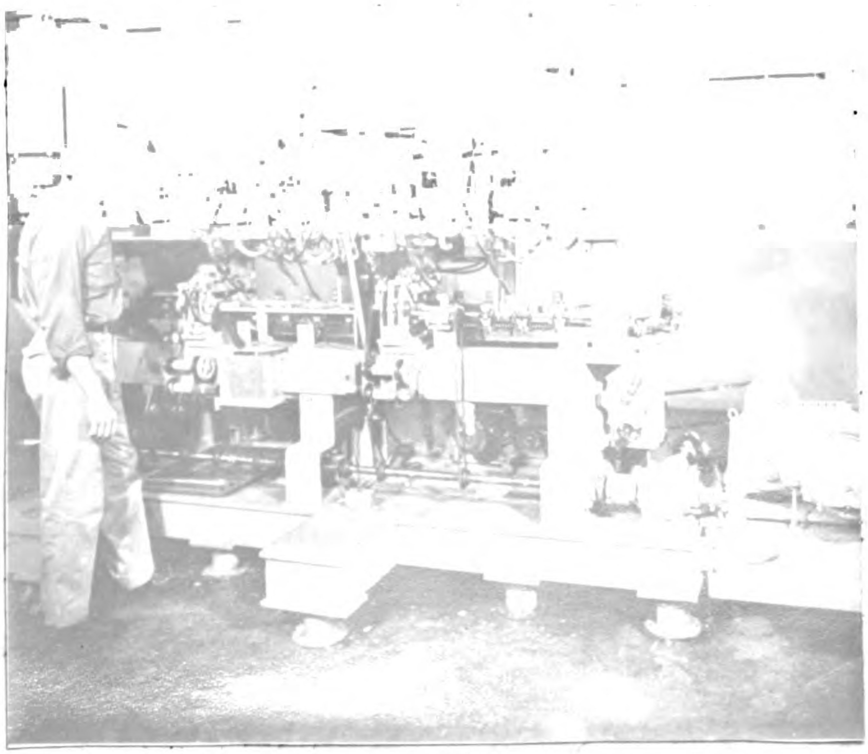

Figure 19
Capacitor Assembly Machine

whose experience was about as remotely removed from the electronics industry as possible, but whose background in producing mechanized equipment for manufacturing a modular product, the doughnut, was an invaluable aid.)

The equipment utilized in the MPE scheme consists of the mechanized transfer-type, utilizing a combination of transfer mechanisms, conveyor chains, and wafer-feeding and positioning units. Actually the manufacture may be considered in three steps: (a) manufacture of the ceramic wafer (in a great degree similar to the mechanized manufacture of ceramic tile); (b) combining the raw materials of resistors, capacitors, etc., to the wafer; and (c) assembly and testing of the module. Wafer manufacture may be completed some time prior to tape or foil additions, and the wafer stored for future use. Since a single design of wafer is used for all of the electronic parts, the economies of such a procedure are obvious.

Component parts of the module may be prepared in the same manner as the wafer, i.e., some time prior to assembly; or they can be manufactured in conjunction with the assembly operations. This allows greater flexibility than previously obtained either in the electronics industry or in the use of transfer equipment. Mechanized equipment is used for application of resistor-tape, capacitor foil, and in printing basic circuitry on the wafers (Fig. 19). (Here printing is used in the true sense, in which silver paint is deposited in the notches and forced through stencil-type patterns to print resistor and condensor leads and inter-notch circuitry.) The control of the manufacturing machinery is of the interlock-limit-switch variety, while programming of the parts manufacture (obtaining resistance or capacitance desired or number of resistors per wafer) is accomplished with punched cards fed into the program reader of the machine.

A method of materials-handling of the wafers is accomplished by the use of a keying notch on one side of the wafer (see Fig. 16). This notch allows indexing and orienting of the wafer as it leaves the vibratory bowl feeder (Fig. 20).

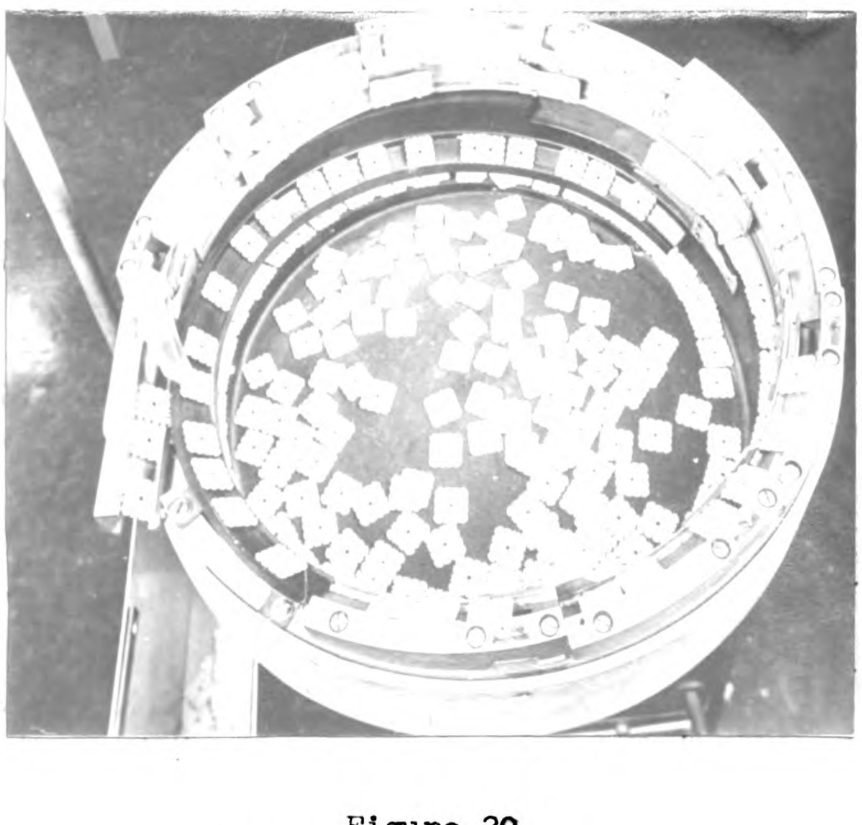

Figure 20
Vibratory Bowl Feeder

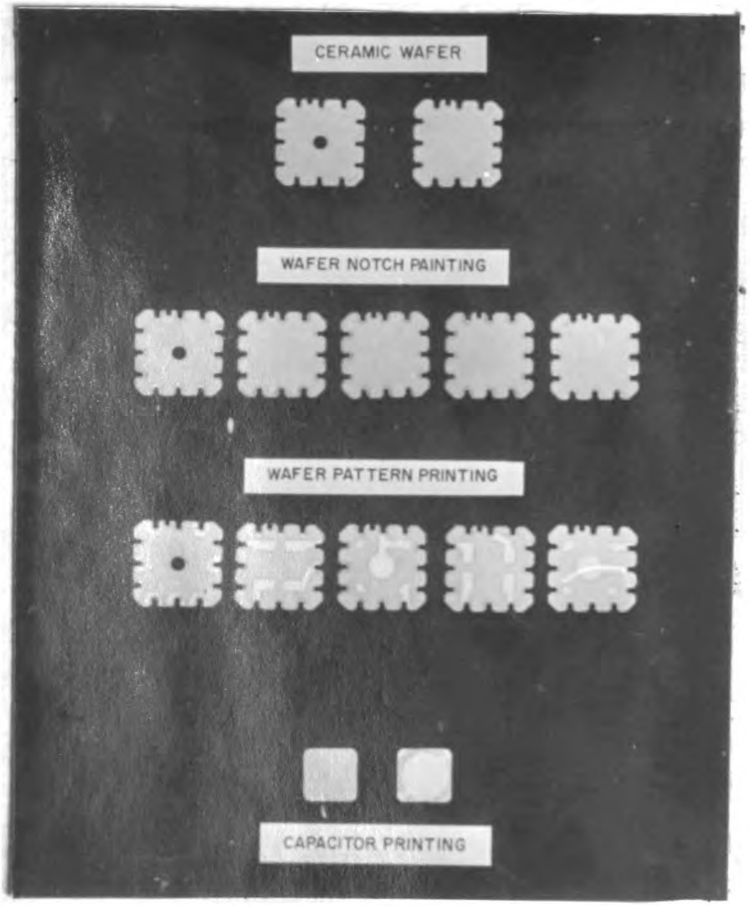

Figure 21
Wafer Printing Procedure

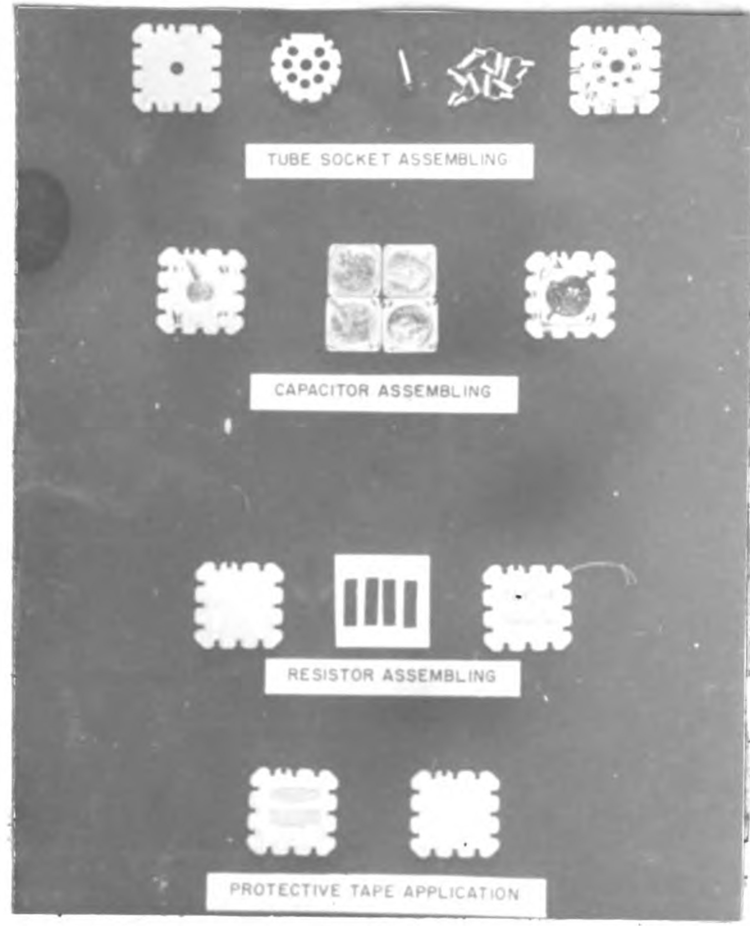

Figure 22
Wafer Component Assembly

The eight channels of the feeder are designed to position the wafer in a series of steps, depending upon the random arrangement of the wafer as it enters the first channel. From this point onward, the wafer enters the particular component-application machine or module assembler.

Module assembly may be separated or integrated with the component manufacturing depending upon the production schedule.[33] Parts are fed from vibratory bowl feeders into the module assembler according to precise scheduling. The modules are assembled from stacked wafers, and riser wires are automatically clipped and soldered into the correct positions. Devices automatically clip risers to complete necessary circuitry, and the module is both mechanically gaged and electrically tested by automatic functions of the machine. The assembled module is then transferred to base-plate assembly areas where the modules are assembled manually. With development of the Admiral and General Mills types of mechanized assemblers, a next step in the automation field would be to assemble these modules to the bases by mechanized means.

The method of programming of the assembly machine is accomplished by use of a modular work sheet, which contains top and botton outlines of six wafers with identifying numbers at each notch. Provision for order of assembly is noted, as well as required circuitry, and this information is then transferred to punched cards and integrated into machine

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[33]"Project Tinkertoy: It Changes the Electronic Design Concept," Product Engineering, 24, December 1953, 139.

control and operation. Manual adjustment is required in setting up the machine, but a punched card system automatically checks electrical properties of the completed modules.

A fairly intensified study of engineering applications of the modules coupled with environmental studies were made by Sanders Associates, Inc., of Nashua, N. H.[34] This company became expert in converting regular circuits to MDE-type modules, and with this information the Bureau of Aeronautics built several thousand experimental assemblies.[35] From this information, complete procedures for fabrication by hand and machine were determined and a study of manufacturing cost determination was completed, the results being published by the National Bureau of Standards.[36] In a study conducted by Harvard researchers, the cost determinations are sidcussed in some detail.[37]

The results of such extensive experimentation soon became obvious. Although Project Tinkertoy was originated as a pilot-plant military-preparedness measure, the increased pressure of the automation concepts upon the civilian industry propelled the modular concept into civilian products.

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[34]"Project Tinkertoy," NBS Bulletin, op. cit., 170.

[35]Van Deusen, op. cit., 146.

[36]Vol. III, Hand Fabrication Techniques, PB 111277; Vol. V, Manufacturing Cost Determination, PB 11315; National Bureau of Standards, Washington, D. C., 1953.

[37]Stephen A. June and others, "The Automatic Factory--A Critical Examination," Instruments & Automation, 28, March 1955, 434.

One manufacturer has experimented with the process and developed it to the point where he will soon use it to produce television sub-assemblies.[38]

Summary

This chapter has included the several types of machines and processes currently classified as automation. Also included is the modular concept of production, exemplified by Project Tinkertoy.

The transfer machine concept developed in the automotive industries through the progressive combining of machine tools until there now exists what is known as the pallet- and plain-type modern transfer machines. These machines are of the open-loop control, built-in-program variety.

The general-purpose-type of automatic machines present an alternate concept of automation and were the result of the need for machines of general-purpose use, yet automatically controlled. They allow a degree of flexibility not generally found in transfer machines. These machines may be classified as (a) cam-follower, tape-controlled or other types of externally programmed open-loop machines; (b) machines using automatic programming and playback (also open-loop controlled; and (c) the MIT numerically controlled type of machine in which closed-loop feedback is present.

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[38]Van Deusen, op. cit., 146.

Assembly techniques constitute a particular concept of automation using adaptations of the above-mentioned types of machines for the purpose of assembly. The method of control of the various systems in use is similar to those of manufacturing equipment mentioned above.

Modular concepts of automation have centered around the National Bureau of Standards MDE-MPE (Project Tinkertoy) experiment. Modular design, as well as mechanized manufacture and assembly, are emphasized in this concept, which has recently been utilized in commercial manufacture of electronic equipment.

Other types of industry have to a lesser degree been described as utilizing automation, but these can generally be grouped as a part of the above concepts.

CHAPTER IV

CLASSIFICATIONS OF THE AUTOMATION CONCEPTS

Introduction

In Chapter III the development of basic automation concepts was discussed. From this discussion it can be seen that there seem to be several conflicting opinions as to just what automation really is. The advocates of one particular concept tend to be highly distrustful of the application of the term to any other concept. Those who are familiar with the metal-working industry, especially the automotive and automotive machine tool industries, tend to think of automation in terms of transfer machines--the basic unit of automatic machining in their particular field. They tend to be highly suspicious of any device which exceeds the level of electrical complexity of a limit switch or an electrical relay. The electronics and control engineers, on the other hand, look with disdain upon the lowly transfer mechanisms, preferring instead to emphasize the electronic computers and highly complex electrical-mechanical servomechanisms as the true concept of automation. Quoting from a roundtable discussion on automatic factories, Eric W. Leaver stated:[1]

> Where industry has attempted to automatize, Brown [his associate] and I feel that it has too often got off on the wrong foot by trying to create highly specialized machines. I don't think you can escape the

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[1]"The Automatic Factory," Fortune, 48, October 1950, 178.

> conclusion that some of these machines rival Rube Goldberg. They have little chains and gears and rods popping in and out all over, and it seems as though the thing may have gone slightly astray.

In rebuttal, Professor Pease of MIT stated:[2]

> The reference to Rube Goldberg is not a recognized retreat of the Electroniker when he faces the complexities of mechanical apparatus. The Mechaniker feels the same way about electronic devices. Mr. Leaver's integrated automatic machine units will be fantastically more complex than anything we know today.

Considering the longevity of the transfer machines, some critics have compared them with the biological extinction of the dinosaur. Perhaps a more valid comparison could be found in the mechanized transportation industry. Originally the railroads were the giants of transport. The struggles of the gasoline-powered automobile were feeble at first but expanded to the point where their intrepid challanges to the railroads are now tending to create a realignment of the entire railroad philosophy.[3] Both transfer and general-purpose types of automatic machinery will continue to be required, but their form and method of operation may be drastically altered.

Attempts at classification of automation have been several. These classifications are usually for a specific purpose and are shaded by the background of the classifier. Current thinking on methods of classification will be presented here, each of them interpreting automation in a

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[2]Loc. cit.

[3]Francis Bello, "Lightweight Trains--At Last," Fortune, 51, July 1955, 110.

particular way. These classifications will include: orientation of automation by terminology; classification by extent of automaticity; a description of management classification; a brief discussion of classification by industry. In Chapter V, classification by informational concepts will be integrated with the application of information to the subject in general.

Orientation By Terminology

This method of classification emphasizes the use of particular words to describe various types of automation. The particular example presented here is expounded by J. J. Brown, whose writings have been used as reference in other portions of this thesis.[4]

In Brown's tables, the subject is broken down into three basic classes--mechanized, automatic self-operating or self-controlled (automation), and cybernetic. He feels that these three words can adaquately describe developments commonly called automation. The terminology can be further expanded as follows:

TABLE Ia [5]

CLASSIFICATION OF TERMINOLOGY

Class	Generic Noun	Noun	Adjective	Verb
I	Mechanization		Mechanized	To mechanize
II	Automatism	Automation	Automatic or Automatized	To automatize
III	Cybernetics		Cybernetic	To cybernetize

[4]J. J. Brown, "Stop Coining Words!", Control Engineering, 2, March 1955, 49.

[5]Ibid, 69.

TABLE Ib
DESCRIPTION OF TERMINOLOGY

Class	Descriptions
I	No program, but repeated action. Control mostly fixed.
II	There is a program (which causes repeated action). Repeated actions are not the same, since sensing devices have brought information to modify action.
III	Records or sensors cause repeated action, but emphasis is on control rather than output. Actions are less likely to be the same each time, because many sensors have brought in control information to modify them.

Table II breaks these classes into degree, characteristics, and examples. The examples tend to give a more meaningful explanation to the classification.

At this point a brief discussion of the term, cybernetics, is in order. It was origniated in this country by Norbert Wiener of MIT to describe " . . . the entire field of control and communication theory, whether in the machine or in the animal."[6] Therefore in its application here it is used in a much narrower sense. Table I shows that the term automation falls midway between the first class, mechanization, and the ultimate, cybernetics.

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[6]Norbert Wiener, Cybernetics, John Wiley & Sons, Inc., New York, 1948.

