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A TEST OF ALTERNATIVE FACILITY DESIGNS AND OPERATIONS BY SIMULATION

by D. O. KNIGHT

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Title Page

AUTHOR D.O. Knight

SUBJECT CLASSIFICATION Simulation Study

NO. R61CD4

DATE March, 1961

TITLE

A TEST OF ALTERNATIVE FACILITY DESIGNS AND OPERATIONS BY SIMULATION

ABSTRACT

Computer simulation is a way of testing the performance of a complex real system or anticipating the performance of a proposed system. In this paper the system discussed is a factory facility the performance of which is simulated, event by event, under the impact of a variety of product volumes, mixes, scheduling rules and facility parameters (design characteristics).

The paper discussed an application of the GEST computer simulation program to test alternative facility design and ways of operating the facility.

CONCLUSION: The GEST simulation project proved a successful application of simulation techniques to an existing facility. Aside from its technological achievements, however, it became an exceedingly effective "sales force" in introducing computer Simulation Techniques to a General Electric operation. It is presented here as a case history.

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Introduction

In the Fall of 1958, at the Medium AC Motor and Generator Department of General Electric, product engineers had developed a new silicon rubber insulation system; manufacturing engineers had formulated a fresh approach to the concept of a facility to manufacture form coils; and the operations research group had a new IBM 704 computer program called GEST (General Electric Simulation Test) which caused the computer to simulate a job shop. These three developments resulted in the "Polyseal* Form Coil Project" and this paper is a report on some of the work done on the project.

To establish the proper background, it would be of value to begin with a brief review of the job shop simulation program. Therefore, this paper will cover:

1. The GEST Job Shop Simulator
2. The Product
3. Problems and Objectives
4. Approach
5. Preparation for Simulation
6. Results from Simulation
7. Recent Developments and Future Plans

The GEST Job Shop Simulator

GEST is a computer program of several thousand instructions which direct an IBM 704 computer to perform as if it were a job shop. The basic program was developed jointly by General Electric and IBM. It provides for a flow of orders through a system of men and machines according to a schedule and rules for dispatching. In compressed time, the computer moves through a sequence of events identical to those which are encountered in a real shop.

Figure 1 shows the program inputs and outputs. Instructions on the program tape tell the computer "how to act like a job shop" and the shop parameter cards inform the computer of the characteristics of the particular job shop it is to simulate. The computer is given rules for sheduling and dispatching and also receives, on a tape, the orders which the shop is to process. At the end of simulation, the computer produces a scheduled orders tape, reports on completions, inventory costs, queue statistics, labor and machine utilization, and static load-capacity analysis.

The GEST program consists of four main sections (Fig. 2). The orders are received by an input edit and analysis section which puts the information concerning each order into required form and then accomplishes statistical analysis on the orders.

