INDUSTRIAL DATA PROCESSING APPLICATIONS REPORT

Applications	Process Control (Paper)
Type of Industry	Paper Manufacturer
Name of User	Billeruds Aktiebolag Gruvon, Sweden

Equipment Used IBM 1710 Process Control System, including:

IBM 1620 Computer

Input/Output Typewriter

Output Printer

Synopsis

At Gruvon, Sweden, Billeruds AB is using an IBM 1710 process control system to integrate all aspects of the paper production process. The system is divided into five subsystems: production planning, production supervising, process control, quality control and reporting.

Production planning includes all five paper machines at the mill; the other subsystems include only paper machine number four. Production supervising optimizes planning and administrates collected process and quality data. The process control subsystem, in conjunction with the machine tender, control and monitor the paper-making process. In the quality control subsystem samples of paper produced are analyzed in the laboratory and the resultant data is fed into the computer system. The computer prints out two daily reports. One presents a synopsis of production and quality variations and the other lists all rejected rolls.

Paper machine number four at Billeruds AB has an annual production of 50,000 metric tons of kraft paper.

Billeruds AB, a leading pulp and paper manufacturer, and IBM Nordic Laboratory, started work several years ago to determine the technical and economical advantages that could be gained by using a digital computer system to supervise and control a paper machine. Karlstads Mekaniska Werkstad, the paper machine manufacturer, also participated.

The Kraft paper machine, designated PM4 in the Billeruds Mill at Gruvon, Sweden, was chosen as the main object of the study together with its stock preparation system. PM4 was chosen primarily because its production exceeds that of any other paper machine operated by Billeruds and any improvement in its operation would thus provide the greatest savings.

A feasibility study was made and the results showed that a process control computer could be used profitably for complete integrated control of PM4. Moreover, production planning for the entire Gruvon mill was shown to be feasible.

An IBM 1710 system was chosen and the project was divided into the following subsystems which were developed in parallel:

1. Production Planning (for the entire mill)
2. Production Supervising
3. Quality Control
4. Process Control
5. Reporting

The purpose of the installation is to provide total integration of all aspects of the paper production process, from the incoming orders to the sorting of the finished paper. In addition, reports are prepared for Billerud management. All of the paper machines in the mill are included in the production planning subsystem, but the other subsystems embrace only the largest, the PM4.

There were a number of reasons for the adoption of this arrangement. Complete production planning had to include all the paper machines since orders sometimes have to be allocated to them on an alternative basis. The other subsystems, however, operate more independently and it was decided to limit them to the PM4 for the following reasons: limited computer capacity, the necessity for taking it out of service occasionally for preventive service and the limited availability of system personnel.

Work on the production planning system turned out to be more extensive than first expected. New methods had to be developed to handle sequencing and trim problems and a great many exception routines had to be included in the system to make it usable.

The economic incentives for a computerized integrated system were evaluated in the feasibility study prior to installation. For example:

1. An estimation of possible savings can be made if a specific paper market situation is assumed.

2. Better planning will reduce trim, grade change losses, machine costs and pulp costs.

3. Better process control will reduce process and quality variations, down-time and raw material consumption. Moreover, it will improve production and quality.

4. Better quality control will enable quality variables to be estimated more accurately, thus reducing substantially the uncertainties involved in rejecting finished paper.

Savings realized by supplying management with better information may be classified as intangible incentives.

Production planning includes all five paper machines at the mill; the other systems include only the PM4 machine. New order information is punched on cards and fed into the system. Orders with the same delivery date and grade specifications are grouped together. A determination of how the reel shall be cut into rolls with minimum trim loss is made. The orders are then allocated to the different paper machines manually. The optimal sequence is determined for production of the different groups on each paper machine with the shortest total grade change time while meeting the specified delivery dates.

Information about new grades on PM4 is supplied to production supervising. Production supervising has two functions: (1) to supervise production so as to optimize planning; and (2) to administrate collected process and quality data. These two functions are sometimes closely related. For example, information about produced sheet length of on-grade paper from process data collection and about rejected rolls from quality control is needed to determine when one grade is finished and the next is to be started. This data is also collected and stored for subsequent use in the preparation of reports.

Before each grade change, production supervising informs the machine tender about the next grade. The machine tender has the option of acknowledging the new grade or ordering another grade. At each grade change, production supervising supplies process control with new reference values. Information about identification and sorting limits is issued to quality control. Data from process data collection, quality control and manual sorting information from the winder crew is stored for reporting purposes.