TABLE II

HIERARCHY OF MACHINES

Class	Degree	Characteristic	Examples
Mechanized	Slightly	Mechanical Advantage	Block and tackle, automobile jack.
	Moderately	Mechanical advantage plus pattern information.	Printing press, packaging & bottling machinery.
	Highly	No overall program. One operation triggers the next	Automobile, transfer machines, Osborn molding machine.
Automatic, Self-operating or Self-controlled	Semi-	If anything goes wrong, it rings a bell to call operator. Has some kind of program. No feedback.	Auto. Screw Machine, follower lathe, doughnut machine, teletypsetting machine.
	Moderately	Has to be set in motion but stops itself. May have feedback.	Vending machines, record changer, digital computers.
	Fully	Self-starting and stopping at end of cycle. Has feedback.	Headlight dimmer, MIT milling machine.
Cybernetic	Function Oriented	Adjusts itself to changing operating conditions.	Automatic pilot, Otis automatic elevator.
	Product Oriented	Adjusts itself to changes in input materials and resulting product.	Automatic digit recognizer, language translation machine, product-controlled oven.
	Sensitive to Environment	Adjusts itself to anticipated changes in conditions.	Minneapolis-Honeywell anticipator, Otis elevator system.

Classification by Extent of Automaticity

A method of classification more applicable to the engineering viewpoint would be one in which symbolic terminology is used. This allows a grouping of the various classes into an arrangement helpful in designing or producing a manufactured product.

The method presented here was originated by George H. Amber, professional engineer of Detroit, Michigan.[7] Amber states that this concept is now being used by Westinghouse engineers. In order to give a logical arrangement, three criteria are used: ascending order; intensity; summation.[8]

> The extent to which man's functions can be replaced by power and automatic control are classified in ascending order; the degree of automaticity is used as a measure of its intensity; the summation of many units, a measure of process automation.

From this statement is evolved the terminology of the classification. The term "order" is used to indicate the level of automaticity of a machine and is designated $A_{(n)}$. The subscript (n) varies from zero (indicating a zero degree of automaticity) to eight (considered the highest type of automaticity possible).

The term "degree" is used to indicate the <u>intensity</u> or completeness of automaticity in a machine. This constitutes a horizontal classification, as opposed to orders, which are arranged in an ascending pattern. Degree indicates the extent to which all of a machine's operations

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[7]George H. Amber, "Orders and Degrees of Automaticity," <u>Electrical Manufacturing</u>, 55, January 1955, 64.

[8]Loc. cit.

TABLE III

ORDERS OF AUTOMATICITY

Order	Characteristic	Examples
A_0	Zero automaticity. Requires manual control, muscular energy.	Hand tools, jacks, hand pumps.
A_1	Energy supplied by machine. Operator must feed work to machine or visa versa. Operator stops, starts machine.	Power saws, simple drill presses, grinders, pumps, electric typewriters.
A_2	Power feed, power assist, plus power drive.	Automatic-feed drill-press, automatic-feed lathe.
A_3	Use of programming; ability of machine to "remember." Continuous operation. "Blind obedience" without "judgment."	Automatic screw machines, automatic drills, transfer machines, automatic-cycle machine tools.
A_4	Use of feedback plus programming. Closed-loop control. Some discretionary sense.	Automatic honing machine, furnace temperature controls, speed regulators.
A_5	Uses feedback, programming. Also accepts programmed message, performs computations, commits the operations.	MIT numerically controlled milling machine, radar directors, bomb sights, gun fire control computers.
A_6	Uses feedback, programming. Computes a course of action from feedback. Logically analyzes result of computation according to built-in rules. Acts upon decision.	Otis autronic elevator control system; certain guided missile control systems.
A_7	Similar to A_6, plus ability to "learn" by experience. Assimilates information obtained from operations and projects into a program of operation. May change process to obrain desired results. Has ability to generalize.	Speculation only. An automatic press, by sensing operating conditions as it proceeds, could plan and pursue a plan of action under existing conditions to obtain desired results.
A_8	Intuitive operation based upon statistical and probability functions. Exercises executive judgment.	Highly imaginative speculation. May never occur.

are automatic and is designated by a fractional exponent of the base (A), as $A^{3/7}$, indicating that three of the seven operations of the machine are automatic.

The third criterion, summation, introduces the use of a third term, the prefex. This is the function factor, denoted by a lower-case letter. This function factor represents the functions of the machine, and is assigned arbitrarily. It may, however, be used in an ascending order depending upon the weight that the particular functions are given. These functions may be the type of operation, rate, method, size of workpiece, etc. A particular machine might be denoted $cA_3^{9/10}$. (For instance: function c assembly ; order of automaticity A_3; degree of automaticity--9 out of 10 of its operations automatic, with one operation loading manual.) In assigning this function factor, however, it is important to realize that a machine may contain or utilize several functions. In machines of a lower order, one function may be of primary importance and hence easy to classify, but in higher orders of automaticity, the function generally is variable. Usually the function of immediate importance is the one which will be emphasized in the summation.

Summation, the addition of the combined characteristics of a series of machines in a system or process, indicates the "automation" (here meaning the quantity and quality of automaticity and function) of the process line. This results in an equation like the following:

$cA_0^{1/1} \neq aA_1^{2/3} \neq bA_2^{3/4} \neq cA_3^{4/6} \neq dA_3^{5/6}$ or, in five typical manufacturing operations, the following might result: unpacking steel plates manually ($cA_0^{1/1}$); manual feeding of the plates into a punch press, which punches and automatically ejects the part ($aA_1^{2/3}$); making bearing pins on a lathe in which only one of the four operations is manual, such as an adjustment ($bA_2^{3/4}$); assembling the stamping and pin, in which loading and inserting a small part are manual ($cA_3^{4/6}$); and automatic degreasing, bonderizing, masking, and painting, where loading the part is manual and unloading the part is automatic ($dA_3^{5/6}$).

Such an equation furnishes a pattern to gauge the entire production setup. Although numerical equivalents or mathematical values have yet to be applied to such a representation, it is entirely conceivable that a method will be devised. With such an evaluation, not only technologically feasible combinations but management decisions could be based upon this concept. In its present form, the equation in a few short symbols can indicate to the trained observer locations of improvement or points of danger.

The classifications of order, with characteristics and examples is given in data supplied by Amber, and is tabulated in Table III. Classifications of functions or degrees of automaticity are not listed, since these will vary with the individual machine design and usage. According to this concept, automation occurs when machines of the A_3 or higher orders are linked together to give continuous automatic production.

A Management Classification of Automation

From the management standpoint, the concept of automaticity or automatic control is not as important as the economic gains which could be obtained by using (or not using) certain automation developments.

A management-oriented method of classification is presented by James R. Bright.[9] Bright analyzes automation in the light of three different qualities (rather than quantities): (1) span of mechanization, (2) level of mechanization, and (3) amount of mechanization. He explains these three terms as follows: Span--the portion over which a given total manufacturing sequence extends; Level--the degree of mechanization characterized by a particular function or activity; Amount--"How prevalent is mechanization of a given function or activity as a whole?" These are the general descriptions which are presented in Table IV.

From these descriptions a comparison can be made with previous classifications. Amber was concerned with automaticity of a particular machine or group of machines. Here Bright uses the same basic concepts--vertical, horizontal, and summing (function) approaches, with a slightly different interpretation and an extended area of application. Although the words used are similar, the shadings of meaning are slightly different, and care should be observed in interchanging or comparing classifications.

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[9]James R. Bright, "How to Evaluate Automation," Harvard Business Review, 33, July-August 1955, 101.

TABLE IV
GENERAL DESCRIPTIONS OF MECHANIZATION[10]

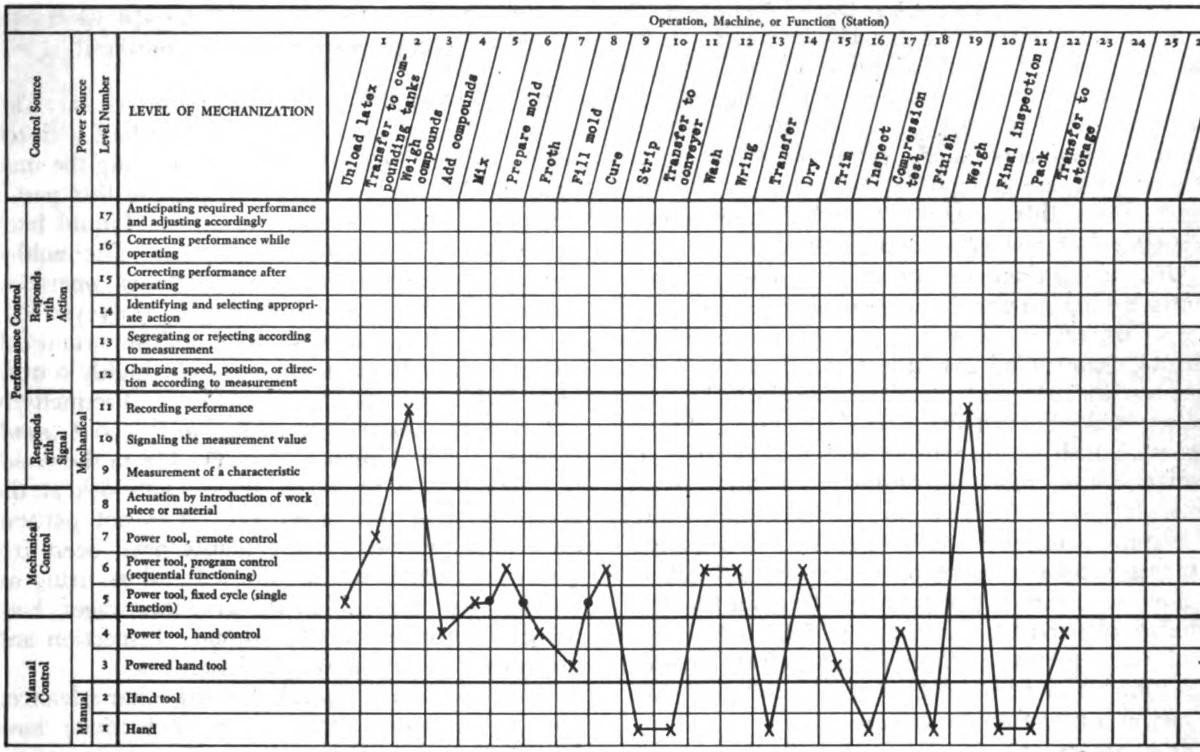
	Basic function (pertaining to the span)	*Major activities*	*Degree of mechanization (indicating the level)*	*Prevalence of mechanization in industry (indicating the amount)*
Largely physical action	Processing (creation of form utility)	Forming	Medium to extremely high	Almost entirely mechanized
		Assembling	Very low, with a few high exceptions	Very little, with exceptions
		Packaging	Very low to extremely high	Much in mass-production industries and bulk-material work (powders, liquids, etc.); little elsewhere
	Movement (creation of time and place utility)	Materials handling	Low to extremely high	Moderate, but rapidly increasing
		Transportation	Medium	Almost entirely mechanized
	Storage (creation of time and place utility)	Raw materials and finished goods storage	Medium to very high	Roughly proportional to size of the volume; much in bulk-material industries
		In-process storage	Low to medium	Very low, with a few exceptions
		Warehousing	Low to moderate, with a few high exceptions	Roughly proportional to volume and size of object stored
Both physical and mental action	Maintenance (retention of utility)	Maintenance	Very low	Hand and hand tools universally used
Largely mental action	Design (conception, analysis, interpretation, planning)	Product design	Low to moderate, with a few high exceptions	Very little, except in highly engineered products such as aircraft
		Process design	Low	Very little, with exceptions
	Measurement	Inspection	Low to moderate, with a few high exceptions	Much (particularly in mass production)
		Testing	Moderate to very high	Much
		Production control	Very low, with slight exceptions	Fairly common
		Inventory control	Low to moderate, with a few high exceptions	Much

From these general terms, a more detailed breakdown is evolved and organized in a chart called a mechanization profile, which charts a product through the entire series of processing functions. This chart is definitely product-oriented, although the process required to evolve the product is used to make up the carted functions. Bright has charted fifteen of the more advanced operations commonly

[10]Bright, "How to Evaluate Automation," op. cit., 102.

TABLE V

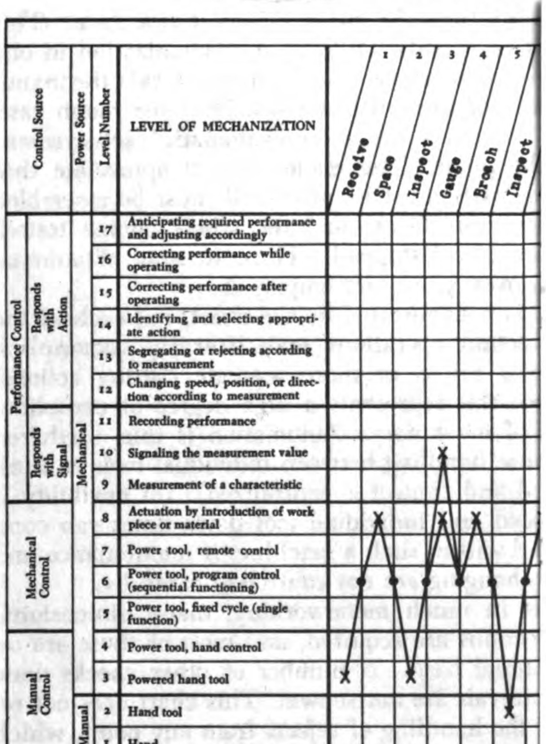
Mechanization profile — rubber mattress unit



Note: Dots on lines between operations represent the level of the materials-handling device.

TABLE VI

Mechanization profile — cylinder block line



Note: (1) Dots on lines between operations rep
the level of the materials-handling device. (2) If an
tional "X" is shown in a column, it represents

classed as automation, two of them being presented in Tables V and VI. These profiles resemble in many ways a sophisticated Operation Chart of a process, and as such could logically be developed and expanded into the field of industrial engineering as tools to determine desired automation situations and to analyze and improve existing applications.

The profile itself utilizes the general qualities presented in Table IV. Function, activities, or operations in the process are grouped in horizontal sequence, giving the chart progression from left to right, starting with the first operation and ending with the last.

Each function (operation) is classified according to the amount of mechanization (here used as the specific amount at a particular operation) and by the type of device employed to accomplish certain functions--represented by various symbols. The third dimension (vertical) represents the level or degree of mechanization of a particular function. Bright utilizes seventeen levels of mechanization as a basis of classification of this concept. These levels are more finely divided than the orders of Amber, and recognize factors of classification other than automaticity, although the idea of a man-machine complex in which the machine assumes a heavier balance of activities (in a sense does things more automatically) runs parallel to Amber's classification.

The description of the seventeen levels are given detail in Bright's analysis, and will not be presented here.

Certain comparisons can be made, however, pointing out the meanings of his groupings. To the left of the Level number (see Table V & VI) the concepts of both control and power are broken down into groupings. To a certain extent, these factors determine the complexity and automaticity of the function. The levels comprise a finer sifting of the factors involved, and allow the introduction of management concepts and a basis for economic and other evaluations not necessarily permitted in a classification by automaticity.

In equating the two systems, Level Six may be roughly compared with Order A_3 of Amber's analysis, both on the basis of the particular type of machine involved (transfer machines) and the type of control and programming. Bright's chart, however, recognizes the fact that other levels are involved and that the type of equipment (or components) used to effect these results may operate on various levels. This gives a broader, richer, interpretation to the classification, "sketching a picture" from which other management and engineering considerations may be derived. Levels Nine to Eleven would probably fall under A_3 order of automaticity, but in their use here allow the injection of a "measurement" concept without pulling the chart out of balance. The levels from twelve to seventeen would roughly compare with orders A_4, A_5, and A_6. Since Bright does not project his concept beyond the current developments, there is no provision for an A_7 or A_8 equivalent.

One of Bright's purposes was to determine the present extent and comparative values of automation. In doing so, he has stressed the fallacy of the value of automaticity *per se*, and therefore this emphasis is reflected in his profile arrangement. Automation in his classification cannot be expressed at one particular level of mechanization, but as " . . . something on a significantly higher level of mechanization than previously existed in that particular activity or plant . . . ."

Classification by Industry

Certain non-technical classifications of the automation subject according to industries which use automation or which manufacture equipment utilized in automation will be briefly mentioned. These classifications indicate a grouping of interests, and as such are important to a degree. Industries using automation equipment are varied, and certain aspects (in particular, the informational aspects) could logically extend into the majority of these groups. Therefore remarks here will be confined to those industries currently manufacturing automation equipment. A general grouping is as follows:[11]

(1) Data processing
(2) Electronic components
(3) Control instruments
(4) Machine tools and machinery
(5) General automation

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[11]"An Economic Report on Automation Stocks," *Instruments and Automation*, 28, March 1955, 439.

The data processing group includes many of the office and business machine companies, and also those companies specializing in photography, duplicating, and manufacturers of special data-handling forms. Consulting firms specializing in data-processing systems, as well as manufacturers of transmission equipment may be so grouped.

The manufacturers of electronic components would include specifically the parts manufacturers, as well as manufacturers of electronic subassemblies.

The control instruments group includes manufacturers of both electrical and electronic controls; hydraulic, pneumatic, and mechanical instruments; servomechanisms; and the more complex test and control instrumentation of scientific nature.

The machine tools and machinery group includes those industries which build automatic machines and attachments, as well as conventional conveyor systems and materials-handling equipment.

Under the classification of general automation may be grouped those industries whose products are varied but which contribute in some degree to the automation field.

These industry classifications are not rigorous in any sense of the term, but they tend to group the by-products of automation into some logical type of order.

Summary

In explaining the varied concepts of automation, several methods of classification are possible. Some of these are: orientation about terminology; classification by extent of automaticity; classification from the viewpoint of management; and classification by industry.

In the technical fields, classification by terminology and by extent of automaticity are by large the more important. The first concept classifies the subject in definable terms, while the second goes a step further and translates terms into symbols. With these classifications, the limits and progress of automation may be described and technical planning using automation may be accomplished.

Automaticity is one of the more important features of automation, and by determining the level of automaticity the extent of automation is defined.

Management classification of automation generally is concerned with the economic aspects affected. By classifying by levels of complexity and overall extent of application, better management decisions can be made. The use of mechanization profiles provides a tool for the industrial engineer in measuring and improving existing or proposed automation facilities, and allows management to relate to automation those factors influencing or being influenced by economic considerations.

Classification of automation by industries presents a non-technical view of the fields which contribute to the automation concept.

CHAPTER V

INFORMATION--ITS RELATION TO AUTOMATION

Introduction

Throughout the preceeding chapters of this thesis, discussion has centered about the more conventional factors influencing automation. From the historical development of automation to the classification of the current concepts, a pattern may be observed--a pattern which expresses a philosophy of manufacturing. This pattern would hardly be complete if it were limited to the external results of automation or the devices used to physically achieve those results.

Underlying the concepts of automation--those of products manufactured or equipment utilized--underlying even the concepts of control and automaticity--are the factors which tie these concepts into this pattern--into a usable whole. Information is one of these factors, and as such will be described in this chapter as it relates in general to automation. In later chapters, the specific uses and applications will be discussed, relating informational aspects to the previously formulated pattern.

Automation and Information Theory

Before relating information to automation, it will be necessary to determine the exact meaning of the word. Several meanings are possible, some of them quite different from the commonly accepted definitions of the term.

Webster defines information as "knowledge of a special event or situation, communicated by others or obtained by personal study and investigation; intelligence; instruction." This definition is the one generally accepted by most people for the majority of applications of the term. Imagine the consternation, however, when one definition implies that information has nothing to do with meaning! Such a definition seems to contradict its very sentence structure, and yet with it, certain phenomena have been explained which were incapable of definition previously.