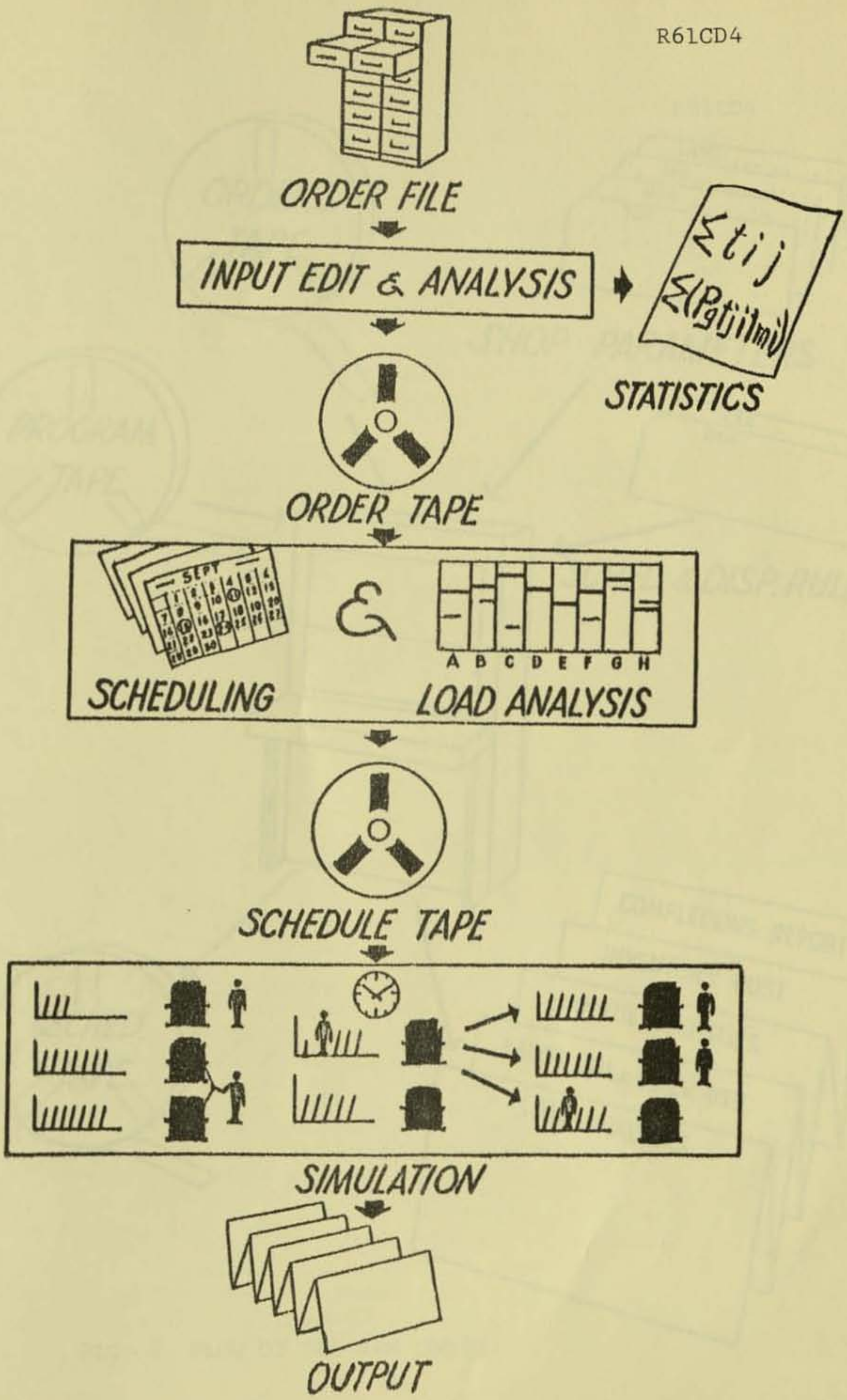


FIG. 1 GENERAL ELECTRIC COMPANY SIMULATION TEST PROGRAM

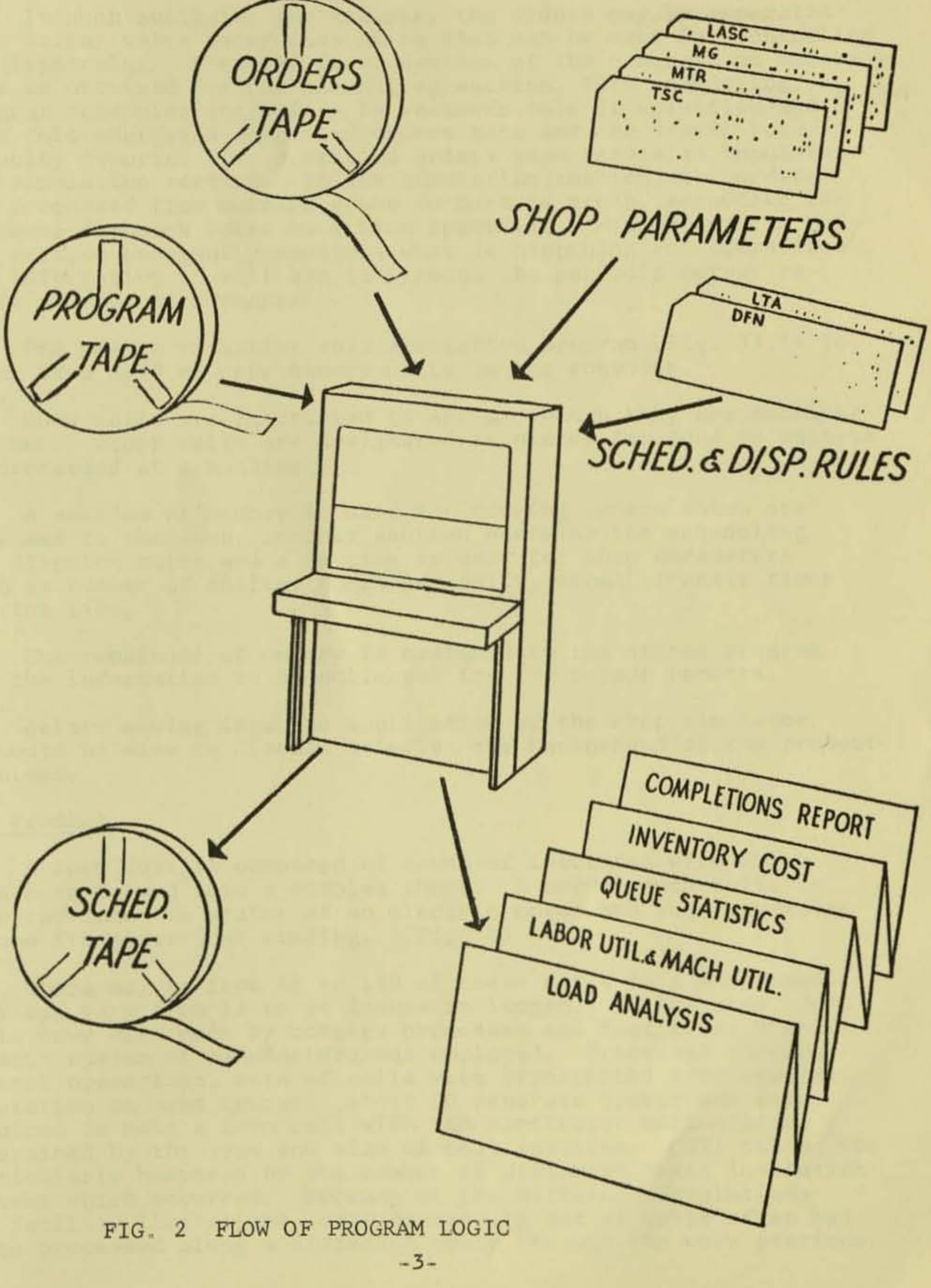


FIG. 2 FLOW OF PROGRAM LOGIC

In such analysis, for example, the orders may be separated into dollar value categories which then can be used for scheduling or dispatching. From the first section of the program, an orders tape is obtained for the scheduling section. This scheduling program schedules the orders by whatever rule is specified and from this emerges a scheduled orders tape and the static load-capacity reports. The scheduled orders tape serves as input to the simulation section. In the simulation section, the orders are processed from machine group to machine group, according to whatever dispatch rules have been specified. Meanwhile, the output section constantly monitors what is happening and summarizes the information it will use to produce the periodic output reports of shop performance.