Process control is probably the most important part of the system. The process control function may be subdivided into three parts:

1. Steady state control.
2. Grade change control.
3. Emergency control.

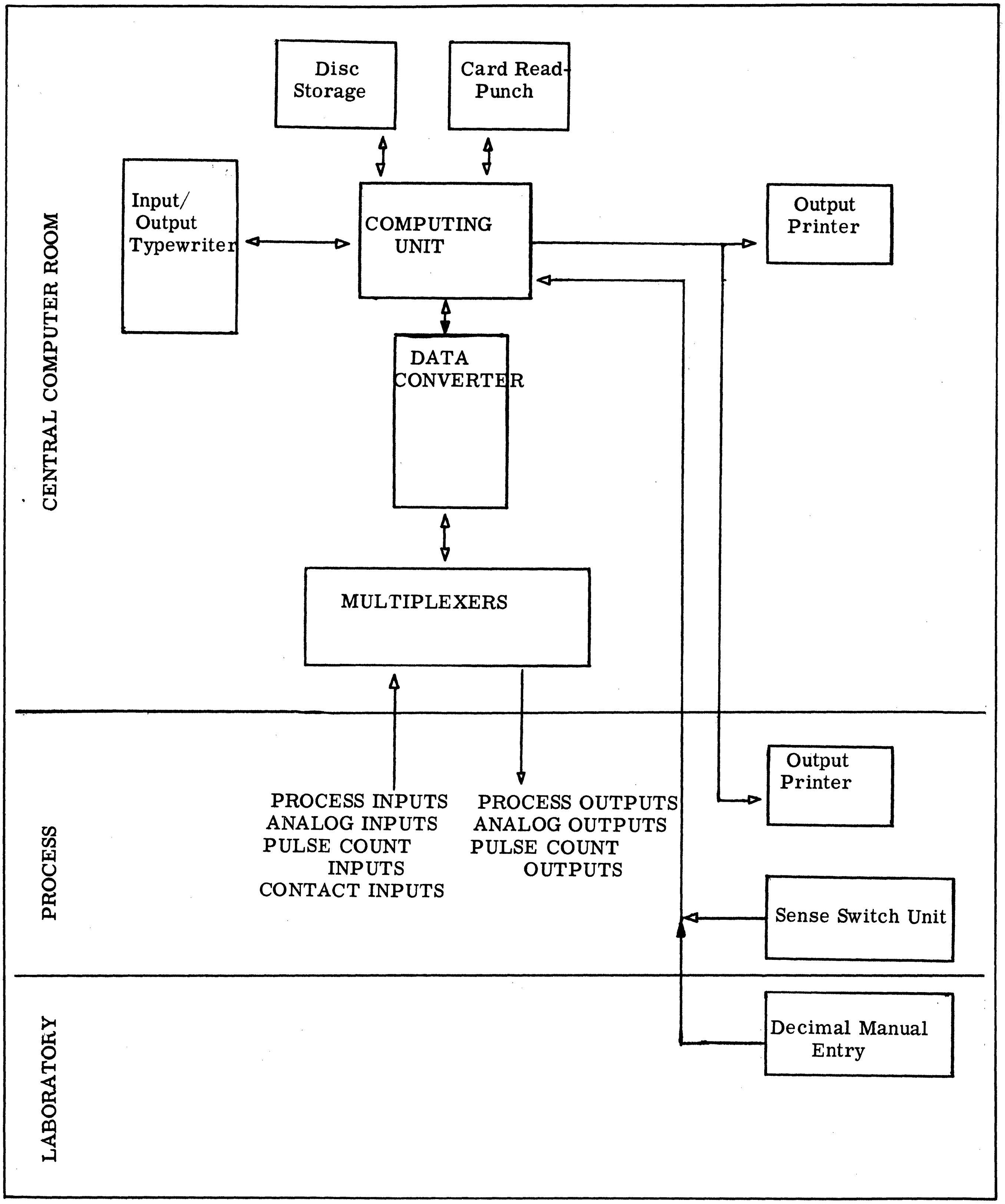
The purpose of steady state control is to run the process as closely as possible to certain given primary reference value with a minimum of process variations. Steady state control is accomplished mainly by closed loop feedback control. The computer makes adjustments in the process based upon process instrument readings.

The purpose of the grade change control is to change the process from the production of one grade to another in the shortest possible time without causing the web to break.

The process control subsystem communicates with the machine tender. Information about abnormal conditions and changes in the status of the process is printed out to the machine tender who has the option of making changes in the reference values; e.g., changing the desired degree of refining.

Process data collection is a part of the process control subsystem; however, data collected at the end of each reel or at a grade change is used mainly for reporting purposes. It is usually collected at the end of each reel or at a grade. Some instrument-reading data is available from process control while other readings are taken specifically for data collecting purposes. These latter include steam and electricity consumption and sheet length.

Quality control is based upon quality data obtained in the laboratory from samples of the finished paper. On-line readings of moisture and basis weight have been assigned to process



CONFIGURATION OF THE CONTROL SYSTEM

control. Since PM4 is a Kraft paper machine, tensile strength and stretch data are highly significant. Quality control has two functions:

1. To issue information to the machine tender which will help him control the paper machine.

2. To determine whether or not the produced paper meets the given specifications. Paper failing to meet the specifications is rejected.