This controversial definition is to be found in the theory of Dr. Claude E. Shannon of the Bell Telephone Laboratories. His theory, known as Information Theory or Communication Theory, states that information is the freedom of choices in a situation. As such, it is a measurable, quantitative rather than (or as well as) qualitative concept. It is a precise, mathematical measurement of the amount of a substance called information, which can be transmitted by a particular method of communication.

As stated by Warren Weaver, co-author of Shannon's text (not of his theory):[1]

> The concept of information developed in this theory at first seems disappointing and bizzare--disappointing because it has nothing to do with meaning, and bizarre because it deals not with a single message but rather with the statistical character of a whole ensemble of messages, bizarre also because in these statistical terms the two words <u>information</u> and <u>uncertainty</u> find themselves to be partners.

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[1] Claude E. Shannon and Warren Weaver, <u>The Mathematical Theory of Communication</u>, The University of Illinois Press, Urbana, 1949, 116.

And in commenting to a group of scientists who had become badly confused by his use of the word, Shannon stated:[2]

> I think that perhaps the word "information" is causing more trouble . . . than it is worth, except that it is difficult to find another word that is anywhere near right. It should be kept solidly in mind that [information] is only a measure of the difficulty in transmitting the sequences [i.e., messages] produced by some information source.

Shannon has stated throughout his book: "Information is defined to be measured by the logarithm of the number of choices" and "Information is . . . a measure of one's freedom of choice in selecting a message."[3] He states that information includes "noise," and the greater the amount of noise, the greater the total information. The fact that information involves randomness gave impetus to the idea that it was a statistical relationship.

Shannon evolved his theory in 1948 while investigating problems in communication at the Bell Telephone Laboratories. Actually Norbert Wiener had previously recognized that communication of information (at least, the measurement of information) was a problem in statistics, and had stated this fact in his various writings. J. Willard Gibbs had also stated an ergodic hypothesis (a peculiar relationship between probability and symbols) which served as a fore-runner of fundamental ideas in the information theory.

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[2]Francis Bello, "The Information Theory," Fortune, 48, December 1953, 137.

[3]Shannon and Weaver, op. cit., 100, 108.

[4]Stanford Goldman, Information Theory, Prentice-Hall, Inc., New York, 1953, 295.

But it was Shannon who wrote the paper first published in Bell Laboratories periodicals and later in book form, _A Mathematical Theory of Communication_, directed toward the electrical engineer. The theory, however, reaches beyond electrical engineering, and has been projected into psychology, neurophysiology, linguistics, and other fields of study.

In formulating his theory, Shannon observed that what he called information resembled closely (in mathematical form) what the thermodynamicist calls entropy. (Entropy is a difficult-to-define thermodynamics term in which the change of entropy is a measure of the unavailable energy.) In like manner information theory deals with the communicativeness or uncommunicativeness of messages, influenced by outside or internal disturbances or interferences (called noise) which affect the reliability of the message.

The term "noise" originated in the terminology of the radio engineer where the word had its literal meaning, but as currently used, noise is present when the same message is not recieved as that which was sent. In other words, if noise is present in a message, it means that the information is not certain to be correct, and the effect is to reduce the usable content of the message. Thus, the message might be said to contain negative information (if such a thing were possible). It was in this manner that Shannon recognized that entropy (the unavailability of energy) and information (its uncommunicativeness) are similar. In extending his concepts, he included the effects of redundancy in creating noise reduction and reliability. Redundancy is the use of more words (or symbols) than are necessary (in the absolutely noiseless case) to express meaning.

Although information (as defined in information theory by Shannon) says nothing whatever about meaning, it paints a picture by default, and leads one to believe that there exists a relationship between the two terms, It is in the light of such a possible relationship and interpretation that informational aspects of automation will be considered in this thesis.

How Information is Related to Automation

In speaking of information in the sense that it contains meaning (or is related in some way to meaning) a certain feeling can be developed about the subject. In this respect, ideas about the nature of information in a qualitative sense can be stated. It can be looked upon as the essence or core of all messages. It is generally considered the fundamental substance used in the thinking process, and could be considered the basis of all intelligent activity. It may be observed that in all activity, information is a basic requirement which must be present to effect an action. A machine or system may be programmed, controlled, and operated automatically, but such action in turn must be instigated by some form of information, as well as the physical force necessary to supply motion.

Here information may be defined as that substance which, in its entirety, comprises the essence of a message or means of transmitting, communicating, or deriving a desired informative action, condition, or result. In other words, information and meaning are in some manner related, in contradistinction to Shannon's theory, which states that information (as he defines it) has nothing to do with meaning. (At least, he does not attempt to relate information to meaning.) The aim of this thesis is not to elaborate upon the mathematical implications of information and communication theory or its application to automation, but to discuss the informational aspects of automation in the sense of the definition as proposed here. It must be remembered, however, that Shannon's concepts can and have been related to those devices used in automation which are of a highly communicative or information-transmitting nature, such as computers and electronic transmitting equipment.

Information and the Control of Machines

Just as energy may be classified and described by the function it contains or performs, so can information. According to Professor Stanford Goldman of Syracuse University:[5]

> There is an interesting analogy between "information" in communication theory and "energy" in physics. We all know that there are many natural phenomena, as well as man-made devices, which transform one type of mechanical activity into heat or electrical activity or chemical change. A unifying concept which greatly simplifies

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[5]Goldman, op. cit., 289.

> all considerations of these transformations is the idea of energy. The discovery that a measurable entity exists, namely, the energy which can measure mechanical, electrical, thermal, or any other kind of physical activity, and which can measure potential as well as actual activity, greatly simplifies thinking about physical phenomena. In the study of any complicated physical or physiochemical transformation the guiding principle is usually to see what happens to the energy.
>
> In a similar manner, the discovery that a measurable entity, information, exists, which can measure what is transmitted by messages, regardless of their form, is a unifying step in communication theory.

Since automation has been pictured as a philosophy of manufacturing or as a method of accomplishing the production of objects through the use of more automatic methods of manufacture than have been previously used, the relationship of information and energy is highly applicable to the devices which automation uses. This relationship has been presented in a classification or tabulation by E. W. Leaver and J. J. Brown.[6] At the introduction to their classification, they state:

> What we have tried to do is discover the least number of concepts which will enable us to describe the various methods of producing work in a highly technological society. These basic concepts we believe to be two: the parameters of information and energy, together with their various subclasses. Working with these materials we have attempted to prepare a chart of devices that is analogous to the periodic table of the elements put in modern form by Mendeleev in the middle of the nineteenth century. Although the chemical elements are quite different from machine elements, we believe there remains some ground for considering this analogy useful.

The classification presented bears little resemblance to a periodic table, either in form or in operation, but it

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[6]E. W. Leaver and J. J. Brown, "A Functional Morphology of Mechanisms," Automation, 2, July 1955, 37.

does offer a worthwhile explanation of the manner in which information exists or is applied to automaticity. Although not stated, Leaver and Brown's use of the word "information" is similar to the concept as applied in this thesis to automation, i.e., as having or conveying meaning of some nature, to accomplish a desired result.

Table VII presents the basis of classification of the information concept. It includes Conditions (signifying a state of being and a method of application) and Classes (represented by energy and information). From this basic breakdown, the various classes of energy and information (which represent the various Conditions) can be arranged and combined so that they may be applied to various existing devices. The term "device" is defined here to mean something whose usefulness lies in its movement (or relation to some other device which has movement).

The informational classes are further subdivided into subclasses according to feedback, patterns, and programs (see Table VII). The concept of collation--the comparing and integrating of information from two or more sources--enters into the classification by the use of parentheses.

This scheme uses the more prominent functions of a device to determine the appropriate class. Since both information and energy are necessary, a device (in this classification) must utilize at least one item from each class, but any item from one class can be combined with any item from the second class to give a complete classification.

TABLE VII

BASIS OF CLASSIFICATION--ENERGY AND INFORMATION

Condition	Information	
	Energy	Information
Immediate--Manual	1	A
Immediate--Nonmanual*	2	B, b
Stored--Manual**	3	C', C"
Stored--Nonmanual**	4	D', D"

* Information from an independent source = B
Feedback information operation = b
** Stored information (patterns) = C', D'
Stored information (programmed) = C", D"
Parentheses ( ) signify collation

Table VIII presents general examples of devices classified by information and energy and Table IX gives specific examples. Although these tables are helpful in understanding informational aspects, they still lack organization into a form approaching a periodic table in any sense of the word. Nevertheless, the scheme presents the subject of automation from the standpoint of the basic motivating forces (information and energy) which govern the operation of machines. As such, it forms the basis for considering various methods of application of automation functions.

A reappraisal of control and feedback concepts can now be made, considering information as an essential part of the scheme. The fundamental device of control systems is shown in Figure 23a. This diagram considers the device to be an operator on energy and information. This concept may be expanded into open and closed loop devices as shown in Figures 23b, c, and d.

TABLE VIII [7]

GENERAL EXAMPLES OF INFORMATION-ENERGY CLASSIFICATIONS

Device	Energy Class	Information Class
Tools	1	A
Machines	2,3,4	A
Dies & Patterns		C'
Records, Programs		C"
Temporary Automata	3,4	
Triggered Automata	2,3,4	A
Automata	2	B,C', C", D', D"
Collative Automata	2	(BC'), (BC")
	3	(BD'), (BD")
Feedback Automata	2,3,4	(b)
Sensor Automata		B
Programmed Automata		C", D"
Pattern Automata		C', D'

Figure 23b expands the device to include a control function and a manipulation function. In this manner information and energy combine in the control function and transmit through the manipulator, controlled energy to effect the desired result.

A logical extension of such a system is represented in Figure 23c. Here collation (the comparing and integration of information from two or more sources) results in a third function of the device. Generally this situation results from the combining of stored-manual information and immediate-manual information--for example the adjustment of a valve, in which stored-manual information (the basic design shape of the valve) and the externally applied adjustment (immediate-manual information) combine (are collated) and in turn control the energy supplied by the flow of a liquid introduced

[7]Leaver and Brown, "A Functional Morphology of Mechanisms," 40.

TABLE IX

SPECIFIC EXAMPLES OF INFORMATION-ENERGY CLASSIFICATIONS

Device	Class	Device	Device
Automobile	4A1	Lathe (motor driven)	2C'A
Axe	1A	Lathe (screw cutting)	2C"A
Auto. Screw Machine (self-fed)	2C"C'	Lathe (old fashioned treadle driven)	1C'A
Automatic Pilot	2(C'b)	Milling Machine	2C'C"A
Automatic Vending Machine	2C"A	Punch Press (foot operated)	1C'A
Bulldozer	2AC'	MIT Milling Machine	2(C"b)C'
Drill (hand)	1AC'	Molder (automatic)	2C'
Drill (electric, hand controlled)	2AC'	Punch Press (motor operated)	2C'A
Drill Press (electric)	2C'A	Punch Press (automatic self-fed)	2C'C"
Elevator (hand controlled)	2AC'	Radar Gun Layer	2(Bb)
Elevator (push-button operated)	2C'C"	Sander (motor driven)	2AC'
Fire Control (radar)	2(Bb)	Typewriter (hand operated)	1AC'
Gage (automatic)	2(BC')	Typewriter (electric)	2AC'
Hammer	1A	Typewriter (teletype receiver)	2BC'

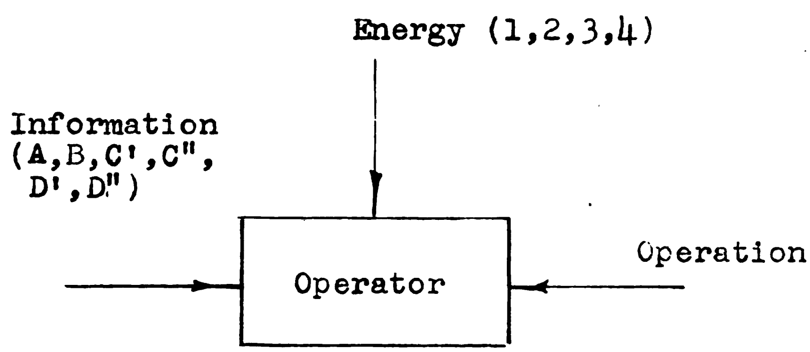


Figure 23a
Fundamental Device

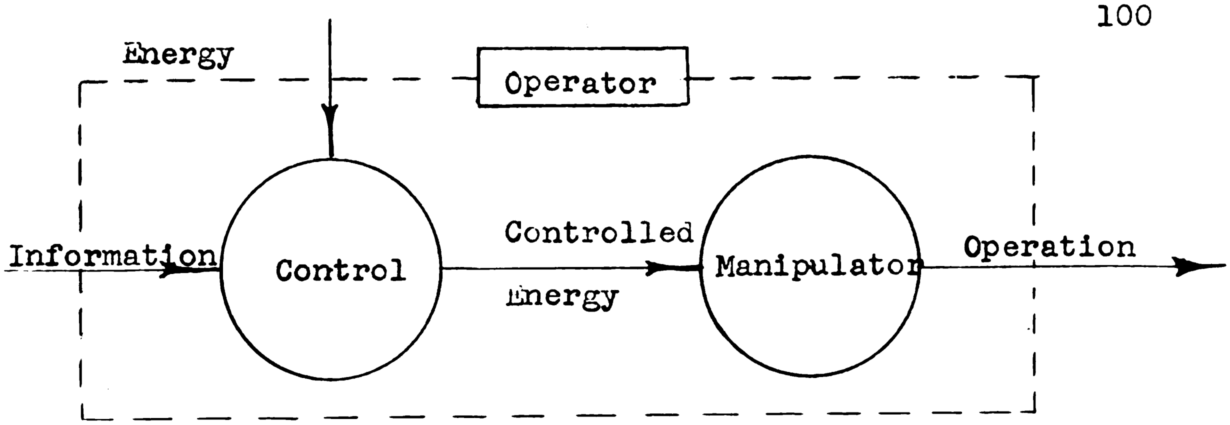


Figure 23b

General Open-Loop Device

into the valve. Thus the simple device, the valve, incorporates the function of collation, control, and manipulation in order to obtain a desired control.

Figure 23d is similar to 23c except that feedback of information is introduced. In this illustration, both stored-manual (or nonmanual) and immediate-manual information are collated.

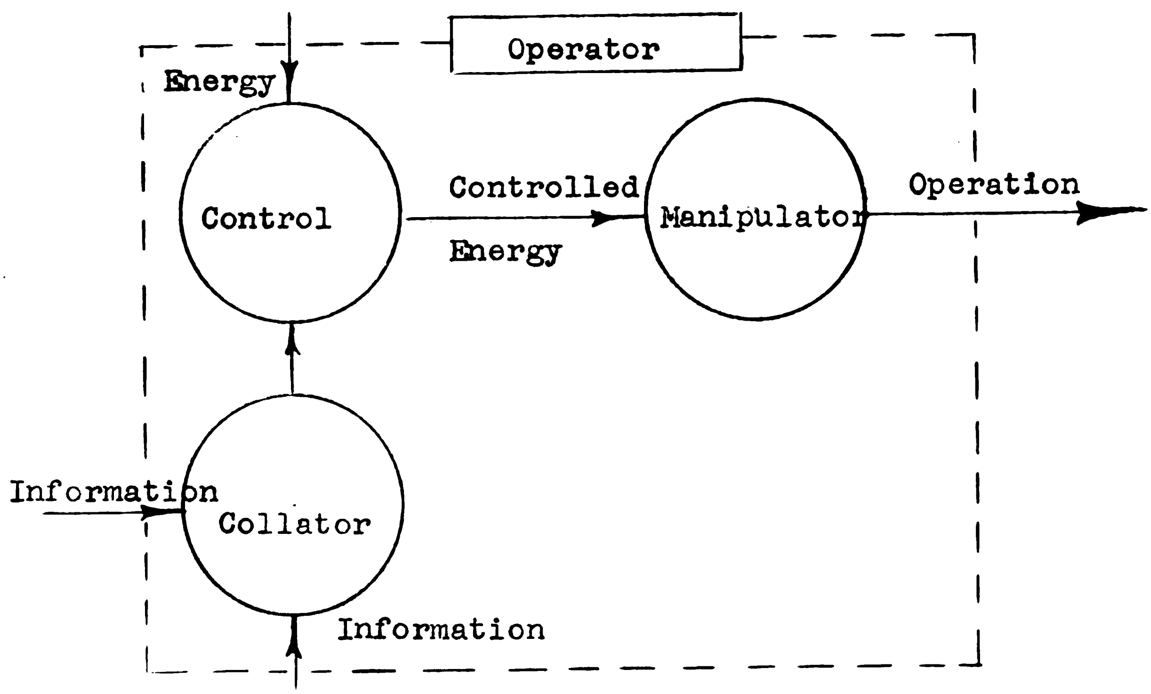


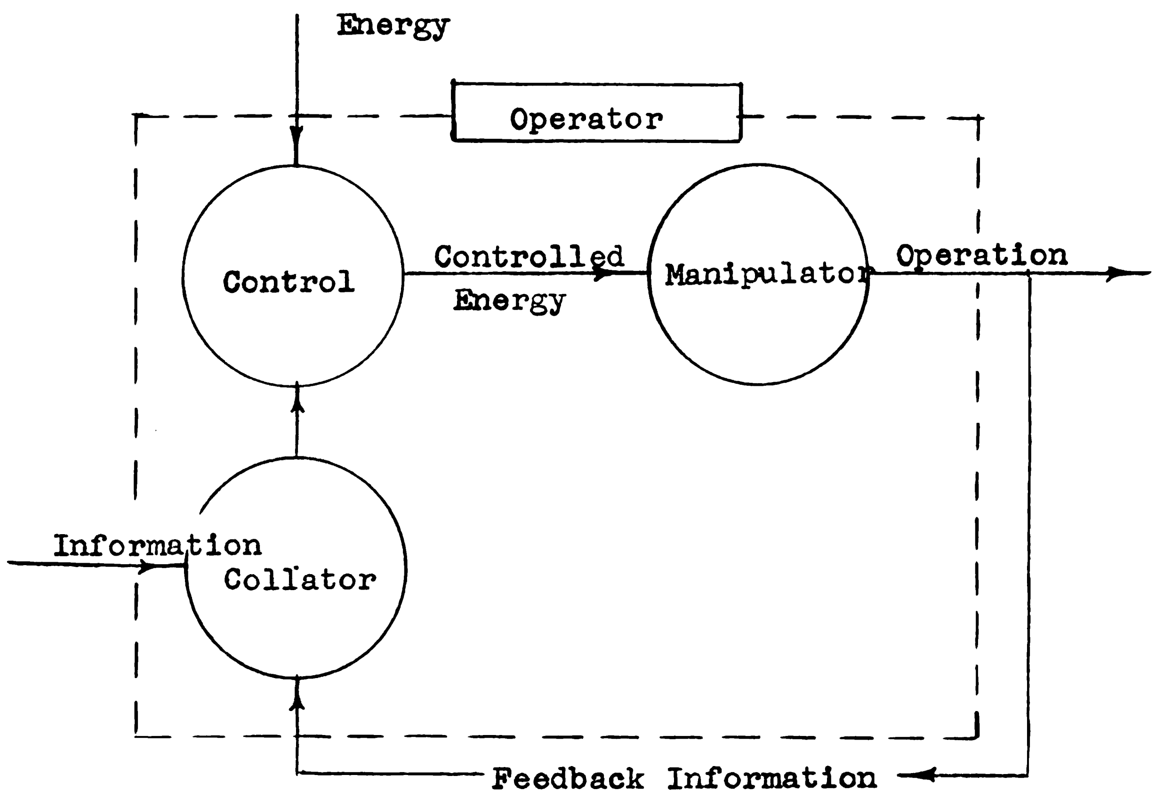
Figure 23c

Open-Loop Collation Device

Although many complex feedback devices could be included, these simple arrangements are sufficient to illustrate the basic concepts involved. These informational concepts of machine control are important because they allow consideration of product and process in terms of desired function rather than by conventional construction.