One way to visualize this simulation program (Fig. 3) is to think of a grid of core memory cells in the computer.

Some cells are instructed to act as though they are machines and men. Other cells are designated as places for jobs to wait to be processed at a machine.

A section of memory is used for storing orders which are released to the shop, another section contains the scheduling and dispatch rules and a section is used for shop parameters such as number of shifts, hours per shift, normal transit times and the like.

The remainder of memory is assigned to the stored program and the information to be collected for the output reports.

Before moving into the application of the shop simulator, it would be wise to discuss briefly the background of the product involved.

The Product

A form coil is composed of turns of insulated wire which have been formed into a complex shape. A set of such coils is inserted into the stator of an electric motor and when connected become its electrical winding. (Fig. 4)

There may be from 48 to 180 of these coils in a motor and they can vary from 12 to 90 inches in length. In the past, form coils have been made by complex processes and facilities wherein a batch system of manufacture was employed. Processed through several operations, sets of coils were transported from station to station on hand trucks. About 20 separate operations were required to make a form coil with the particular work station determined by the type and size of coil involved. Coil making was particularly hampered by the number of different basic insulation systems which occurred. Because of the different insulations and facility limitations, each succeeding set of coils often had to be processed along a different route through the work stations.

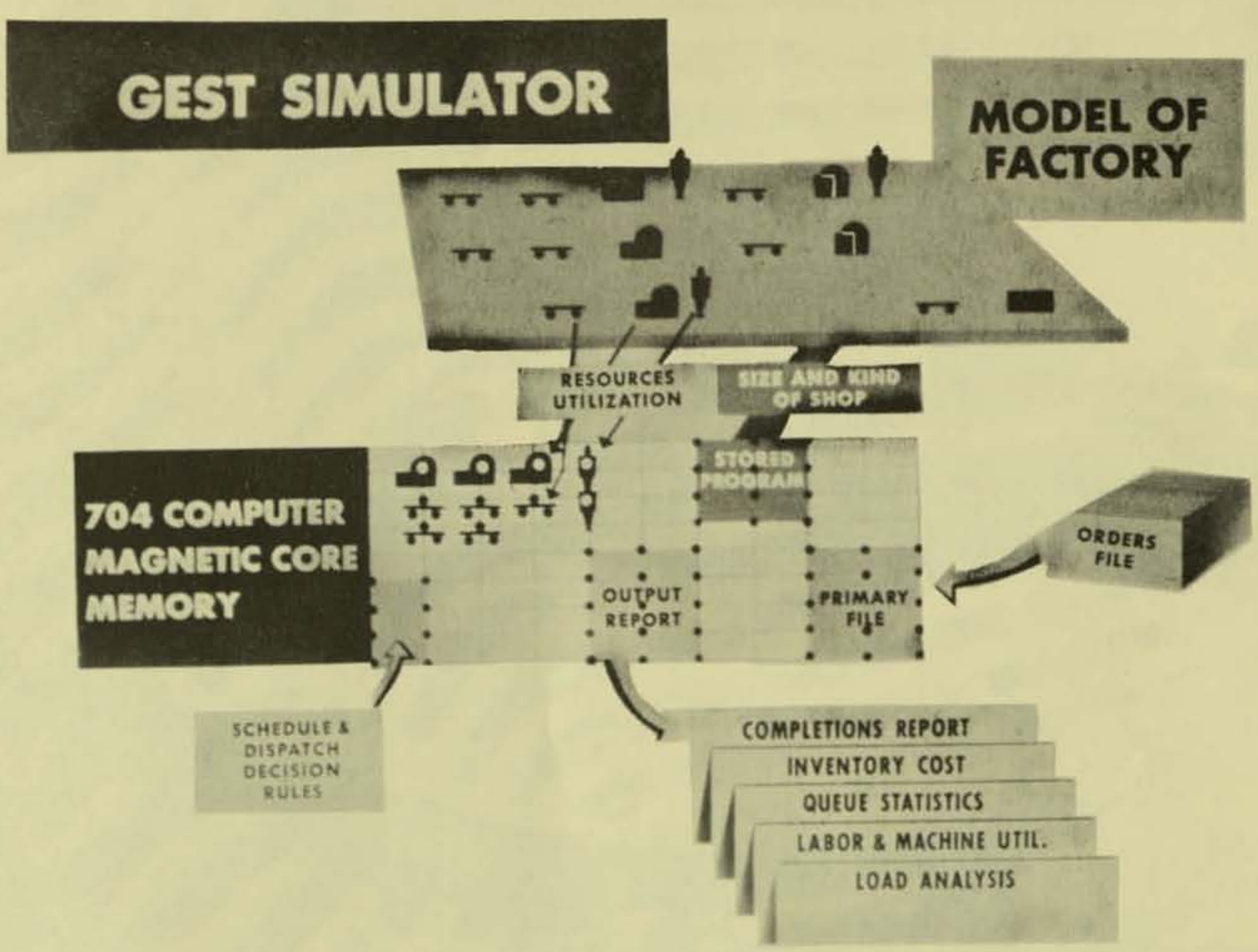


FIG. 3 ORGANIZATION OF COMPUTER MEMORY