Figure 23d

Closed-Loop Collation Device



The Relation of Programming to Information Supply

The concept of programming--the direction of a mechanism through a desired operating cycle--has been discussed in general in Chapter II. But there are certain relationships of programming, when discussing it in the light of informational aspects, which make the subject worthy of additional consideration.

Programs have often been referred to as "messages" since, like messages, they convey certain ideas. Computers utilize a program as a precise sequence of coded instructions or directions in order to solve a problem. Other mechanisms use sequences of instructions in one form or another in what might be referred to, for analogous reasons, as a transmission (or utilization) system. This transmission system, regardless of its form or shape, will convey the intended message only if the message is converted into the language which the system is designed to comprehend. Professor Goldman states:[8]

> In order to transmit a message (an idea) in a given transmission system, it is necessary to translate the message into a signal which can be carried by the transmission system.

This statement seems rather obvious, but the concept is often overlooked in attempting to program machine tools.

Programming generally can be divided into two classifications: patterns and programs. Patterns constitute programming of the built-in variety, in which the pattern is an integral part of a component or single part of a machine.

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[8] Goldman, op. cit., 286.

Dies, cams, gears, and devices in which permanent physical shape is the primary consideration are usually placed in this classification. The level of automaticity of such devices is generally quite low. The class of information involved is usually of the stored-manual variety, since it is manually built-in (stored) until called upon to effect control. Any sequence of instructions in this case is limited to position (as in the rotation of a cam or gear).

"Programs" (which transfer their message in sequences over a period of time) may be either built-in or external to the mechanism in question. If the mechanism consisted of a non-adjustable timing device, the information involved would be of the stored-manual variety, built into the design of the mechanism. If adjustments were possible, the information in this case would still be of the stored-manual variety, but would constitute a program composed of both the designed-in sequence and the external adjustment.

A program invariably indicates the use of stored information. This information is generally of the manual variety (set in by a human operator), which indicates the level of automaticity of the programming function is quite low, compared with many of the systems it in turn programs. In order to have much automatic programming (with no human intervention) the information functions would of necessity be non-manual--a system only visualized in Amber's higher orders. Systems which come the closest to such a situation are the controls of various guided missiles and certain electronic computers, which sense their operation and temporarily store and program their succeeding movements. These devices operate on rules of logic, however, originally programmed into them by their designers, and originate only a temporary form of program. Perhaps for this reason (the need to supply information through a program) machines may never become automatic in every sense of the word.

In the design of conventional machines, the concepts of information and programming are of slight importance--traditional approaches are satisfactory. But as processing functions have been integrated and become more complex, programming has advanced in importance also. In the design of equipment, either a provision for built-in programming is made, or an arrangement to add external programming is included. If the latter is the case, then the machine design must be compatible with the external programming function.

In performing simple, non-integrated tasks, energy is generally of prime importance; the programmed function being neglegible and the information being supplied immediately and manually. As the control function becomes more important, the situation reverses. Instead of information being used to supplement or assist an energy transformation, information becomes the commodity of prime concern and energy becomes the secondary or aiding factor, being present only to aid in obtaining a desired informational result. Here the program also takes on added significance--it becomes the primary tool for accomplishing the desired result, while the machine manufacturing function becomes secondary. Those systems which are primarily data-handling in nature fit this classification.

Information and Management Decisions

In conducting interviews with various users or manufacturers of automation equipment, the question, "What effect will automation have on management decisions?" brought forth varied answers. None of those interviewed felt that management decisions would be eliminated. On the contrary, most saw automation as creating new problems in this respect. Answers varied as to background and the nature of the relationship of automation to the individual, but most recognized that the problems of obtaining, organizing, and utilizing the information necessary for management decisions were becoming even more difficult. One representative of a chemical manufacturer stated that they were interested in improving their routine data-handling methods, and also that computers had been used to some extent in sifting the data required for certain operating decisions.[9] Speed and accuracy were stressed as important factors in utilizing what automation they could in management functions. Although elimination of clerical help was a factor, most management people concerned with this problem stated that such programs were instituted only when the need for rapidity and accuracy exceeded the capacity of the existing office force.

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[9] Hugh A. Bogle, Management Engineering, E. I. DuPont de Nemours, Wilmington, Delaware, oral communication, March 11, 1955.

Management reorganization has been studied in certain instances to take advantage of the benefits of automation and mechanized information processing. Here the effort has been directed toward more economical use of existing systems and the integrating of the newer groups resulting from the use of computer and data reduction techniques, and product, process, and project developments.

Those companies whose major activity centers around project research and development face special problems in applying automation to their informational needs. (Note here that the emphasis is on applying automation to information, not information to automation.) Some companies, such as Arma Division of American Bosch Arma Corporation, have organized their management and engineering skills to best utilize committee organization and the project team concept.[10] Other test and development facilities have maintained vertical organization with provision for specific groups to handle scientific data reduction and automatic processing of information.

Other attempts at integrating the data handling and informational activities of decentralized manufacturing are now being considered. Representatives of Remington Rand, Inc., state that certain automobile companies in the Detroit area have contemplated the tying together of their spread-out facilities by integrated data processing systems.[11] And in

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[10]E. D. Gittings, "Management of Systems Engineering," Automation, 2, March 1955, 55.

[11]R. Granger, Remington Rand, Inc., oral communication, March 28, 1955.

the fields of scheduling and production control, computers have been designed to construct production schedules.

In all of the examples mentioned, the idea of making management decisions by automation methods has not entered into the discussion. Most management representatives have indicated a concern for speeding up the routine data handling, processing, and resulting paper work in order that planning can be accomplished and decisions made on the basis of prompt, accurate, complete information. But management has not proposed that one of its basic functions--the making of decisions--be absorbed by automation!

Summary

In this chapter the relationships between information and automation have been discussed from several points of view. Concerning the meaning of information (and the relationship of information to meaning) it was pointed out that information in its mathematical sense as proposed by Dr. Claude Shannon is a measurable quantity, and not to be confused with meaning or conveying an idea.

Information as here related to automation is used in the sense of conveying a message in order to achieve a desired result. Information in the mathematical sense has also been applied to certain communicating systems and electronic computers used in automation applications, and care should be taken to recognize the difference in terminology.

In discussing information and machine control, the understanding of the energy-information relationship is necessary, in which information and energy function together to effect control. This relationship may be classified according to the methods of application and use.

Programming takes on added significance when considered in the light of information, its main ingredient. Programming uses stored energy, generally of the manual variety. Patterns, programs, and the relationship of planning in the design of automatic machines and systems becomes more important as the system increases in complexity. The emphasis upon energy is reversed as control becomes more important, and information becomes the primary factor in the relationship. Programming, the method of guiding the information in a sequence, then becomes the primary tool for accomplishing the desired result.

Management with automation requires the use of better information processing systems in order to keep pace with manufacturing functions. Reorganization or integration of the management structure to allow the handling of information with automation methods is often necessary. The tying together of decentralized facilities by integrated data processing techniques has been contemplated, as well as the use of computers in solving production scheduling problems. In all of these concepts, management proposes to maintain its basic functions of planning and decision-making, using improved information-handling methods to better achieve the desired results.

CHAPTER VI

THE AVAILABILITY OF INFORMATION

Introduction

Information, to be of any value, must exist in some form that is readily available. In the light of the discussion in Chapter V, information (as applied to machine control) was classified as being either manual or nonmanual, and immediate or stored. Genreally information of the nonmanual variety (supplied by the machine) existed in the immediate form. Feedback information was considered as immediate, because it was used for the immediate purpose of altering the controlled state of the machine.

As storage generally implies a time delay, the idea of placing something (in this case information) at a location, leaving it there, and returning at some later period to retrieve it seems perfectly natural. But consider the situation where information may be "stored" for only a few thousandths of a second, and then, for all practical purposes, eliminated entirely. Does this constitute storage? If storage implies the postponement, delay, or holding of information (regardless of the time period) in order that some condition regarding the information (such as mathematical functions of addition, subtraction, or integration) is altered and then the resulting alteration is used in some way, then such an example may also be considered to be stored information. The device which accomplished this delay would be considered an information storage device.

Information availability, as it applies to automation, must take into consideration the information sources. Much of this information is contained in reports, tables, handbooks, or records of previous occurances. Such so-called "original" information is original only in the sense that it is derived from or contained in one form or another of raw (unprocessed) data. The data--the accumulation of items or occurances forming the basis and reference for activity--contain information and are original to the extent that they constitute the first record or observation of an occurance. In such instances, however, the information may be considered to be in the stored state. As the data is processed, the information it contains is transformed from one type of storage to another, often being discarded when the desired end result is obtained.

In Chapter II coding was defined as the procedure of expressing the necessary information in a language or medium acceptable to the particular system. In pattern-type programs any code is simply the designed shape of the pattern. In sequence-programs, the medium may vary, and in situations where information is considered the prime commodity, the code may be one of several, each method being designed to operate under the various conditions imposed by the specific situation.

In discussing information availability, the concepts introduced above will be emphasized. Information storage and its various coding methods play an important role in automatizing information-using systems. With these tools, the essence of an idea may be grasped and manipulated in order to render a desired result.

Information Storage Concepts

Attempts at retention or storage of information over the span of history are innumerable. Early hieroglyphics, carvings, and even the knotted cords of the Incas all were systems of storing information. The development of printing constitutes a history in itself. But in applying storage to automation, interest must be directed to those specific means which in some manner contribute toward a greater degree of automaticity. Reports, tables, graphs, and other documents are currently used in information-handling, some of them integrated with automatized systems. Although essentially a manual method of storage, information in this form is sometimes stored automatically by measuring and recording instruments which function in accordance with a programmed procedure.

Punched Cards. One of the advantages of automaticity is usually speed of operation. A device for achieving speed in the assimilation and storage of information is the punched card, which can be mechanically read and the information which it contains processed in the desired manner. The punched card principle is not new--in its modern form it has been used since the beginning of the twentieth century--but in the card form it constitutes the modular unit for performing most of the varied mechanized data-handling tasks possible.

Cards used by IBM contain 80 vertical columns per card, each column being composed of eight channels. Series of rectangular holes may be punched at various locations to effect a coded message. The pattern of the holes is sensed by a series of electrically energized brushes which enter the holes and make contact with a plate beneath the card. This information is then translated into coded electrical form to effect the desired reaction. Various procedures of sorting, selecting, duplication, printing, etc., may follow, according to the information contained, equipment used, and programmed system selected.

A second type of punched card--used in Remington Rand systems--uses round holes punched into the card in much the same manner as IBM cards. The cards are of thinner construction, since photocells make or break the circuits as the cards are positioned. Uses similar to the IBM procedures are adaptable to these cards.

Punched Tapes. Although cards are much in use today, they contain serious drawbacks of bulk and non-continuity. To obtain a medium that has continuity, punched tapes may be used. These tapes operate in much the same manner as punched cards, except that they constitute a continuous strip of information.

The width of the tape varies with the application. In tape-controlled machine tools, this width is often great. One inspect-record system utilizes a tape of 60 holes per scanning line.[1] Usually machine tools require a large number of holes per line if the controlling function is at all complex. In controlling machine tools, one method of adequately describing a machining cut would be to use a large number of holes per line.[2] However, by requiring only an increment in direction from the last position recorded, the width of the tape (and number of holes) could be reduced to practical limits.

Punched tape has been used with teletype machines for many years. For this reason, it often provides a common language vehicle with which to extned the mechanization of information handling, using a relatively simple storage system (see Fig. 24). A variation of paper tape is the punched plastic tape or movie film. Here dimensional stability and durability are important. Most tapes contain a series of ratchet holes for engaging the drive mechanism, as well as information holes.

The basic difficulty with this system, as with the use of punched cards, is bulk. Although contained on fairly compact reels, paper and plastic punched tape are too bulky for many applications.

Photographic Storage. Photographic processes have long been used as storage devices for information. Microfilm is generally used in recording printed pages, and as such constitutes an extension of printed storage systems. Although

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[1] "System Inspects and Records," Automation, 1, October 1954, 30.

[2] Cunningham, F. W., op. cit., 78.

the information is condensed into a relatively small surface area, the reading and selecting process must be accomplished manually. Such a system is difficult to automatize because without some concise coded summary of each item, preliminary searching for desired information would be very difficult. Actually a system devised by Dr. Vannevar Bush used a rapid-selector film device in which summarized key words are en-coded in a binary digit system to the left of printed material on photographic film.[3] Photocells scan the film for key words and position the film for manual reading of the printed matter. Here the difficulty lies in the problems of indexing and cross-listing all of the possible reference subjects.

Magnetic Tape. One of the most versatile systems in present use is magnetic recording tape. Magnetic recording allows permanent records of information without chemically affecting the recording medium, but merely changing its magnetic state. Unlike photographic film, the record may be reproduced immediately without processing, and there is no deterioration of the record with repeated use or over a period of time. Information in the proper code may be recorded on several parallel channels, or alternately with other information on the same channel. The information may be discarded when no longer of value, and the tape reused for other information storage (see Fig. 25).

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[3]Gilbert W. King, "Information," Scientific American, 137, September 1952, 141.

One primary difficulty of information storage and access-the need for a changing time-scale--is solved through the use of magnetic tape. Rapid recordings from high-speed output devices may be slowed down to permit transfer and analysis. The recording speed may also be adjusted to allow for different rates of operation of the various equipment used. Rapid scanning is possible, and allows the selection of specific items of information desired. The tape has great flexibility of use, since various equipment may be used to record information and also to further use or process certain parts of the record. The tape may be switched from machine to machine, or transported from one area to another. Information may be monitored from the source, and only a particular portion be recorded. The tape is completely compatible with various electronic signal transcribing and modulation procedures, and in this way is able to discriminate between signals not discernable by punched tape systems.

One serious limitation of magnetic film (or any information-storage medium of tape form) is that the data is recorded in serial form--one item following another in the order of recording. Consequently, in searching for a desired item of information, much unwanted material must be passed over before the desired information is observed.

Magnetic Memory Drums. In the construction of electronic digital computers (to be discussed in Chapter VII) storage devices are necessary, and are often referred to as the "memory" section of the machine. Although incorporated into computers, such devices are often separately constructed and used as auxilliary storage mediums.

One form of storage device is the magnetic memory drum. The drum surface is coated with a magnetic dispersion similar to that of magnetic tape. This drum rotates constantly at a high rate of speed, and in this way creates small loops of information storage about the circumference of the drum. Electrical heads positioned at intervals about the drum pick up or transfer coded information to or from the drum in much the same manner as magnetic tape is recorded and read. Since the drums spin at a very high rate of speed, thousands of bits of coded information can be recorded or read per second, allowing the devices to function as part of a high-speed system.

Random and Serial Storage. Random versus serial storage concepts become important when discussing the more intricate storage devices. In certain scientific applications the short loop of stored information of drums is satisfactory, since information requirement is small in comparison to the mathematical computations which would be applied. But in using storage drums for many business procedures the use of random access storage is necessary.

> A random system is one in which the number of items is relatively constant but each item is subject to periodic additions and modifications.
>
> A serial information storing system is one in which the list of entries is of indefinite length and items are not subject individually to future modification.[4]

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[4]Glen E. Hagen, "Automatic Information Storage With Random Access," Automation, 1, August 1954, 66.

Tape and card systems are readily adaptable to serial systems because of their continuous nature, but this very fact limits their use in random access systems. Such a system requires direction to a specific location to modify or acquire information stored there, rather than the continuous "tacking on" of information used in serial storage. Serial storage is required for permanent continuous records but has its limitations when specific items of information are desired.

One type of random access magnetic memory drum has been developed by a California firm.[5] This drum is of large diameter (approximately four feet) and the reading heads are air-floating, circumventing the previous engineering limitations of rigidly positioned reading heads which (because of physical expansion) kept the drum size relatively small. The head is free to move across the surface of the drum, locating or entering desired information. Use of several heads would allow simultaneous access to various items of information--a decided advantage where rate of utilization of one system is slow enough to allow the storage from various sources. In this way information could be channeled from one source, through the storage drum, and into the input of another source.

<u>Delay Lines</u>. Another type of storage medium is the physical delay system. This system uses the characteristics of impulses passing through a medium (such as quartz crystals

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[5] Ibid, 68.

or tanks of mercury) which delay the signal and continually recirculate or reflect the impulses through methods physically designed into the system.

Electrostatic Storage. Strictly electronic systems of storage are also used. One method (used in the IBM 702 business calculator) makes use of electrostatic properties of a cathode ray tube. Electronic charges are stored upon the face of the tube in a predetermined pattern. Although the area available for storage is small (1,000 characters as compared with 60,000 per drum) access is random and the information may be directly selected from a particular location. Therefore these devices are generally used for internal computer storage while the magnetic drum units are for large volume external data storage. One disadvantage of using tube storage is that if the power fails, stored information is lost, while this is not true in most of the external systems. That is precisely why permanent or semi-permanent information storage uses slower-responding but less vulnerable media; volatile storage devices being used generally for temporary storage only.

Magnetic Core Matrices. A less volatile system, and yet one which offers random access, is the use of magnetic cores. Small rings of magnetized metal are used to store, read, and erase information. Two wires of the pattern (one vertical, one horizontal) are required to magnetize a core, while a third wire is used to read the stored signal. The cores are so arranged that several hundred may be placed on a surface a few inches square. These core patterns serve generally as intermediate storage devices in large computers and cushion the rate of information flow from the computer as it feeds to the less rapid external recording devices.

Other forms of storage include mechanical wire delay lines and the cycling of impulses through banks of electronic tubes or through relays. In certain guided missile designs, wire-wound delay lines retard information flow in order to allow feedback damping operations.

Perhaps the most important point to keep in mind while discussing storage concepts is not so much the exact method of storage used, but the fact that storage is necessary in applying automation to most informational systems.

Coding the Information

Codes have been defined as systems of symbols for representing information, and the rules for associating these symbols. They serve as the channels for conveying information, much as physical circuitry acts as the channels for electrical impulses.

There are many types of codes, each one having a specific purpose. Some of the codes used in the automation of information processing will be discussed in this chapter, in order to consider another preliminary informational aspect before discussing actual automation applications. Although different coding systems will be mentioned, the importance of the coding function is to be emphasized rather than any individual code. The industrial engineer (or anyone else applying automation concepts to business and industry) must be able to assimilate the informational requirements in whatever form presented, applying the proper method of application to the particular situation.

Familiar Coding Systems. Regarding the printed word, the alphabet comprises the code. Here the characters vary in size, style, and in other ways to make difficult the automatic processing and control of the information they contain. Louis Braille recognized this when he invented the Braille code for the blind.[6] Instead of raised letters, he used a pattern of punched holes based on a binary system of six digits. Using combinations of these six digits in two columns, 63 characters were possible, providing for letters, numbers, and punctuation. The Morse telegraph code is another example of using numerical values for alphabet letters arranged in a coded form. Most of the codes in automation applications use a variety of the numerical arrangements.

The IBM Coding System. The IBM punched cards contain a code consisting of eight channels (horizontal rows) and 80 columns (vertical rows). Each vertical row is punched to represent one symbol, hence the possibility of a maximum of 80 symbols per card. This code is also used on punched paper tape and provides a method of transferring information from individual cards onto a continuous strip, without changing

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[6] King, op. cit., 132.

the code. Because of the associated equipment, IBM punched card coding is quite versatile.

The Teletype Tape Code. Teletype systems have used for many years a code containing five channels. These five channels constitute the punched pattern of teletype tape. This tape has often been referred to as the "common language vehicle" because of its wide acceptance in the communications field. Although there exist many varieties of the five-channel code (6, 7, 10, etc., channels) this code has been adopted in the operation of many business machines and therefore is a desirable code from the standpoint of usablity. Figure 24 is a diagramatic representation of the tape, and Table X constitutes a five-channel code chart.

Magnetic Tape Code. This code generally includes seven channels, with each character represented by two or more magnetized spots. It may be noted in Figure 25 that the number portion of the code represents a pattern of 8-4-2-1. (1 is represented by a magnetized spot in the "1" column, 2 by the "2" column, 3 by the "1" and "2" columns, etc.) This system allows translation into a purely binary notation (the code used most frequently in digital computers). Magnetic tape has the advantage of coding a large volume of information within a very brief space (see Fig. 25).

The Binary Code. This code is the one generally least familiar to those who are not closely associated with the communications field, and yet it constitutes the basic method by which digital computers perform their thousands of

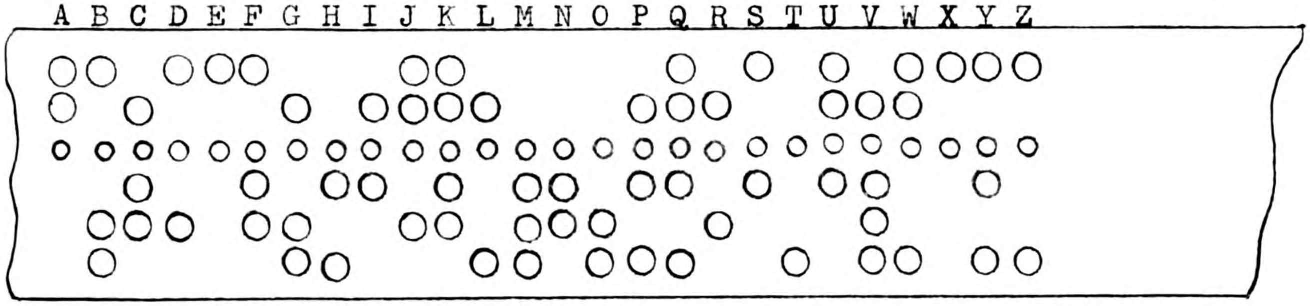

Figure 24

Five-Channel Teletype Tape

TABLE X

CODE FOR FIVE-CHANNEL TELETYPE TAPE

Figures					3				8						9	0	1	4		5	7		2		6	
Letters	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
Code Chart	1	1		1	1	1				1	1						1		1		1		1	1	1	1
	2		2				2		2	2	2	2				2	2	2			2	2	2			
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
			3			3		3	3				3	3		3	3		3		3	3		3		3
		4	4	4		4	4			4	4		4	4	4			4				4		4		
		5					5	5				5	5		5	5	5		5		5	5	5	5	5	5

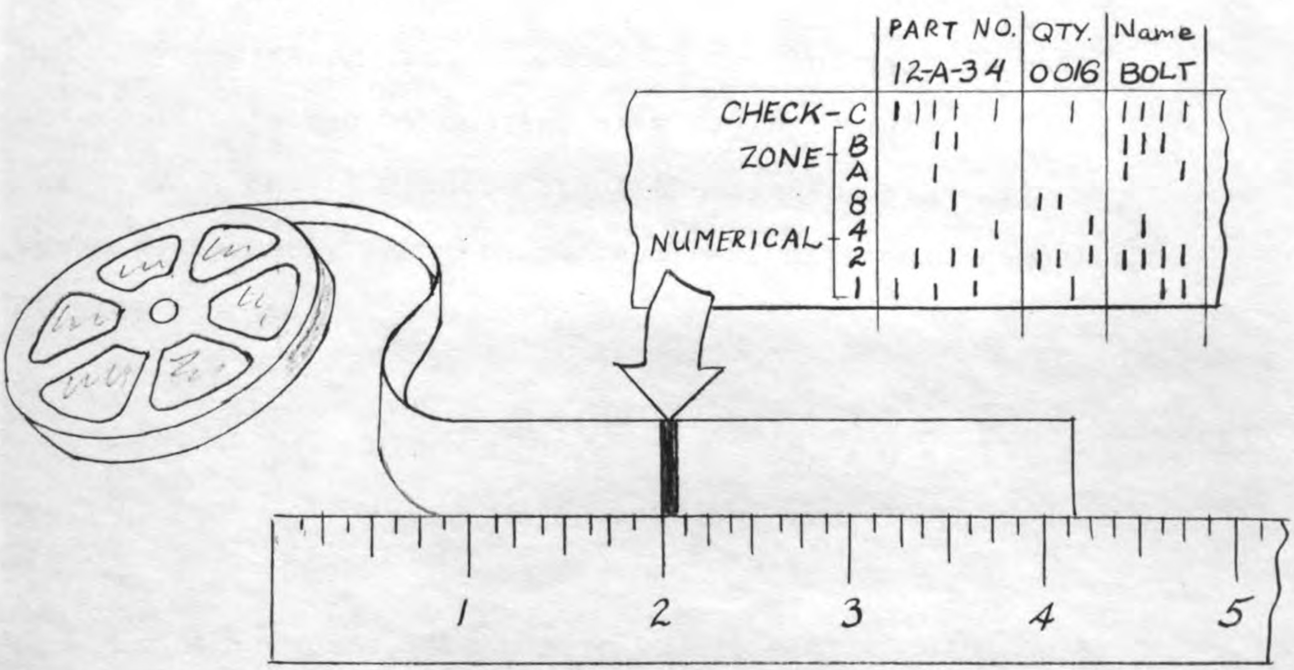

Figure 25

Magnetic Tape Code

counting operations. Information-handling systems are including the computer in an ever-increasing degree as a basic unit of automation, and therefore it is imperative that a basic, if brief, understanding of the binary system be included in the concepts of information availability.

The binary code is actually a very simple mathematical system using only two digits (0 and 1). Such a system is valuable in using equipment in which the only possible conditions are "on" and "off." Variations of this procedure would be "yes" or "no", "conducting" or "not conducting", a positive pulse or negative pulse, etc.

The use of a decimal system tends to increase the complexity of the computing device to a point where it becomes impractical. A binary system, however, allows the use of equipment which can make the simplist of decisions (yes or no). By repeating such decisions very rapidly, a logical answer is obtained by continuously trying solutions until the correct one is found. Since the system uses only two symbols, 0 and 1, the mathematical manipulations are quite simple:

Digital		Binary		
1	=	1	Addition:	$1 + 1 = 10$
2	=	10		$1 + 0 = 1$
4	=	100		
8	=	1,000	Multiplication:	$1 \times 1 = 1$
16	=	10,000		
32	=	100,000		$1 \times 0 = 0$

In other words, the number 101 (binary) would equal 5 (decimal system), or $1 + 4$ (decimal) $= 1 + 100$ (binary):

$$4069 = 9 \times 10^{0} + 6 \times 10^{1} + 4 \times 10^{3} \quad \text{(decimal system)}$$

$$4069 = 1 \times 2^{0} + 0 \times 2^{1} + 1 \times 2^{2} + 0 \times 2^{3} + 0 \times 2^{4} + 1 \times 2^{5} + 1 \times 2^{6} + 1 \times 2^{7} + 1 \times 2^{8} + 1 \times 2^{9} + 1 \times 2^{10} + 1 \times 2^{11} =$$

$$1^{0} + 0^{1} + 4^{2} + 0^{3} + 0^{4} + 32^{5} + 64^{6} + 128^{7} + 256^{8} + 512^{9} + 1024^{10} + 2048^{11} = 111111100101 \quad \text{(binary system)}$$

Converting 4069 to its binary equivalent:

Highest power of 2 4069 is $2^{11} = 2048 =$	100,000,000,000
Highest power of 2 [4069-2048] is $2^{10} =$ 1024 =	10,000,000,000
Highest power of 2 [4069-(2048 + 1024)] is $2^{9} = 512 =$	1,000,000,000
Highest power of 2 [4069-(2048 + 1024 + 512)] is $2^{8} = 256 =$	100,000,000
Highest power of 2 [4069-(2048 + 1024 + 512 + 256)] is $2^{7} = 128 =$	10,000,000
Highest power of 2 [4069-(2048 + 1024 + 512 + 256 + 128)] is $2^{6} = 64 =$	1,000,000
Etc. $= 2^{5} = 32 =$	100,000
Etc. $= 2^{2} = 4 =$	100
Etc. $= 2^{0} = 1 =$	1
	111,111,100,101

Figure 26

Converting the Number 4069 Into its Binary Equivalent

	Decimal		Binary
Add:	1	=	1
	4	=	100
	5	=	101

or: 101 (binary) = 1(4) + 0(2) + 1(1) = 4 + 0 + 1 = 5

Figure 26 presents a more complicated conversion problem.

The relation of the 1-2-4-8 system of the magnetic tape code now becomes obvious. Such a code, through proper sensing devices, can be converted into binary code for computer use.

Summary

In order to automatize information, it must exist in a form readily available and be contained in a medium easily usable. Stored information is the form generally considered most applicable to automation concepts, and therefore the concept of information availability includes the ideas of information storage, and also the methods of representing the stored information--coding.

Various media of external storage include punched cards (IBM and other systems), punched tapes (paper and plastic), photographic storage, and magnetic tape storage.

Internal storage methods (within equipment) include magnetic memory drums, mercury delay lines, electrostatic (cathode ray tube) storage, and magnetic core matrix storage.

Coding techniques include the systems used with IBM and other punched cards, teletype tape codes (often referred to as common language code), magnetic tape codes, and binary codes.

These various coding and storage techniques emphasize the importance of understanding the need for availability of information in the proper arrangement and medium, when applying these techniques to automatized systems.

CHAPTER VII

THE MACHINES THAT HANDLE INFORMATION

Introduction

In order to automatize any information-handling process, equipment which can mechanically or electrically handle the data is necessary. This equipment may vary in complexity and automaticity from that of a pencil to that of a high-speed matirx printer, or from a slide rule to an analog computer.

The problems of adaquately describing the multiplicity of instruments, devices, and machines are many. Most data-processing systems use a variety of equipment. Many combinations are possible. In this chapter, the object will be to discuss equipment as it applies to automation from the standpoint of automaticity, informational characteristics, and general functions performed.

Portions of the discussion will center around familiar general-purpose equipment, more highly specialized data-processing equipment, instruments, and computers. The discussion on computers (as they apply to automation) will consider both analog and digital computers, and various methods of conversion between the two.

A further arrangement of informational devices groups them as performing either a scientific function or a business-manufacturing function. Certain devices of the instrument class tend to be used more in scientific fields, while other types of specialized equipment, such as the business machines, are more applicable to business functions. The emphasis upon automaticity and mechanical handling, however has tended to intermix the functions and to produce systems using an assortment of devices.

Familiar General-Purpose Equipment

Most general-purpose information-handling equipment could be classified as slightly or moderately mechanized. Machines such as typewriters, cash registers, adding machines, and the like would be considered in this class. Concerning their automaticity, Amber would class them as mainly of Order A_0, or zero automaticity. These machines require both manual control and muscular energy for operation. According to the Leaver and Brown information-energy classification, these devices would be considered in Class 1AC', or in other words, the energy would be immediate-manual; the information which is fed in (typed) as also immediate-manual; and the stored information (linkages and type) as stored-manual, patterened. Bright, also, would list such equipment as hand tools, at Level Two of mechanization.

The next level of automaticity, mechanization, or information classification would include equipment such as electric typewriters, electric adding machines, and electric cash registers. All that has been added is a power drive. Respectively, the classifications would be: Order A_1, Class 2AC', and Level Three or Four. These machines are of a general-purpose nature, being used for various office work and general mathematical problems. An electric or electronic calculator might also be so grouped, and here the classification would be the same, except that Bright might list the device as Level Six (sequential functioning) as part of the operation. The rest of the operation would remain at Level Four. Since most general-purpose office equipment machines have the information fed into them manually by the operator, the level of mechanization is not very high.

Specialized Data-Processing Equipment

Under this classification are placed many of the special-purpose office or business machines. The various IBM and other punched card machines could be considered to be in this catagory. Also included would be line-printers, collators, tape punches, sorters, tape recorders, magnetic memory drums, tape-to-card converters, and specialized typewriter-coder combinations.

Much of this equipment operates at a higher level of automaticity than the general-purpose machines. For example, the IBM and Remington Rand punched card sorters operate on the same levels of automaticity and mechanization as the average transfer machine. Since they are programmed to perform a particular function, they would be classified as Order A3. But since their inherent purpose is generally to measure characteristics, they would be classified to include both Levels Six and Ten. They exceed the capacities of the transfer machine in the fact that they utilize external programming, allowing greater flexibility of performance.

Certain equipment such as Teletype machines and Flexowriters may operate by remote control, receiving coded information from some distant source. In this case, Level Seven could be added to Levels Six, Nine, Ten, and Eleven (according to Bright's classification). At other times when used as an electric typewriter, the mechanization level would fall to four (power tool, hand controlled) and the order of automaticity to A_1 (power drive, manual feed).

It is interesting to note that usually the first piece of equipment to be used in an information-handling process is not very automatic. This machine may be a standard or electric typewriter, containing orders of automaticity of A_0 or A_1, or a manually operated card- or tape-punching machine, Order A_2. Subsequent equipment which use punched cards as input are of the Order A_3, which would be considered quite automatic in the machine-tool and fabricating industries.

Where the "original" information is obtained in a form compatible with automatic recording, then higher levels of automaticity may be applied. In the scientific fields, perhaps, greater opportunity for these applications are found, and it is in these areas that business machine procedures and scientific instruments combine to give a more highly mechanized system. (Conversely, scientific instruments could logically be used to measure some of the business functions now performed manually.) One example is in the recording of wind-tunnel data. Some installations record electrical impulses from wind-tunnel experiments directly on punched cards, which in turn may be automatically processed.[1] The use of sensing and translating instruments are of course necessary to convey information in the desired code to the card-punching machines.

Instruments

Introduction. In order to obtain nonmanual-immediate or stored information in the "original" form, devices are required which may sense the information as it occurs (or becomes observable, in the case of nonmanual-stored information). These devices are known as instruments, and may vary in complexity from the common thermometer to complex analog recording and translating instruments.

The term "instruments" has generally been applied to those devices of a scientific observing, testing, measuring, or data-originating nature, as opposed to equipment used for processing information. Such a classification has its weaknesses, since instruments also convert data from one form to another. Instruments are no longer used solely for scientific or engineering purposes. They are now frequently incorporated into manufacturing and business data-processing systems. However, those devices which have been so classed will be the ones discussed here.

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[1]From information supplied by Consolidated Engineering Corp., Pasadena, California.

Instruments may consist of components or completely autonomous systems. They can perform primary information-collecting and storage functions, or translating, amplifying, and sorting functions; hence the difficulty of applying a specific classification system. In their application to automation, however, they can best be sescribed by starting with initial functions and considering them in the light of automaticity and informational functions. Also may be observed the concept of analogy, which becomes increasingly important as the devices become more complex.

The Analog Function. Webster defines an analogy as "resemblance of relations; agreement or likeness between things in some circumstances or effects, when the things are otherwise different." An analogue (analog) is that which is analogous to, or corresponds with, some other thing. It is in the similarities of instruments and the physical phenomena which they measure, that allow these measurements.

As instruments become more complex, the analogies become more subtle, more involved, until it generally is necessary to transfer some of the information carried into digital forms. In a simple thermometer, the analogy consists of relating change in temperature with a proportionate expansion or contraction of a liquid, which in turn is measured against a linear scale. In more involved situations, the analogies "pile up" until the inaccuracies resulting at each successive stage combine, as in Babbage's machine (page 3), to effect a practical limit.

Simple Instruments. Such devices as thermometers, barometers, and non-recording indicators of physical phenomena constitute this type of instrument. The level of mechanization is non-existent, and cannot be measured by Bright's classification, unless Level Nine (measurement of a characteristic) is considered. An order of automaticity A_3 might be appropriate, since the device functions automatically according to a "program" of a sort. But since "nothing happens", i.e., there is no end result, no solution, the classification is not entirely appropriate. A better indication is given by the information-energy classification system, which indicates that the information observed is immediate-manual and the device contains pattern-type stored information in its operational design. Since there is little, if any, energy involved, the classification would be (BC'). Parentheses indicate collation of stored and immediate information. Leaver and Brown avoided this problem by classifying as devices only items whose usefulness existed in their movement.

Simple Recording Instruments. Recording instruments are one step advanced in mechanization from the simple indicating instruments--they are powered and record their output. Such devices as recording thermometers and recording barometers are typical. With recording devices, the observing instruments become A_2 devices. They use a combined pattern-sequence program, power operation (for the recording system), and the information is supplied automatically by nonmanual means. Their information-energy classification would then be 2(BC'). The interesting observation that in communications systems "the idea which a message conveys is also a message" is also appropriate in this type of instrument. Here the informational functions are two in nature: the information stored or supplied to the mechanism, causing it to function in a desired manner, and the product of operation--the information being handled.

Transducers. These devices are instruments which sense physical phenomena and translate them into measurable signals, usually in electrical form. They differ from recording devices in that the information is converted directly to a form usable by the next instrument stage. Such instruments as electrical strain gages, electrically operated pressure pickups, thermocouples, certain types of gyros, and torquemeters are typical of this group. Scanning by photocells might logically enter into this classification. Timers and counters fit intermediately between this group and that of recording instruments. Information would again be of the class (BC'), and power function negligible. Automaticity by Amber's classification would indicate a level of nine or ten.

Intermediate Recording Instruments. These devices are supplied with data from a transducer or some other form of pickup, and record the data in one form or another. Examples would be the tape recorder, recording oscillograph, telemetering equipment (a remote form of recording), and the various types of automatic plotting boards. Since these are mechanized devices, they may be classified as Order A_3;

Levels Six, Seven, Eight, and Eleven; and information-energy Class 2(BC').

Such equipment is often self-actuated by introduction of input information. Equipment such as the tape recorder would be considered intermediate, since the information (stored on magnetized tape) is usually conveyed to some other medium such as punched cards, or goes through further processing, such as analysis, amplification, reduction, etc. Information stored on records by plotters or recording oscillographs may be in a final state, and here the recording instrument acts as a final output device.