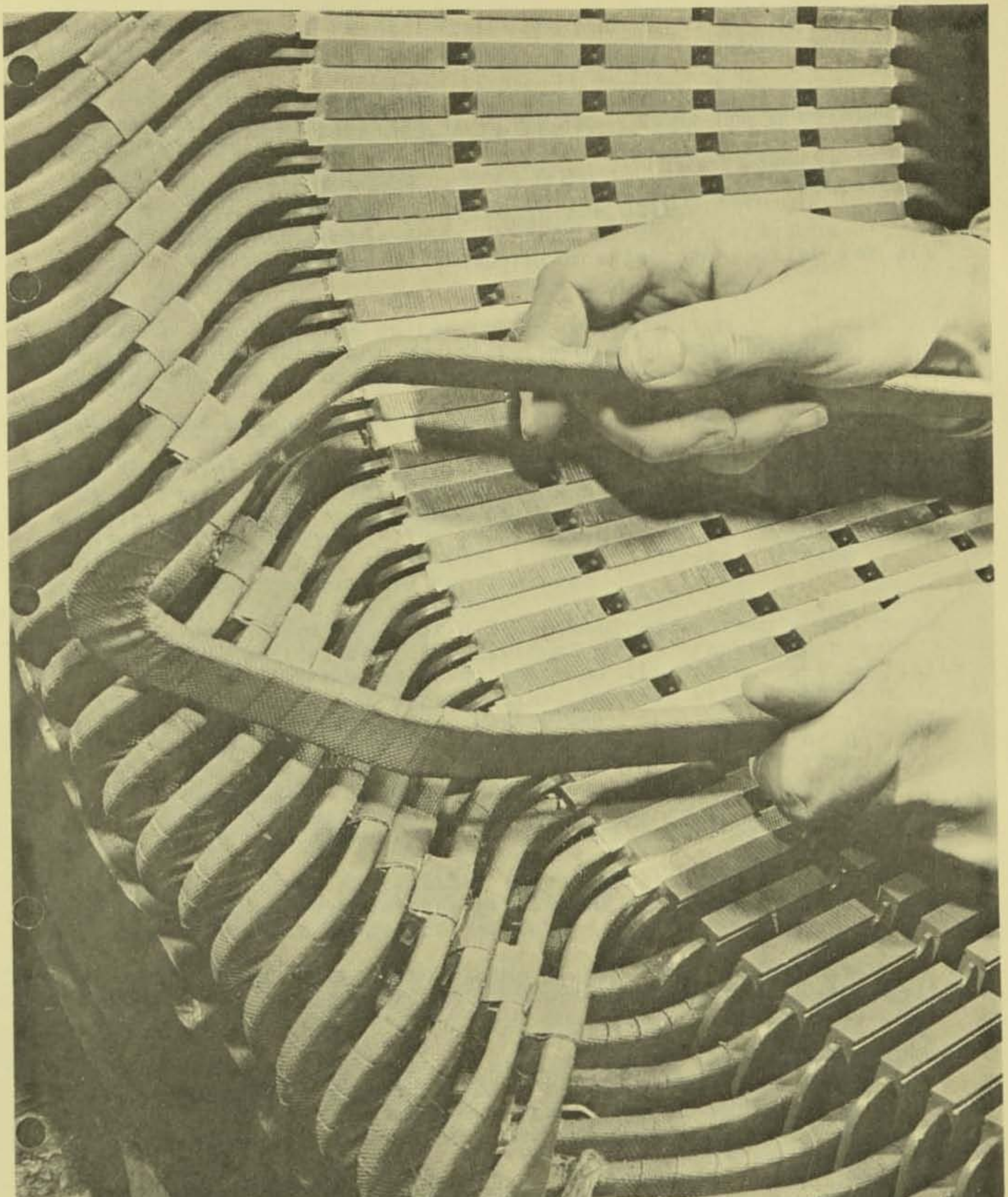


FIG. 4 PICTURE OF A FORM COIL

There were more than 40 such routes for different sets of coils.

The introduction of Polyseal insulation resulted in a number of important changes in form coil making. Among the most significant were:

1. Reduction and deletion of many of the insulation systems which could be specified in the past,
2. The requirement for only half as many operations,
3. A single sequence of operations and one routing for all coils.

Thus, the door was opened by the introduction of Polyseal insulation, manufacturing engineers initiated many ideas for changing and improving the concepts of form coil manufacture.

Problems and Objectives

Returning to the Polyseal Form Coil Project, it is not often that an exciting tool like a shop simulator, a new product, and a fresh approach to the concept of a producing facility all are involved in one project. The combination of these three presented an unusual opportunity to explore a new philosophy in the manufacture of form coils. For example:

1. The desirability of a flow shop rather than a job shop.
2. The possibility of individual coils, rather than sets of coils, moving in a continual flow from start to finish.
3. The concept of a paced-line, perhaps with a conveyor bringing work to successive work stations.
4. The elimination of coil carts to be replaced by an integrated handling system which moves coils from raw material to insertion in the stator.
5. The realization of a balanced line so that work entering the line flows smoothly with efficient operator utilization.

Many variations of facility arrangements were studied, and it might be of value to present a picture of the above ideas. Figure 5 is one of the first physical layouts.

It consists of five labor classes and nine machine groups, organized in a straight line with appropriate conveyors connecting them.

In looking at this concept of a facility, there are a number of rather difficult questions to be raised. Some can be and in the past, have been answered with pencil, paper and a slide rule, but the best possible answers, taking into consideration all of the interactions which occur in a facility of this kind have never been readily available in the depth desired. Such questions fall into two general categories. The first are those which a

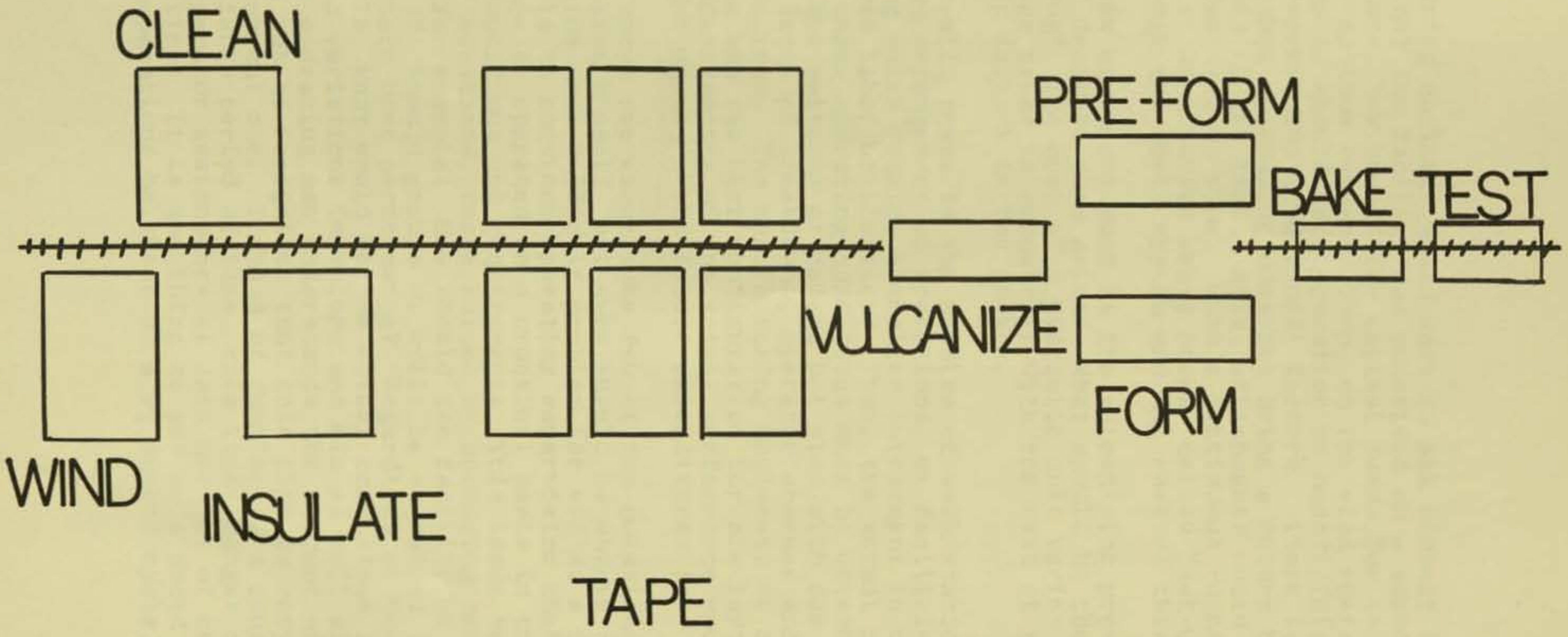


FIG. 5 INITIAL FACILITY LAYOUT

manufacturing engineer would want to ask himself in order to be certain that the facility was conceived on a sound technical basis. For instance, how should the capital funds for this project be spent for optimum return? Then, on the wind operation, for example, how automatic should this operation be made? This is a question which involves many conditional factors. There is a point beyond which further up-grading does not bring a return because of other limitations in the line. Also, attachments could be developed which reduce set-up time. With a continuous running conveyor, a set-up at wind causes empty hooks, called "set-up bubbles" to pass through the whole system and the cost of this is significant.

On new equipment such as the vulcanizing press, a number of points of decision also arise: What should be the speed of opening and closing? The cost of a hydraulic unit varies with pump capacity. If a slower press is compatible with the rest of the system it means many dollars in the pocket.

Over-all, there is the problem of work station utilization. Would a re arrangement of operations, or facilities, or different scheduling rules require a smaller investment in machine groups or improved labor utilization? Then, the actual capacity of the facility under operating conditions must be determined, not only with various patterns of demand but also with due consideration of the effects of breakdowns, operator absence and other unforeseen conditions. The manufacturing engineer, of course, wants to know if he has the best configuration for his layout and if a better understanding of the actual performance would change his concept and thereby avoid future expenditures for rearrangement.

The above represent some few of the questions a manufacturing engineer asks himself, but even should he obtain the best possible answers, the most difficult problem for him as a manufacturing engineer is to convince operating supervision that a new facility concept can be operated on a practical basis in the real world of shop conditions and requirements. This leads to the second series of questions, those raised by operating personnel and supervision. For example: How should the facility be scheduled and dispatched? Should groups of coils be sequenced in some particular way to obtain best performance? Regardless of how one would "like" to schedule, what would be the actual conditions in scheduling because of variations in volume and mix of coil sizes and types? Also, the operating man understands the concept of a paced line operation but he recognizes that this line is very different from the normal one. Instead of running at a constant cycle for an appreciable period of time, this line changes cycle and often changes operator assignments as each new set of coils is introduced into the line. It is one thing to set up a paced line to operate with all operations balanced on a 9½ second cycle. This can be done with a pencil and paper static analysis. One can, with no trouble, run the same paced line on a second shift on a 16 second cycle simply by slowing the conveyor speed to balance the line with the fewer operators brought in on this shift. But, in the Polyseal line, the conditions are different. The number of operators must be constant while the cycle will change 2, 3 or 4 times per shift. Furthermore, with two and sometimes three sets of different coils in the system at the same time, the line will never be balanced ideally for either set and this will vary in degree, depending on how many coils there are in each set and where they exist in the line. This line is planned to operate in a turbulent condition from two-thirds to its total running time. At first glance, this little facility may have appeared simple, but it didn't take operating people long to recognize that this would be a highly complex shop to operate at a peak performance level. At the same time, they recognized that the improved performance of this new facility over traditional form coil manufacturing more than justified any effort required to achieve its operation.