Converting Instruments. These intermediate instruments amplify, control, segregate, monitor, and transform the information carried, in one manner or another. Electronic amplifiers fit this classification. These devices would also be A_3, 2(BC') devices. Converting equipment of the analog-digital nature will be discussed under the computer concepts.

Higher Classifications. Although some overlapping exists, instruments may generally be considered according to the above classifications. Devices containing a higher extent of automaticity (feedback and automatic control) exist, but these devices generally include as components the instruments mentioned. Here the information handled might be considered feedback information, Class b, but the transducers, converters, and recorders function in a manner similar to those using natural physical phenomena. Higher classes of instruments such as the computers and guided missiles obtain their higher levels of automaticity and control by combining functions of the simpler instruments.

The Use of Computers in Processing Information

Introduction. Both instruments and special-purpose data-handling equipment reach a point of complexity in their development where simple storage or conversion of information is no longer adaquate. Then the considerations of calculating, computing, and controlling--the introduction of logical choices--becomes imperative.

Machines which perform such functions have been given the name of computers. (Many of them are designed for this specific purpose--computing.) But their capabilities are not generally limited to this function. Louis N. Ridenour proposes that these devices be called "information machines", which would be quite appropriate in this discussion.[1]

Computers are classified as digital (numerical in operation) or analog (solution by comparison). These devices are generally combinations of lesser information-handling devices. Although they differ in method of operation and in results obtained, both digital and analog computers may be related through the use of analog-digital converting devices, to obtain the particular advantages of each system.

Many excellent papers have been written describing the operation, construction, and design details of the various

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[1]Louis N. Ridenour, "The Role of the Computer," Scientific American, 187, September 1952, 116.

computers, and similar effort will not be duplicated here. This presentation will consider computers in the light of automaticity and informational functions, as have discussions on the various other topics throughout the thesis. In Chapter VIII the various contributions of the computer to automation will be brought together with other concepts presented throughout the thesis, to illustrate applications of the computer in automation systems.

The Analog Computer. Analog computers are the logical extension of the intermediate forms of analog measuring instruments. Here, however, the device is usually composed of several units, each one performing a particular mathematical function. Some of these computers are designed to perform computations for a variety of inputs, having the same basic qualities but differing in overall application. Others are adaptable to the use of exchangeable components, plugging in or out the particular elements as desired.

Analog computers may be either electrical or mechanical. The electrical computer utilizes the similarity of electronic circuits to the measured system, converting input data into the desired solution. An example is the network analyzer used by power companies to simulate complex electrical power systems.

The mechanical computer generally includes mechanisms to simulate addition, subtraction, multiplication, integration, or the generation of trigonometric functions; various devices being combined as required by the particular problem.

A device used to continuously sum (integrate) varying input data is illustrated in Figure 27.[2] Here a rotating disc, shaft, and two intermediate balls, continuously sum the input rate from the disc shaft.

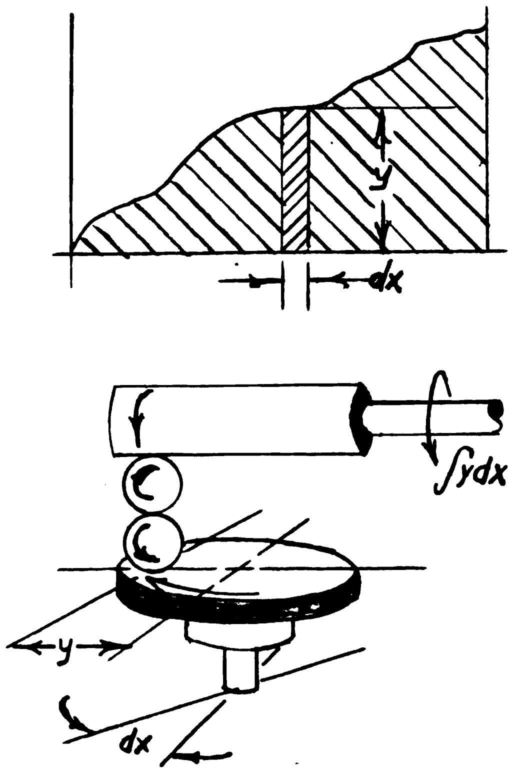

Figure 27

Ball and Disc Integrating Device

A varying fluid flow measurement would be an example of use for the ball and disc integrator. The fluid flow would represent input to the disc shaft (dx); location of the balls from the center of the disc (the second adjustment, y) might represent a second factor, such as concentration of a substance in the flow. The total integration at any time would be determined by the sum of the disc revolutions and the

[2] Alvin Piatt, "Computing Mechanisms Integrate Process Control Elements," Automation, 2, June 1955, 61.

ball location (y), which in turn would vary with the concentration of the substance in the fluid. Of course, the suitable transducers would be required to furnish the input data to position the computer elements.

Other devices of the analog computer would include rack-and-pinions, variable potentiometers, etc. The complete computer would equal the sum of all the various analog devices used to solve the problem, and need be no more complex than the problem requires.

Because of their ability to work with mathematical functions, these computers have been used extensively in the fields of chemical and petroleum process control. The computers are integrated into the system, each analog device performing a particular measuring, computing, or regulating function. As such, their order of automaticity varies from A_3 to A_4.

According to Bright's classification, levels of mechanization of the analog computer penetrate that region in which the device responds with action. This would correspond to Levels 15 and 16. In the more complex guided missiles (for example, the Nike I or the Terrier), Level 17, "Anticipating required performance and adjusting accordingly" might be applicable.

The information fed into analog computers is usually immediate-nonmanual, being supplied from some transducing device. It may have been recorded on magnetic tape, however, and in this case would be of the stored-nonmanual variety.

These mathematical machines generally accept information in the form of voltage, angular position, or frequency and time inputs. This information is usually transferred immediately through the series of links, discs, cylinders, and other mechanisms in the machine, and connot be described as becoming stored information while in the computer.

Concerning the operation of the computer itself, the use of mechanical or electrical elements forms a pattern-sequence combination of stored information. The energy is nonmanual, and is usually of negligible value, acting only as the carrier of the information. Classifying analog computers by information-energy concepts, they would vary from 2(BC') to 2(bD"). Other classifications are possible, depending upon particular system features.

To avoid placing too much emphasis upon a particular classification, the important points to keep in mind from the viewpoint of the industrial engineer are perhaps those of the functions to be performed, and the levels of complexity possible with this type of computer. These have been sumarized by Alvin Piatt, of Librascope, Inc., manufacturers of analog equipment:[3]

1. Complexity of the computation.
2. Character of the inputs and the outputs--whether they are electrical, mechanical, pressure, or force, and what scale factors can be used.
3. Accuracy required.
4. Required speed of response of the system.
5. Power available.
6. Environmental conditions.

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[3]Piatt, op. cit., 64.

<u>Digital Computers</u>. The digital computer is related to the special-purpose business machines in the same manner as the analog computer is to analog instruments. It is a continuation of digital data processing at the computing, controlling, and logic levels.

In comparing the usage of the two, digital computers are used in extremely complex computations which will tolerate only very small errors, but do not require continuous output. Analog computers are generally specified when the computation problems are not complex enough or the accuracy requirements are not severe enough to economically justify digital computer use.

Digital computers are composed of five basic units. (In fact, the first computers were combinations of these separate units, hooked together into one system.) These systems consist of:

1. Input devices.
2. Output devices.
3. Storage devices.
4. Arithmetic unit.
5. Control center.

Input devices transfer the information to the computer from some external storage media, such as punched cards or magnetic tapes. Most of the computers in operation today are designed to handle one or both of these media at input and output.

The information is then fed to an internal storage device, such as magnetic drums, cathode ray tubes, or magnetic cores. These devices give more rapid access to the information, since they are usually of the random access variety of storage device, while tape and cards constitute serial storage.

Computations are performed by the arithmetic unit, which is controlled by the control center. These computations are fed into output devices, which transfer the information onto external storage media (cards or tape), completing the computer function (see Fig. 28).

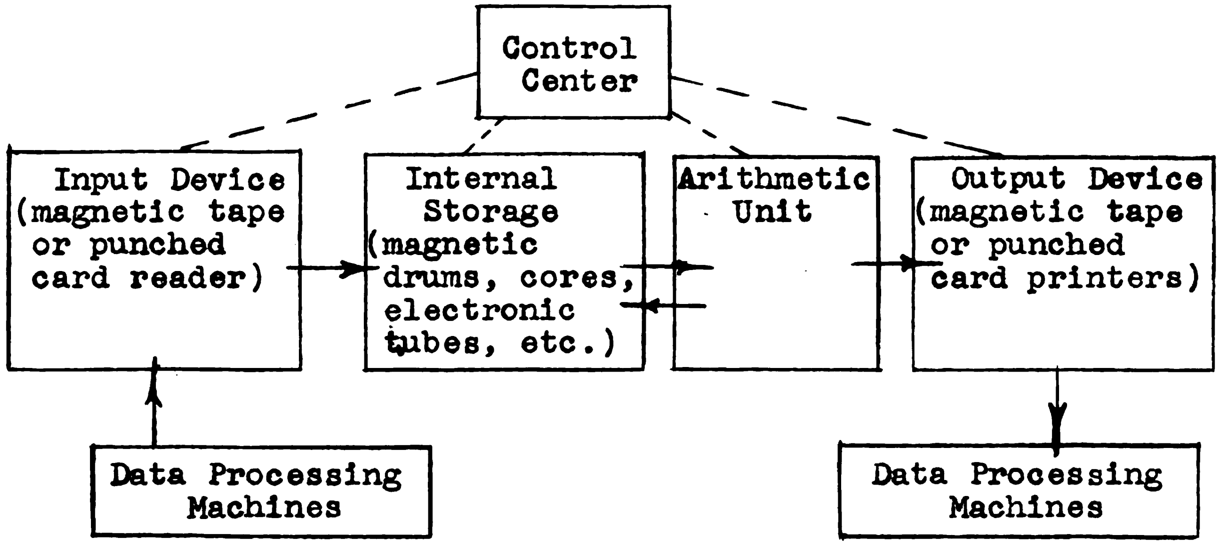

Figure 28

Components of a Digital Computer System

Information is generally fed into the computer in the form of seven-column magnetic tape code, or eight-column IBM code. In these codes, four magnetic tape or six IBM columns are data-handling and three tape or two IBM columns are coded instructions (programs) for machine operation. The coded input media is usually prepared on electric typewriter-coders or IBM card-punching equipment. A sample problem, as prepared for General Electric's ORAC computer, is presented in Figure 29.

In the equation--

$$y = 3x^2 + 5x + 2 = [3x + 5]x + 2$$

find y for all values of x between 1 and 1000 in steps of one.

The following information is stored at addresses in the computer's memory--a rotating magnetic drum:

Address	Number
0000	x = 1
0001	999
0002	1
0003	3
0004	5
0005	2
0006	y

Operation	Address	Instruction	Address
1	1201	21	0000
2	1202	24	0003
3	1203	22	0004
4	1204	24	0000
5	1205	22	0005
6	1206	12	0006
7	1207	31	0006
8	1208	21	0001
9	1209	23	0000
10	1210	30	1215
11	1211	21	0000
12	1212	22	0002
13	1213	12	0000
14	1214	32	1201
15	1215	34	0000

Key to Instructions

21 = put into accumulator
22 = add
23 = subtract
24 = multiply
30 = choice (see further)
31 = read to tape
32 = go back to
12 = write into memory
34 = stop and ring bell

By turning a knob and pushing buttons on ORAC's front panel, the operator tells it to go to address 1201 and perform operation 1. It automatically proceeds from there to operation 2,3,4, and so on, performing the operations as follows--

Operation Number	Operation
1	"Bring what is at at address 0000 into the accumulator." At this address the number 1 is stored. (x = 1)
2	"Multiply the number in the accumulator by 3." Result: 3x = 3
3	"Add to what is in the accumulator, the number at 0004." Result: 3x + 5 = 8
4	"Multiply result of operation three by value at 0000." Result: (3x + 5)x = 8
5	"Add what is in 0005." Result: (3x + 5)x + 2 = 10 = y
6	"Put answer at address 0006 on the magnetic drum."
7	"Record answer on magnetic tape for future printing."
8	"Put into accumulator the number at address 0001."
9	"Subtract x from that number." Result: (999-x)
10	"Make a choice . . . if (999-x) is positive or zero, continue with operations 11, 12, and so on; otherwise perform operation 15, ringing bell to indicate problem is finished."

Figure 29

How the Digital Computer Solves a Problem

11 "Put x into accumulator."
12 "Add 1, giving (x / 1), the new value of x."
13 "Record this at address 000, making the new value of x available for calculating y."
14 "Go back to operation 1 at address 1201."

From here on, the computer repeats steps 1 through 14 until x reaches 1000. Then operation 10 stops the calculation and rings bell to signal operator his instructions have been carried out.

Figure 29 (continued)[4]

How the Digital Computer Solves a Problem

The digital computer is both controlled by and performs operations on stored information (in the form of the combined program and information data of the input media). Amber would consider such a device as A_6 order of automaticity, and the energy-information classification would correspond to 2(bC") or 2(bD")--immediate-nonmanual power with stored, manual or nonmanual programmed information, combined with feedback information. Bright would probably consider the computer to be of Level 17, combined with several of the lower levels. Measured by any of the classifications used here, the digital computer far exceeds the levels of automaticity of any individual piece of data-processing equipment.

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[4]Charles R. Wayne, "Digital Data Processing--A Key to Technical Progress," General Electric Review, 56, July 1953, 12.

<u>Analog-Digital</u> <u>Converters</u>. These devices convert analog data--either in the form of mathematical analogies or electrical comparisons--into digital codes. Some of these devices utilize mechanical drum counting arrangements with commutating or other physical interrupting devices. Other systems use completely electronic conversion systems. Complexity of the system varies with the input and output parameters involved.

The advantages of such devices is obvious--if information of the "original" form can be sensed, measured by analogous methods, and directly converted into digital media, then a completely automatic data-processing system could be evolved. The key to the solution of integrating manufacturing and data-processing systems lies in this link between analog computers--adaptable to many types of production equipment--and the digital processing equipment, which can process most data-handling functions.

Summary

The machines that handle information can be grouped in the catagories of general-purpose equipment, specialized data-processing equipment, instruments, and computers. Such equipment can also be considered as performing scientific-engineering functions, or business-manufacturing functions, although emphasis upon automation has tended to mix the uses of these devices.

Machines such as the office standard and electric typewriters constitute that group of machines known as general-purpose equipment. The levels of automaticity of these items is quite low.

Special-function office equipment generally process information at a higher level of mechanization or automaticity. Many of these devices are program-controlled. Examples are the punched-card sorters or Flexowriters.

Considering the scientific devices, most instruments come under this classification. These devices function on the principle of analogies between the measured phenomena and the measuring device. Instruments may vary in complexity from the simple devices, through transducers, simple and intermediate recording devices, converting instruments. and higher types of analog devices verging on computers and containing a high lèvel of automaticity.

Computers perform the functions of information-handling and data-processing of the lesser specialized equipment instruments to greater degrees of complexity. Analog computers deal with mathematical analogies, while digital computers handle digital (generally binary) coded information. Levels of automaticity of these systems are quite high, compared with those of the lesser instruments and office equipment.

Devices which convert analog information media into digital media allow the processing by digital means, the information sensed and transduced by the analog instruments. Such devices form a link to the further development of integrated data-processing systems.

CHAPTER VIII

APPLYING AUTOMATION CONCEPTS TO INFORMATION PROCESSING

Introduction

In previous chapters the discussion centered about the primary informational aspects of automation--information, its availability, and the machines that handle information. In this chapter, methods of combining these various aspects into useable systems will be discussed.

The areas of information processing are three in nature--information systems related to production; those concerned with scientific data reduction; and "integrated data processing," or the automatized processing of paperwork. These systems tend to overlap and merge, much as the functions of the equipment and instruments which make up the systems tend to be useful in varied situations. In order to discuss these various ideas, however, such a basic arrangement is convenient. From it, variations, extensions, and combinations might be considered.

Most of the ideas as proposed for the "automatic factory" consist of informational and overall control systems for mass production, which do not actually exist at the present time. There are, however, systems of production which incorporate many of the anticipated features of the automatic factory. These are generally found in the fluid processing industries. Here automaticity and control concentrate on the information functions. Since information has of itself many of the properties of fluidity (when conveyed by the proper media), it would be logical to begin the discussion with these systems. The progression would then lead to the discussion of scientific data reduction. Here the object is more rapid, accurate informational records of scientific experiments. The final steps would be the integrated processing of the data in these records and other paperwork, which in turn control the organized activities of the production facility.

Automation in the Process Industries

Introduction. Much of the automatized functions of the petroleum and other liquid flow industries deal with the handling of information. The individual process flows are controlled by automatic feedback devices. Analog-type instruments constantly monitor pressures, temperatures, etc., feeding the information to a control mechanism which adjusts the system to maintain a state of steady flow. As such, the devices would constitute an A_4 order of automaticity. These instruments are not capable of correcting for major disturbances, however. They are able to adjust a flow, but when observed conditions exceed their capacity for correction, an additional control system is required.

The Central Control System. Automaticity has not yet reached the stage in these processes where overall control is completely mechanized. The human operator is still required. It is up to him to interpret major disturbances and dispatch aid if necessary. In order to do so, he is provided with automatic sensing, indicating, and signalling devices. These generally consist of a graphical panel board (including the indicating instruments), annunciators, and automatic scanning devices, usually coupled with recording systems. It is the scanning and recording devices which concern us here.

Processing the Data. The scanning device is programmed to periodically sample the indications of the various instruments, and to report through recorders any irregular occurrences (as well as to signal these facts to the operator). Since the steady state of the flow is of little importance as long as it remains as programmed, only disturbances and information for accounting purposes are recorded. These data are processed according to the system indicated in Figure 30. Information is fed through analog-to-digital converters and thence to a code translator and readout control (actually a simple form of digital computer). The information is then fed to card punches or printers, or to computers for further computation.

This method of data processing indicates the automation pattern for all production systems requiring such processing: measurement of phenomena (through analog devices); indication and selection (scanning); conversion of information to digital form; interpreting or computing; and recording, either in coded or printed form. The actual control of an automatic factory would be much more complex because of the production of units containing form, shape, and size, but the starting point would be with the more fluid components of production--information.