Operating men had many more questions dealing with such things as how to handle extreme variations in volume and mix, appeal jobs, how to re-balance the line without being required to pull additional operators out of thin air at a moments notice. It is probably needless to say, but when operating men who were used to a three week normal manufacturing cycle and 200 to 300 set of form coils in process, found that the new facility had a 14 hour cycle and two or three sets in process, they took a great deal of interest in the simulations of this facility.

Although the preceding is by no means an exhaustive list of the questions to be explored by simulation, it does reveal the scope of the problem. Next, a few comments will be given on the approach used.

Approach

Primarily, the simulation studies were accomplished by three people: the Manager of Manufacturing Engineering, a Manufacturing Trainee, and the author who was then with Operations Research and Synthesis. Of course, many more people contributed to the input data and facility designs as a part of their regular job.

In analyzing the facility, several approaches were used. Many static pencil and paper analyses of such things as capacity and line balances were made. When variations in volume and mix were considered, the arithmetic became voluminous so a computer was used to do this work. It was soon discovered, however, that dynamic simulations were required to obtain the type of analysis desired. To do this, the GEST Simulator was utilized.

Preparing for Simulation

There are two classes of information which must be gathered to do a simulation; data on the requirements to be placed on the facility and data on the facility itself. Even when simulating an existing facility, the data often is not available in the form required. It is necessary then to construct, or deduce, the needed information from what is available and to evaluate the practical workability of a facility before that facility's design is completed. This is exactly what was done on the Polyseal Form Coil Project.

In a case such as this, it is necessary to obtain the facility parameters for simulation from the facility layouts and manufacturing concepts. Several simulations were run to cover a range of parameters, including the number of people, number of shifts, and employee productivity. Data-gathering work determined operation times, set-up times, normal transits, normal waiting times and the like. Since the accuracy of the simulations is only as dependable as the input data, considerable effort was devoted to assuring true values for the inputs. Motion time studies, extrapolation of time standards for similar operations and processes, stop watch studies, and high speed motion pictures were utilized by manufacturing engineers to develop this data. Before the facility design was frozen and orders for equipment were placed, five sets of time values and nine different facility designs were simulated and studied.

Because the Polyseal insulation system was a major departure from historic insulations, it was necessary to deduce patterns of demand on the facility from marketing forecasts. These forecasts were analyzed, segregated into motor types, and the predictable quantity for each size and type of Polyseal coil was found. From this data, a range of volume levels and a range of mixes of sizes and types were constructed. With this information, the performance of the facility could be evaluated over the whole range of possible demands on it.

In addition to data gathering, preparing for simulation involved certain modifications to the GEST program. It may be recalled that GEST is a job shop simulator whereas this facility represented a small but complex flow line. It turned out, however, that GEST was versatile and, with some changes, could simulate flow shops. For example, a change in conveyor speed was simulated by having the computer switch to another table of transit times, and line un-balance was discerned by noting the difference of queue length between two work stations and the number of hooks on the conveyor between the same two work stations. The line was considered balanced when no operator had to take a step to obtain his next piece of work.

Results and Conclusions

First, a few comments about the impact of simulation on the facility itself. A story will illustrate one point. One day recently a man from the Department was showing the new Polyseal line to a group of customers and told them,"You should have seen the first layouts we came up with (Fig.5). They were lousy." With this our Manager of Manufacturing Engineering disagreed. As he later explained, "That first layout was a good one by all the rules manufacturing engineers have worked with up to now. We wanted a straight line flow and, that conveyor is straight. An old factory says to use vertical space and this conveyor loops up in the air at its output and down again at the beginning so we're using vertical space. This arrangement also saves installation costs because the conveyor can be hung from a series of rods and this is inexpensive. This line also has the minimum in-process inventory and it has the shortest manufacturing cycle. No one should say the design is lousy."

Actually, there was only one thing wrong, simulation proved that at a number of volume levels, the facility could not be operated efficiently and meet its objectives. Simulation also revealed that the problem was the little "clean leads" and "insulate leads" operations. These were the trouble factors, they were small operations and had to be combined with other operations to provide a full one man job. With the first layout, they could only be combined with "wind" or "tape". At the particular volume levels where the problem arose, the wind and tape stations were already limiting the pace of the line without the clean or insulate leads operations. The manufacturing engineers, though not completely willing, began looking for other ways to achieve their objectives. Once their reasonable doubts were raised, however, the simulations helped them to throw out methods they had believed always would work. In this case, they came up with a new and essentially different concept of layout which placed close together the six operations of wind, clean leads, insulate leads, vulcanize, preform and form without upsetting the paced flow line concept. This permitted a combination of operations in many more ways than previously had been possible and the line could be balanced at the various levels of output. (See Fig. 6)

Early simulation runs indicated that a particular feature in the design of Polyseal coils was causing many of the problems in facility performance. The product engineers were shown by simulation how much could be saved by modifying this feature. Given the facts, they accomplished changes which resulted in a $30,000 annual cost saving.

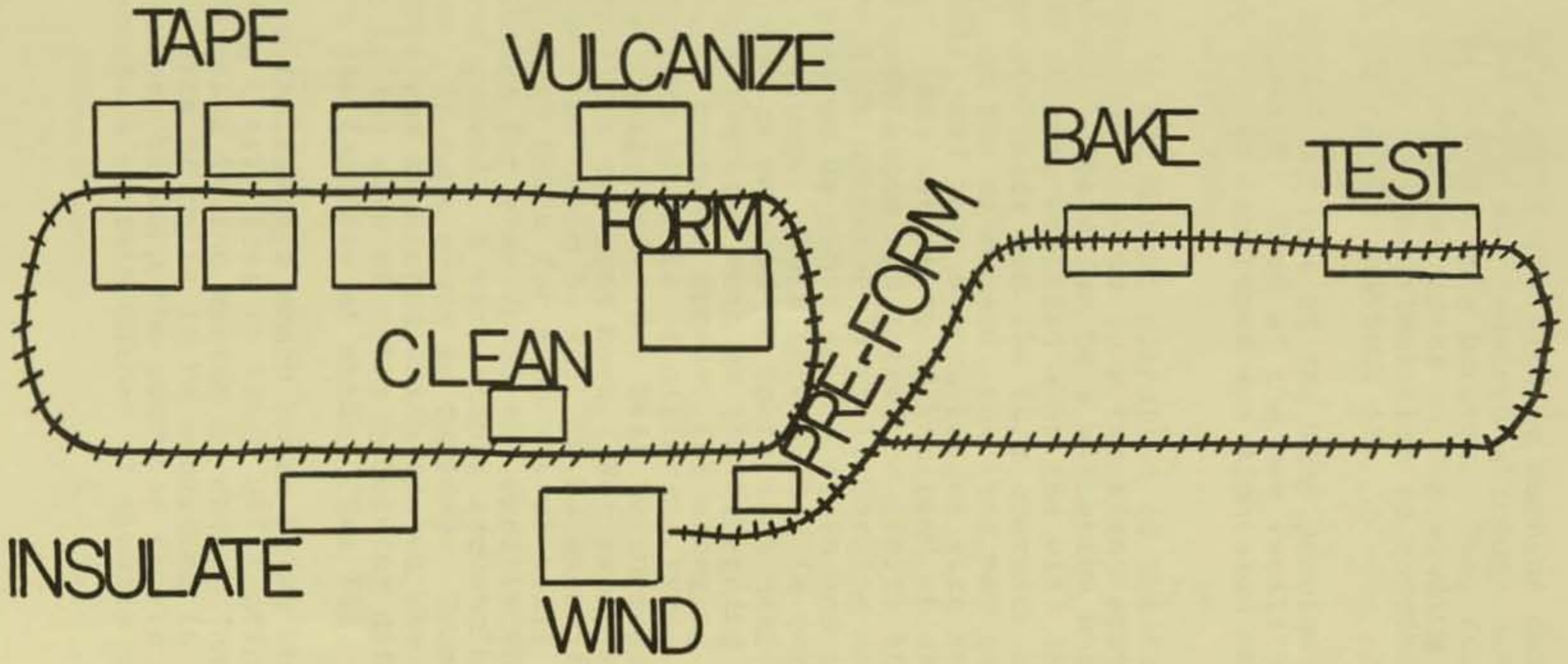


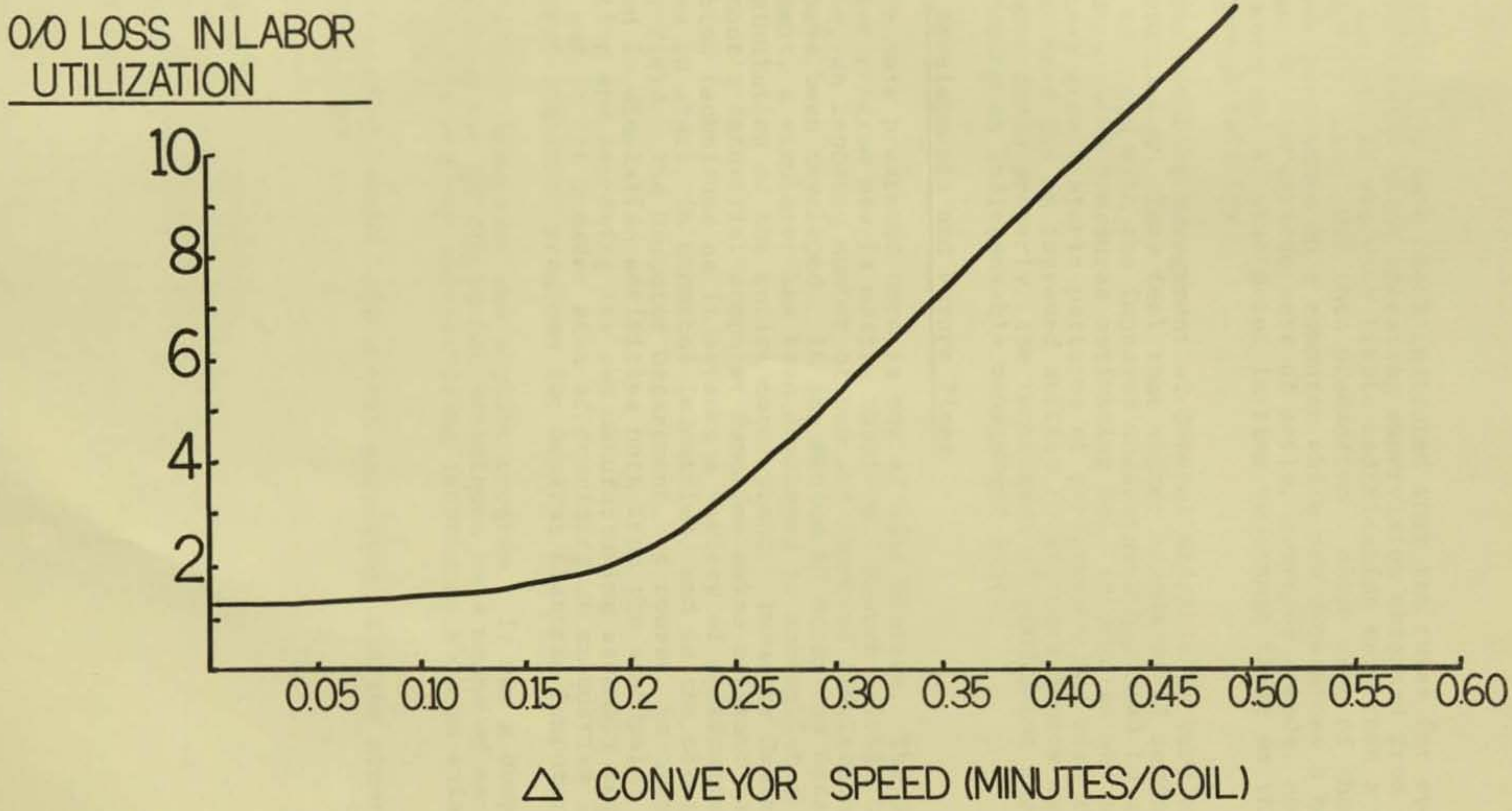
FIG. 6 LATER FACILITY LAYOUT

On the upgrading of the winding machine mentioned earlier, simulation showed none was required although manufacturing engineers had requested $4,500 for this purpose. They frankly admit that this money would have been spent on the winding machine "just to be sure", had they not had simulation to convince them the line would perform efficiently without it.

These are just a taste of the many problems and relationships studied by simulation. Each of the new facility designs manufacturing engineering developed was simulated and studied from a number of points of view.

Moving on to the actual operation of the facility, it has been pointed out that the line is in a transient state more than it is in a steady state. There can be a situation where the operators are nearly 100 percent utilized when the wind operator also does clean and insulate leads and the form operator handles vulcanize and pre-form. On the otherhand, the line may run for awhile with one set of coils, and then a much larger size set of coils starts into the line. This set is "wind limited" which means that wind is the longest operation and therefore limits the conveyor speed. Meanwhile, the form operator is still working on the first set and is fully utilized so he can't do the clean and insulate operations. The line is in trouble. This interaction is complexed because early operations are related to operations near the end of the line. Simulations of situations such as the foregoing helped to develop rules for setting conveyor speeds, for changing conveyor speeds, for sequencing sets of coils of different types, when and how to change operator assignments, how best to increase the production rate of the facility and many more. For example, simulation showed that the line could be kept in balance if the conveyor speeds were changed twice for each set of coils to pass through the system. Rules for what speed and exactly when to re-set it were tested and proved. A very simple sequencing rule turned out to be adequate. It came about as follows: From a series of simulations, a curve was developed which showed how much labor utilization was lost if two sets of coils requiring different conveyor speeds were in the facility at once. (See Fig. 7.)

This curve indicated a sharp break below which the line could be operated with little loss in labor utilization due to two different sets being in the system at once. Thus, a rule is used which requires sets of coils to be sequenced in such a fashion that the difference between the conveyor cycles of two adjoining sets never exceeds a certain number of minutes per coil.