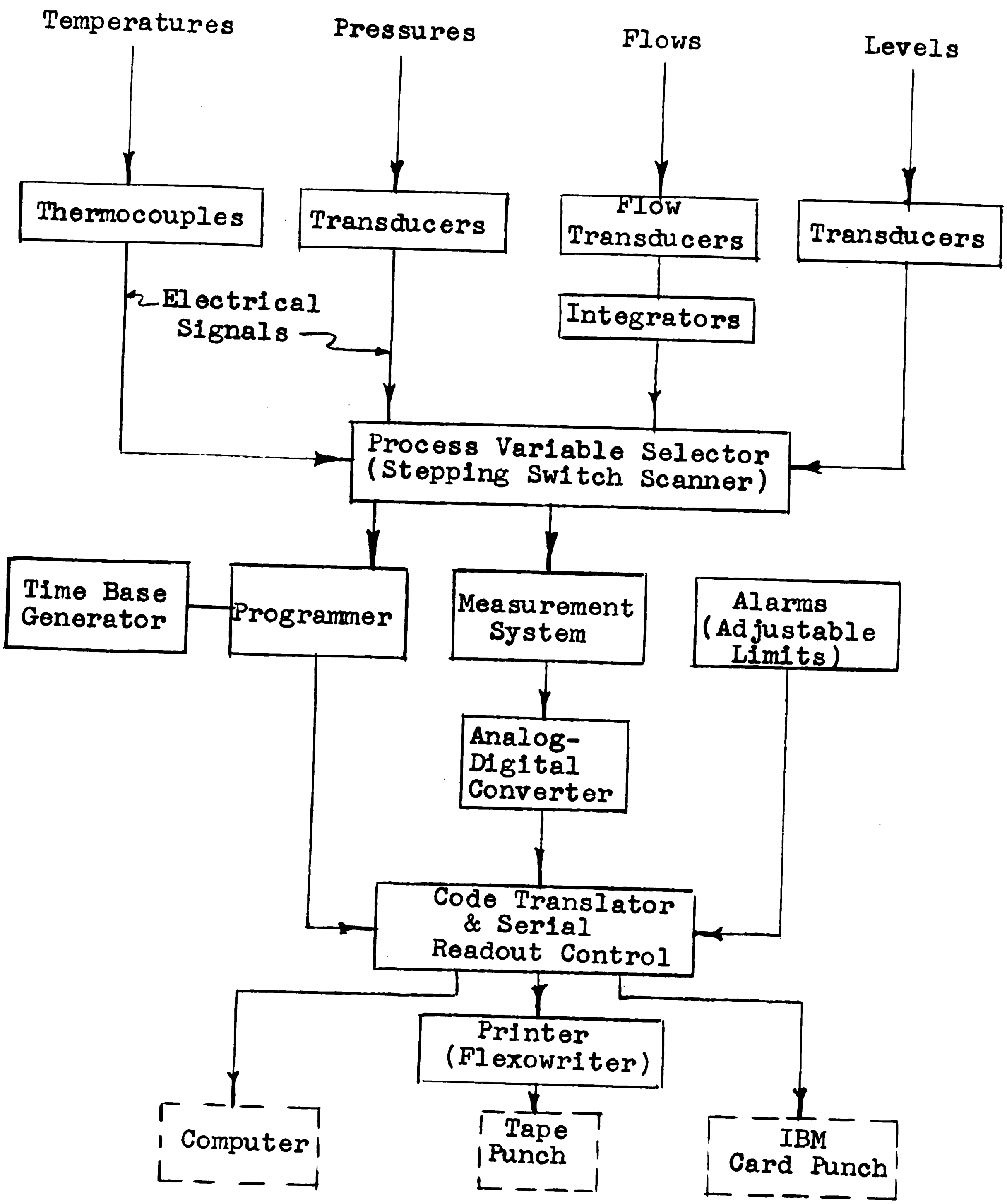

Figure 30

Automatic Process Data-Handling System

Scientific Data Reduction

Introduction. Scientific experiments and engineering tests have traditionally provided a means of obtaining knowledge in many fields, or in the better understanding of common occurrences. Early experiments were based upon the observations as seen by the experimenter. Eventually instruments of the analog variety became the sensing devices, indicating in some scale understandable to the observer. As the experiments became more complex, recording instruments became important, relieving the experimenter of some of the routine duties and allowing him to concentrate upon the experiment itself. Recording and computing devices have now evolved to the point of automaticity of computations and mechanized data conversion.

Basic Methods of Data-Reduction. Seismic studies, guided missile testing and development, atmospheric studies, and other complicated experiments now use a wide variety of data-handling systems. Most of the systems follow the order outlined in the section discussing the process-flow industries. But in this type of data-handling, control of the system originating the signals is not as important as the measurement and recording of the irregularities as they occur. The immediate purpose of scientific experiments is to observe, not to control (although the scientist does attempt to control or eliminate undesirable factors in the experiment.) A progression of methods for solving the data processing problems has evolved from a system using little automaticity, to one

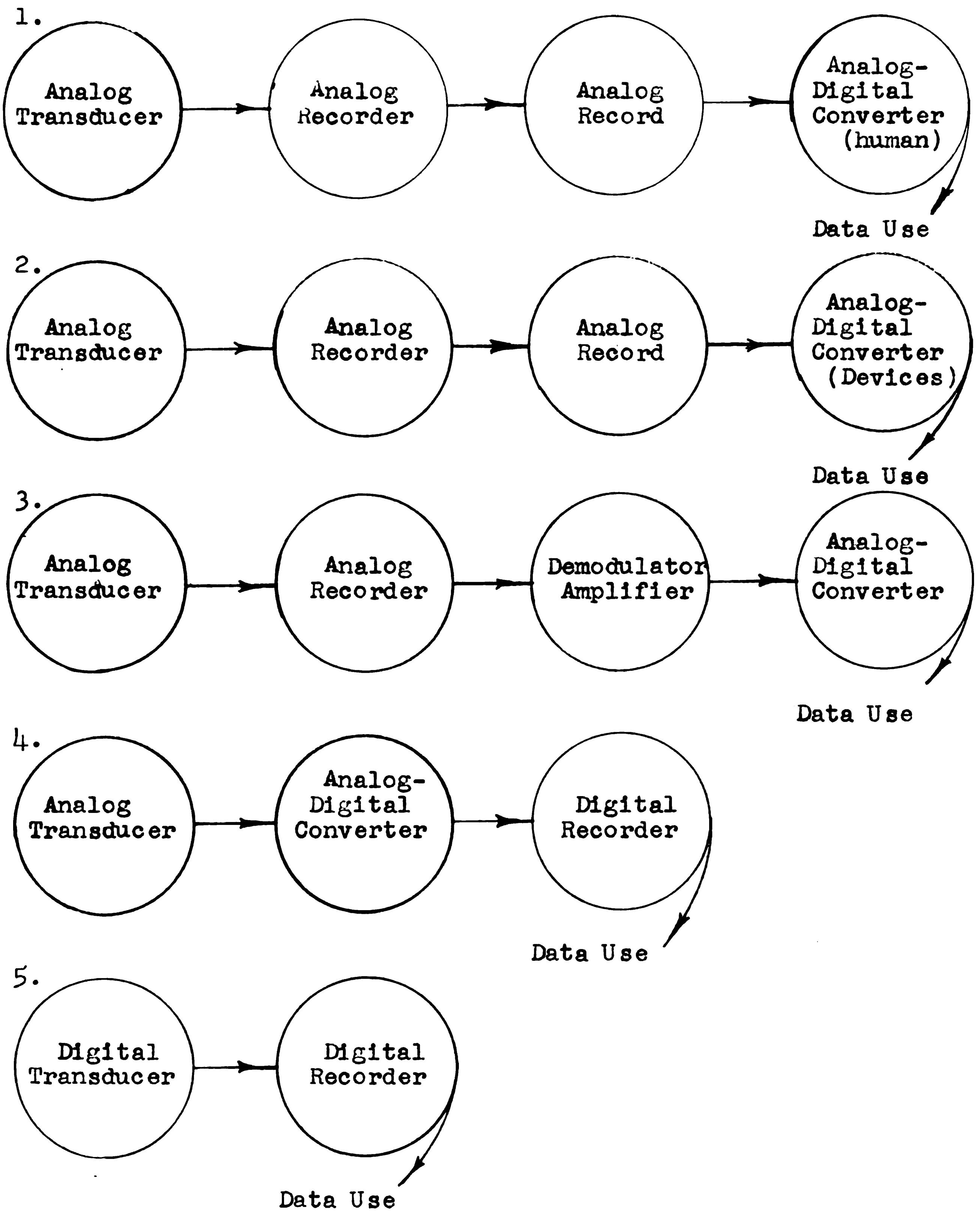

Figure 31

Evolution of Scientific Data-Reduction Systems

that is quite automatic. Figure 31 illustrates this progression.[1]

Here a gradual transition from the use of stored analog records to direct analog-digital conversion and thence to digital recording may be observed. The rate of transcribing from stored analog to digital media is fairly slow, and more rapid systems are desired. In the final stage in which a digital transducer is used, actual digital measurement of the phenomena occurs. Devices such as the mass-spectrometer actually measure the numerical contents of a system, giving an output in digital code. This allows more rapid processing by digital methods.

In scientific data analyzing as in process control data analysis, the primary information desired is that which is abnormal. Steady state information, once the fact has been determined, no longer is of value, the engineer being interested in irregularities. In order to check for worthwhile information before converting or processing further, a recording oscillograph record of all measured phenomena may be observed and the desired data culled for further processing.

Multiplexing. In order to record simultaneously information from several sources, or the measurement of various parameters, an arrangement for sharing the recording medium has been devised. This is called multiplexing, and makes better use of existing equipment, both in scientific and other applications.

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[1]F. K. Williams and M. L. Klein, "Survey of Integrated Data Conversion Systems," Instruments & Automation, 27, September 1954, 1460.

Multiplexing may exist in several forms: space division, frequency division, or time division.[2] Space sharing consists of the storing of information on different parallel tracks of the recording medium--usually magnetic tape. Frequency division utilizes several modulated frequencies on one track, and time division utilizes a commutated sharing of the same track. These methods are often used in seismic explorations for the various information desired, or in the telemetering of internal responses of a guided missile during experimental tests.

The Automaticity of Scientific Data Reduction. Now that the systems have been discussed, the automaticity of these systems may be considered. In most, there are large gaps consisting of time delays, manual transfers, and partial reduction of the data by manual methods. As a complete system, mechanization may drop to Level One, and may soar as high as Level 15. But is a high level for all functions feasable or even desirable? Economic factors may prevent automatizing certain functions which are of a very low level. Certainly the input (or sensing) function should be automatic, but what about the output and following operations? Here the question that is basic to all automatic systems occurs: Should management decisions be automatized? Herein lies a fertile field for investigation which has barely been scratched. Such a system would be extremely complicated, and will be a long time being developed, if at all.

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[2] L. L. Fisher, "Magnetic Tapes Are Versatile," Automation, 2, July 1955, 105.

Integrated Data Processing

Introduction. With the increase in automaticity of manufacturing operations, the paperwork which preceeds, parallels, and follows up the manufacturing cycle must also be mechanized, or the overall manufacturing system would tend to become snarled and bogged down. In an attempt to automatize the information-handling of office procedures, a technique known as integrated data processing has been developed. This system integrates repetative data-handling functions and increases the fluidity of informational procedures.

Integrated data processing is a plan for mechanizing the handling of business paperwork. Its basic rules for achieving this mechanization are two:[3]

1. Record data at the point of origin on office machines which create punched tapes or cards as the automatic by-product of the recording operation.
2. Process original and subsequent data on office machines which read and punch tapes or cards, so that all data are self-perpetuating.

Integrated data processing points up the reasons why industrial engineers are interested in automation. It uses work simplification procedures and methods improvement to eliminate steps by combining them, and consequently simplifying the procedure. With such improvements, the processing of information is more accurately accomplished and completed in a shorter time period.

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[3]P. B. Garrott, "Integrated Data Processing Brings Automation to Paperwork," Automation, 2, January 1955, 39.

The Common Language Vehicle. In Chapter VI, punched paper tapes were discussed under the subjects of information storage and coding devices. Here the punched tape is applied to create a continual flow to the concept of information handling.

With the punched tapes, equipment is required which can handle the coding and repetitive processing functions, and specialized office equipment plays an important role. The central machine is the device used to originally encode the material on tape. Simpler systems, where corresponding conventional business forms are not important, make use of the teletype machine. But more complicated systems require a machine that can both punch the desired tape, and create a corresponding paper form at the same time.

The Flexowriter, a typewriter with built-in tape punch and reader, is one such system used. Another is the IBM electric typewriter, coupled with a tape punch attachment. The tape which results is processed through the various office machines designed to handle punched tape as a by-product. Figure 32 illustrates this procedure.

The Use of Business Forms. Much of the information placed on standard business forms is repetitive. In the process of copying this information from one form to another, errors of recording invariably occur. To eliminate this, punched tape is used as the transferring agent. When a form is typed, information common to the entire procedure or several parts of it, is automatically entered on the by-product tape.

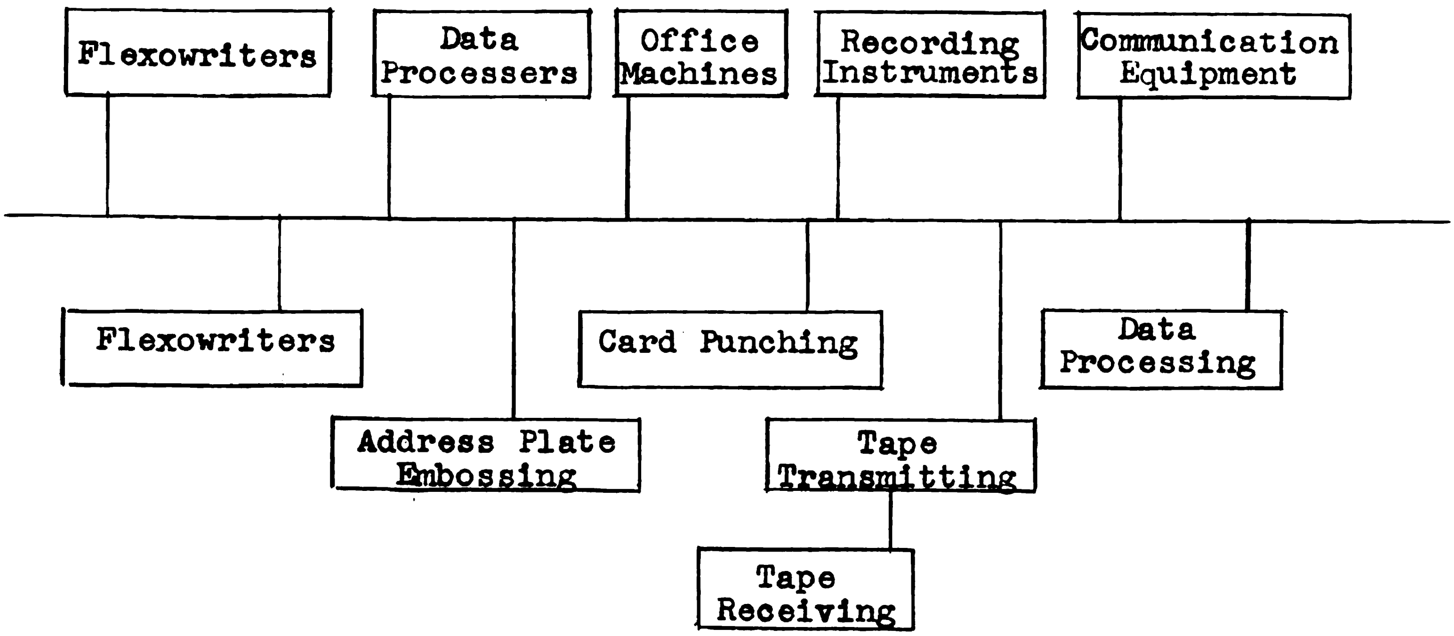

Figure 32
Equipment Used in Integrated Data Processing

The forms are used for their originally designed purpose, such as invoices, requisitions, etc. The punched tape, however, is sent on to the next stage of paperwork, where information common to the original form is prepared in addition to the original data. In this case, the old tape reproduces the original data on the required business form, positioning the machine so that the new data may be typed in manually. At the same time, a new by-product tape is punched. Once the information is recorded upon the second tape, the original partial tape is usually destroyed. But if it can be used in some other function, such as accounting or record control, it is transferred to this department and used, stored, or destroyed according to the requirements of the system. Colored tapes make the identification of its origin simple, and various storage methods have been developed.

Flow of information is rigidly controlled in an integrated data processing system and careful design of the system is necessary. Here the tools of the industrial engineer--procedure charts and flow diagrams--are helpful. The design of the typing form must be carefully planned in order to fit the requirements of code, machines, and system. When these features have been carefully considered, though, the use of the integrated data processing system is relatively simple.

Examples of Application. Integrated data processing may be used either within the office, between office and plant, or in linking the information-handling functions of several plants. A system devised by the management engineering department of E.I. DuPont de Nemours Company utilizes teletype machines to integrate batch-scheduling and customer ordering, billing, and invoice systems in their die manufacturing plant.[4] This has resulted in the reduction of processing time by eliminating many manual references to formulas and past records.

In the Detroit area, indications of use of integrated systems by the decentralized automobile plants are apparent. Here the tying together of physically separated facilities is the important factor. (See personal interview, appendix.)

The Alcoa Aluminum Company uses these methods to integrate their production paperwork with office procedures, and

[4] Hugh A. Bogle, E. I. DuPont de Nemours Co., oral communication.

at Chrysler Corporation, embossed metal plates for car body identification are completed in the shop by integrated methods.[5]

<u>Using the Computer With Integrated Data Processing</u>. Most of the data processing methods may be handled on the specialized office equipment mentioned above. But certain functions, such as production control, scheduling, etc., which require computation, could include computer techniques in the system. Scientific data reduction, once it has been converted from analog to digital code, often uses digital computers and integrated processing equipment. Thus integrated data processing ties together the more widely separated informational aspects of automation through the link of the computer.

Figure 33 illustrates a Remington Rand file-computer system which performs scheduling and other planning operations. This system is used by the General Electric Company at their Louisville, Ky., plant for applications in the areas of payroll, materials scheduling and inventory control, order serving and billing, and cost accounting.[6]

The computer has been used in the insurance business and other organizations handling a great amount of stored data. Storage of information has been reduced in bulk drastically by using magnetic tapes as the storage media.

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[5] P. B. Garrott, "Tying Paperwork to Production," <u>Automation</u>, 2, July 1955, 54.

[6] W. W. Smith, "Impact of the Computer on Methods," <u>Automation</u>, 2, May 1955, 107.

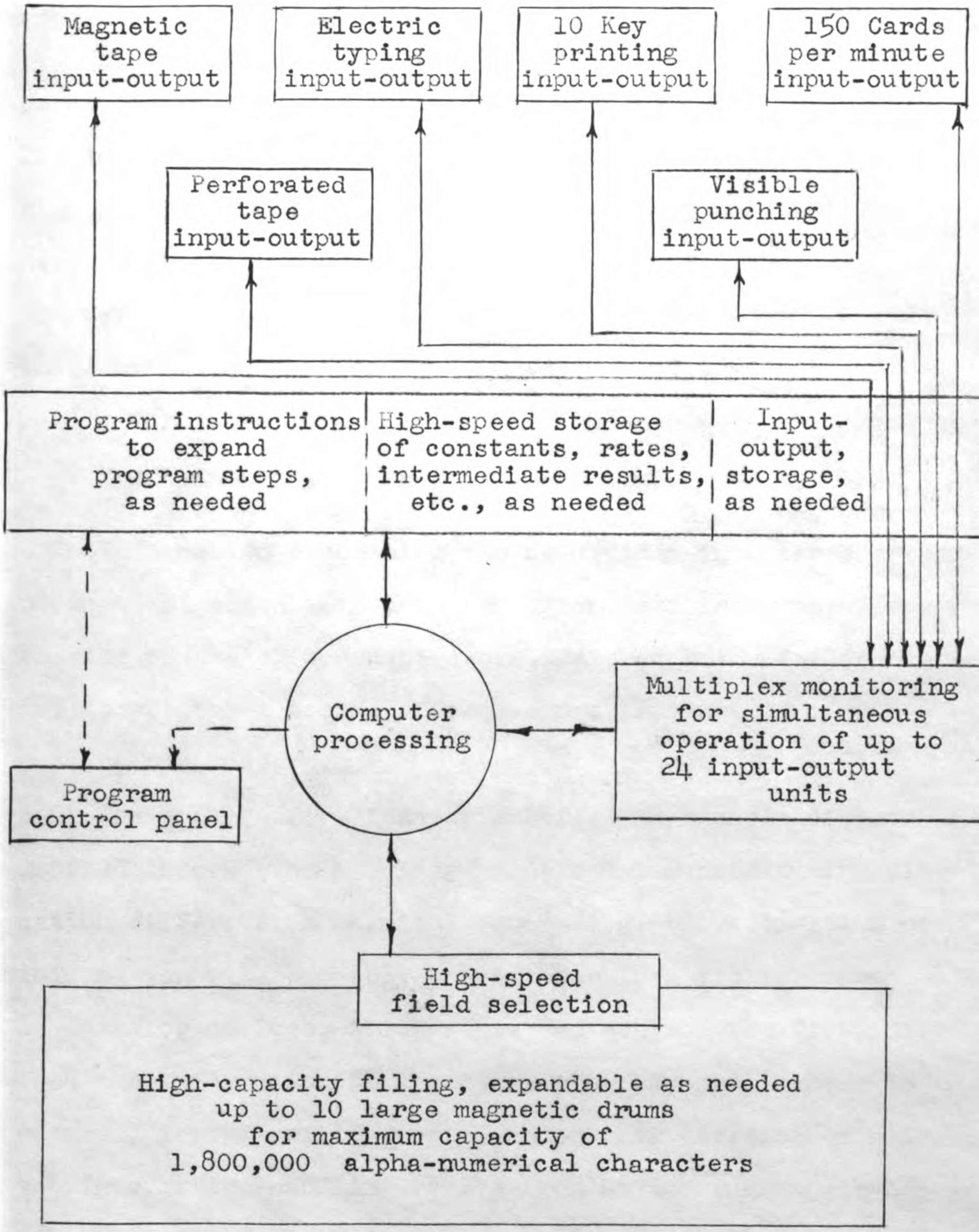

Figure 33

Integrated Data Processing With Computers

Conclusion. Integrated data processing in its various forms has aided greatly in the mechanization of information. The automaticity of the system has not been increased to a high level, but mechanization has been made more uniform. Here again the end-point of the system--the final output and use of information--is not automatized, and indicates the continuing importance of management in the decision-making functions.

Summary

Information processing can be divided into three areas: production, scientific data reduction, and integrated processing of the office paper work. Although the fields overlap, these three topics offer a convenient method of discussing the subject.

The process flow industries offer an example of automatized information handling. The usual manufacturing situation differs from chemical processing, but automation of information will probably be effected in a similar manner.

Analog devices, which sense and control the flow, also feed the information to a central control panel, where it is scanned, irregularities noted, and proper corrections made. The information-handling varies from an instrument reading to the use of analog-digital converters, computers, and mechanized output coding, printing, and computing systems.

Scientific data reduction systems have developed through a chain of analog-sensed to digital-recorded data systems,

using intermediate indicating, recording, and converting devices. Optimum arrangements being developed use direct sensing-to-digital conversion, eliminating the slower intermediate steps.

Multiplexing systems of several types allow the sharing of data flow channels and conversion systems. This allows measurements of various parameters to be recorded simultaneously, and to be analyzed separately under more convenient conditions.

Integrated data processing systems originate office paperwork semi-automatically and mechanize the intermediate data-handling functions. Using typewriter-coders for original form preparation, by-product punched tapes or cards are produced, allowing the flow of information common to the complete procedure to be duplicated upon each successive form automatically. Information which applies only to a particular form and/or succeeding forms is then manually typed in, and a new tape is cut. Flexowriters, IBM typewriter-tape combinations, or teletype machines may be used in the system.

The system may be used in linking office and plant data-handling functions, the data systems of several plants, or in integrating intra-office paperwork procedures.

By using computers with these systems, both scientific data reduction and production data analysis may be integrated into the system, as well as the file-storage functions of insurance or similar large-volume paperwork institutions.

In most of these systems, automaticity of various components is not very high, but by integrating the entire system, mechanization has been made more uniform. The computer, of course, constitites the highest level of automaticity of the system, while probably the input devices (by typewriter or hand) are still the least automatic.

CHAPTER IX

RELATING INFORMATION SYSTEMS TO THE PRODUCTION FACILITY

Introduction

Throughout the thesis, the topics discussed have been related to each other by a process of integration--the summing of interrelationships, similarities and functions. In the discussion of controlling an overall production facility (the automatic factory), an integration of the second degree is necessary--combination of the many automation aspects into an operating whole.

Much of the current preoccupation with the automatic factory is mere speculation. Only a few of the many manufacturing systems approach complete automaticity, and those which do are similar to the petroleum or other continuous flow process industries mentioned in Chapter VIII. This speculation is worthwhile, however, if it can lead to a more desirable phase of automatic manufacturing.

In this final chapter, concepts of the automatic factory will be discussed. The component automation systems necessary, the overall system of operation, and the current environmental conditions--social, economic, and technical--as they apply to the automatic factory, will be discussed.

Integrating Component Automation Functions

If the automatic factory is to be considered as being composed of several lesser automation functions, then the various component systems should be discussed in the light of their relationship to the overall plan. Therefore, a summary of the previously-mentioned approaches in this respect is appropriate.

In the earlier chapters, the controversies or conflicting functions of the transfer machines versus the general-purpose automatic machines were mentioned as an introduction to the formal classification of these approaches. It was pointed out that both types of equipment played a part in automation systems, and that the use of one or the other depended upon several factors, such as the degree of automaticity required, the product and process flexibility necessary, and certain technical considerations. In the automatic factory, also, a great deal will depend upon what the factory is designed to do--whether its products will be relatively rigid in design or adaptable to radical change.

In all probability, the automatic factory will contain both the transfer equipment and the general-purpose equipment in its design. The mass-production type of factory, with lower automaticity level and unvarying products, will be used where simplicity is the basic operational requirement; here design change is not too important. The general-purpose machine concept will be incorporated into automatic factories producing a variety of similar products.

It is difficult to say which will come first, but some forms of each approach will be used. The use of general-purpose factories--since they will have to be more complex--ordinarily would require a longer time period to develop, but under certain economic or political situations (in time of war, etc.) concentrated effort might first produce this as the most desirable factory arrangement.

The modular design concept is an important feature of the automatic factory. The Project Tinkertoy developments illustrated that flexibility could be achieved through the use of modular components. Here a combination of special-purpose machines handling a modular component become, in effect, a limited form of general-purpose equipment.

Assembly has always been a stumbling block in automatizing production processes. Because parts are designed for manual assembly, applying automation has required redesigning of the workpiece, assembly procedures, or both. The modular concept is applicable here also, and will aid in integrating the other manufacturing functions.

Technical computations and many of the empirical design decisions of the engineering staff, as well as scientific data reduction, will be completed automatically and directly--much in the manner in which the mass-spectrometer senses and transduces its observations directly into digital form.

Paperwork has imposed an increasing burden upon the operation of factories, and the use of integrated data processing systems in the factory has helped to automatize this function. Since the paper is simply a physical carrier of the information being stored or processed, the linking of the various production facilities will tend to eliminate to a great extent this present means of conveying information, and the term "paperwork", for all practical purposes, will become obsolete. The ideas to be communicated, however, will still exist, but will be conveyed by systems of a more fluid nature.

The functions of control will play an important part in the automatic factory, synchronizing present operations and merging the current state of production with any anticipated changes as they occur. Here the information-handling concepts of gathering original information, storage, processing, and application will take on new significance. As opposed to the separated functions of office and production facility of today's factory, these automatized components will be meshed to function as a unit. Much of the minor decision-making will be eliminated or automatically completed.

Overall Systems of Operation

The overall system of operation of the automatic factory can be compared to the tactical and strategic functions of a modern military force. The tactical functions will consist of the continual day-to-day performance of the correct manufacturing operations. The strategic functions will regulate the long-range manufacturing considerations, altering and adjusting current production through regulation of the tactical control portion of the system, to meet the changing needs.

As the concept of end-point control (a system whereby signaled changes in the end product automatically bring about the required changes at each point in the manufacturing process) is essential in the production facility, so also does the function of future prediction by logical methods become necessary to perpetuate the long-range program of operation, whatever that may be. First applications might use computer systems to control production planning, as sales forecasts (fed into the system manually) are varied. But later developments might include the machine described by Amber's Order A_8, which has intuitive powers. Such a device could make its own sales forecasts by reasoning along statistical lines.

The devices developed for control can only perform those actions designed into them. Since linear observations are the natural human way of looking at things, the machines are built accordingly. The output of the machine can be no better than its design, and it can be wrong even though it follows its designed procedures. This point must be kept in mind when considering the ultimate control and planning of automatic factory control systems.

In breaking down the control and information-handling functions into the two groupings stated above--strategic and tactical--it is well to consider the devices which will effect the control. The tactical function--control of day-to-day production--will be effected by a combination of digital and analog devices. Since relatively simple controls can detect and (through feedback) adjust operations to control output, these devices will be utilized for this purpose. The analog device is an immediate information-conducting device; hence its usefulness in maintaining and balancing the immediate production output. Since its complexity would increase with the complexness of the analogous situation, the use of analog devices and analog computers would probably not extend far beyond individual product or processing lines. (See Fig. 34.) Computations from the analog computer could be fed into digital systems of control (much as in the scientific data reduction systems mentioned in Chapter VIII). Then, according to logical control procedures, digital computer systems would determine adjustments (such as raw material selection) and feed this information back into the production cycle (Fig. 34). Connections with other such systems throughout the factory would assure an integrated system.

The strategic control function of the automatic factory will be performed by digital computing devices, as described in Chapter VIII. These machines will coordinate information fed to them from the production systems, with information from outside sources. They will then issue the program of operation (production schedule) to the various factory computer systems, which in turn will control production accordingly.

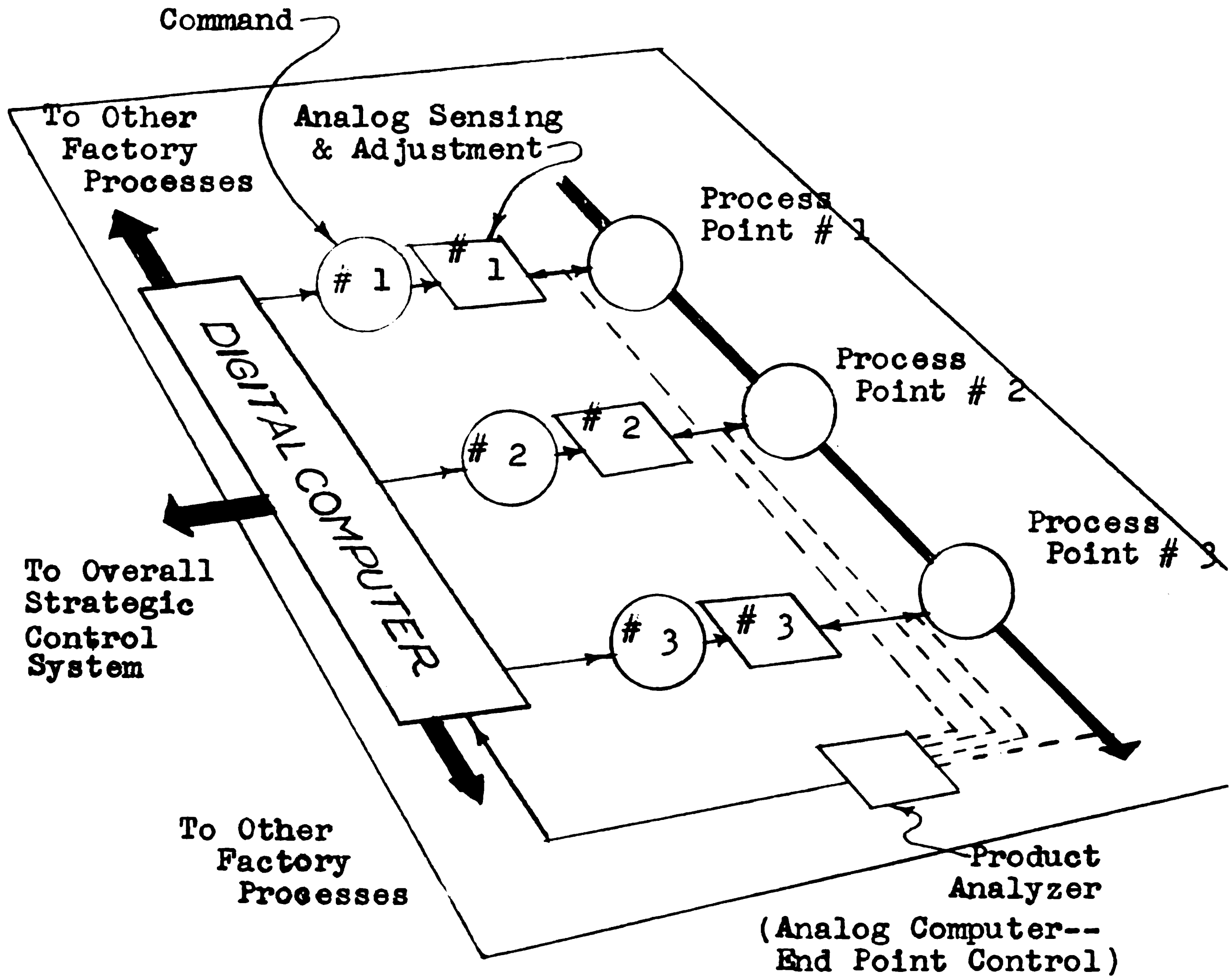

Figure 34

Automatic Factory Control of Production

The computer arrangement used by General Electric at Louisville, Kentucky, is scheduled to perform many of the production control functions, although it does not control the actual production machinery.[1] Their computer is expected to furnish all of the related information required for making changes in the production schedules. For example, if production were to be doubled, the computer would show the effect of such action upon every inventory item involved.

[1]W. W. Smith, op. cit., 108.

It would indicate at what time inventory items would run out, or the possible over-loading resulting from certain scheduling arrangements, and give alternate solutions necessary to effect a proper rate of production. Although this system is not connected directly into the control of the production machines, it indicates the possibility of such an arrangement. Such an integrated system would include the necessary data-processing equipment to inter-connect purchasing, order service and billing, payroll, and shipping schedules. It could logically reach all the way to the distributers, who, through punched cards, would furnish the necessary data for scheduling and production purposes.

Several factors exist that impede (or control) the development of automatic factories. Among these are the social, economic, and technical conditions which have prevented their development thus far.

Social problems of worker unemployment and retraining may tend to cause the implementation of automation to overall factory systems to be slow. The net effect of such problems is difficult to ascertain, but they certainly are influencing factors.

Technical problems, of course, are many. Any untried project of this nature requires a vast amount of experimentation and preliminary design work. Much equipment would be experimental, and development would probably be on the level of pilot plants.

The economic factors, perhaps, exert the most pressure in determining the advent of automatic factories. Until the present developments of automation have been fully exploited, and many of the technical problems solved in lesser degrees, the expense of automatic factories will prevent their realization. However, rising costs may hasten the development of the automatic factory as a means of keeping production costs low enough for a manufacturer to hold his place in the competitive market. All other factors being favorable, it is likely that such a situation would hasten the advent of the automatic factory.

CHAPTER X

CONCLUSION

In this thesis, automation has been discussed in several ways. The word "automation" has been defined, described and related to the various terms and topics commonly associated with the subject.

Some have asked, "Why coin new words? The ones we now have are good enough!" Others have said, "We'll use the old word, but (like the Mad Hatter in Alice in Wonderland) we'll let the word mean just what we want it to mean." And still others state, "We need a new word to describe a new concept." Often the difficulty in describing an idea lies in the existing means of communication, which has been designed to apply to an established approach, and perhaps needs reconsideration in the light of new circumstances.

Many people have claimed that automation, and the things it represents, constitute a panacea for our present or future society. Some have denounced automation as a chain of events pressing mankind on toward moral servitude and economic disaster. Others have warned against the rash application of automation per se, preferring rather to consider it to be a tool to aid in the accomplishment of the conventional (however dynamic) objectives of manufacturing, applying or laying aside its concepts as the complexity of the situation may require.

Certain antagonists have questioned not only the validity, but also the desirability of the entire concept of automation. They have passed the subject off lightly as being "only a state of mind," implying, of course, "that nothing new has happened--there's now just something else to waste time talking about." But if a state of mind may be taken to mean "a way of looking at things," then such an implication is not quite appropriate. Often the best way to discover the truth of a statement, or its falsity--to decide whether it is something or nothing--is to investigate the things said about it, consider these in the light of consistency, the sources, and the intent, and decide upon its validity on these grounds.

Throughout the preceding pages, the ideas of automaticity, mechanization, control, and the automatic factory have been woven into the automation pattern. The informational aspects have been emphasized as being some of the more important influencing factors. Other concepts, also, have been introduced as they apply to the engineering view of the subject.

If this thesis has explained automation in a clearer manner, has spread a certain amount of enlightenment upon the subject, then its basic purpose has been accomplished.

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APPENDIX

Interview With Mr. R. Granger,

Electronics Representative, Remington Rand, Inc.

March 28, 1955

Q. Mr. Granger, are there any companies in the Detroit area now using integrated data processing systems?

A. No, not at present, although there are several with whom we are working to install such systems.

Q. Could you tell me who these firms are?

A. I'm not at liberty to say.

Q. What seems to be the biggest problems involved in setting up such systems?

A. Well, communication is the biggest problem.

Q. How does that enter into the situation?

A. The first companies that will use an integrated data system will be those with several plants or offices, somewhat spread out. That means that inter-area transmission systems are important, and we're having a lot of trouble here.

Q. How do you transmit the data--by teletype tape?

A. That's right, but also by means of magnetic tape, and through electronic channels and received on magnetic tape. Present teletype systems are too slow and inaccurate for a good data-processing system. We'll probably go into greater use of Bell Telephone's coaxial cables, and that runs up the expense. As the speed of transmission increases, the data will have to be better integrated at each end of the system.

Q. What type of company will use this system first?

A. In the Detroit area, the automobile companies are a natural--their plants are decentralized enough to require a better system tying them together.

Q. When will this come?

A. We think that within the next year or two, we'll see some companies in the Detroit area using our systems.

Q. What other types of companies could profitably use your systems?

A. The chemical companies in particular. DuPont is using one of our Univacs for various purposes, including general engineering problems. They've set up a system in one of their plants using a punched-card, teletype combination to integrate the data problems of batch orders and related problems.

Q. What do you feel are the biggest obstacles to introduction of these and similar systems?

A. There are still engineering problems, of course. But most of these are being rapidly licked. The main obstacles are costs, which we are constantly reducing, and in convincing and educating businessmen to see the possibilities of such systems.