IG. 7 RELATIONSHIP BETWEEN PERCENT LOSS IN LABOR UTILIZATION AND CHANGE IN CONVEYOR SPEED

Recently, a spot check indicated that the rules for operation and the know-how which operating supervision obtained from simulation still are in use with little modification more than a year after the facility went into production. Also, some of these rules have been programmed on a computer which now determines a best sequence for the various sets of coils, conveyor speeds, operator assignments and at what point in time to change these as the coils pass through facility.

Manufacturing management at General Electric is very enthusiastic about simulation. They feel that higher standards of performance can be achieved with the improved understanding gained by simulation. With competitive pressures motivating bold innovation and major steps away from historic patterns of performance and with the constant need for an improved ability to allocate scarce capital investment funds properly, the techniques of simulation rapidly are becoming an indispensable management tool.

Recent Developments and Future Plans

The case presented here is one of past history. The GEST simulator program now is mostly obsolete. However within General Electric, an imposing number of new and improved simulation programs have been developed. In the Medium AC Motor and Generator Department, a simulator has been developed to accomplish a more gross simulation of the entire motor plant. Industry Control Department's industrial computer function makes constant use of simulation techniques as it attacks a variety of application problems in steel, in chemical industries, and in the electric utility field. The Computer Department, of course, is deeply involved in simulation activities both from the standpoint of simulating and improving its own manufacturing assembly techniques and in the broader area of providing an exhaustive library of general simulator programs for General Electric Computers.

The GEST simulator was a pilot program. It was a completely satisfactory use of simulation techniques as a means of marrying a new process and new manufacturing techniques with an existing product line.

This brief report covers that experience for the record and for your review.

D. O. Knight, Specialist
Operations Research and Synthesis
Business Planning Operation
Computer Department

3 March 1961