The first function is based mainly on data obtained from samples taken at the end of each reel. Information is printed out to the machine tender. The sorting function is based mainly on data obtained from samples taken at the end of each roll-set. (All of the rolls slit side-by-side from a single length of reel paper are called a roll set.)

Two options are included in the system: manual and automatic sorting. For manual sorting, the estimated quality test values are printed out to the shift foreman. He then has to determine whether the paper fulfills the specifications. When he wants to reject a roll he enters this information into the system. The sorting can also be performed automatically against fixed limits. In this case, information about sorted rolls is issued to the winder crew. Special prediction and estimation techniques have been developed to improve the information issued to the machine tender and to get a more accurate base for sorting. All collected data about quality and rejection is fed to the production supervising system. Calibration of on-line basis weight gages and moisture gages, based upon quality test data, is automatically performed.

All of the process and quality data collected is used to prepare reports. Each day reports are printed out giving a synopsis of the production variations and the most important quality data. A list of all rejected rolls is also printed out. A report containing production figures and an economic evaluation is compiled every month. All important quality data for a given order can also be printed out on demand. The collected process and quality data is evaluated to ascertain improved standard settings of reference values for process variables for the different grades.

The machine tender supervises all manual process operations. He receives information about the process from indicators, alarm signals and his own observations and sends information back as setting adjustments for analog controllers and valve positions.

The winder crew sets the winder slitters and rejects faulty rolls in accordance with information from quality control. They also sort rolls manually on the basis of visual inspection and keep an eye out for wet sheets, curled paper, etc. Manual sorting information is fed to the computer system. These functions may also be performed by the shift foreman.

Samples are taken from the finished paper and sent to the laboratory where their quality is tested. Quality test data is then fed into the computer system.

EQUIPMENT

The IBM 1710 Process Control System is provided with an IBM 1620 as the central computing unit with 40,000 core memory positions. In addition, a disc storage unit provides additional memory space of two million characters.

An input/output typewriter is used mainly during program testing. A card read punch is used for assembling of programs, for entering of program instructions and for input and output of data during normal on-line operations.

Data converter and multiplexer units connect the computer to the process and make the necessary signal conversions.

Output printers, the sense switch unit and the manual entry unit are used for communication with operating personnel.

For communication with the process, the computer system has the following input-output features:

1. Analog inputs -- electrical signals from measuring instruments can be read randomly or at a rate of 200 points per second. At the Billeruds installation 80 inputs are connected.

2. Pulse inputs -- pulses generated by tachometers, flow and power integrators are counted at a maximum rate of 60 pulses per second. At present, 22 pulse inputs are connected.

3. Contact inputs -- the status of contacts of manual switches, on/off detectors, limit sensors, etc., is sensed. These contacts are used in three ways:

   a) The contact sense feature permits sensing of contact status by scanning contact points on demand of programed instructions.

   b) The process-branch-indicator feature associates the on/off status of process contacts with the status of internal indicators which can directly be interrogated by programs.

   c) The process-interrupt feature permits interruption of the routine operation of the computer and to execute high priority programs. Interrupt is caused by process contacts related to conditions demanding immediate action. Up to 104 contact-inputs are presently connected.

4. Analog outputs -- an output timer provides pulses of predetermined duration at a rate of one pulse every 3.6 seconds. These pulses operate reversible motors for operating other actuating devices. Several actuators can be pulsed simultaneously. Of a total of 45 analog outputs available, 31 are presently used.

5. Contact outputs -- contacts are momentarily closed to switch process devices on and off. At present, 14 contact outputs are connected.

THE SYSTEM

PRODUCTION PLANNING

The IBM process control system at the Gruvon paper mill of the Bileruds Company aims at the total integration of all aspects of the papermaking process, from the incoming orders through to the sorting of the finished paper. The production planning part of the system comprises all five paper machines at the mill, while the supervising and control sections are limited to paper machine number four. This machine alone, the largest paper machine at the mill, accounts for almost half of the mill's production. The main reason for including all five paper machines is that production planning, in order to be effective, must include the entire mill; supervision and control, on the other hand, may be effectively performed on a single paper machine.

The production planning system is divided basically into two functions:

1. Regular planning.
2. Emergency planning.

Regular planning is performed at regular intervals. These intervals are short enough to allow significant amounts of new order material to influence the planning, but not so short that changes in the production plan will cause the paper mill to be run so erratically. The regular planning interval for the Gruvon mill is about two days.

As the name implies, regular planning takes care of the normal situation in the mill. Since disturbances in the mill are expected to be relatively infrequent, there is an incentive for optimizing the regular planning.

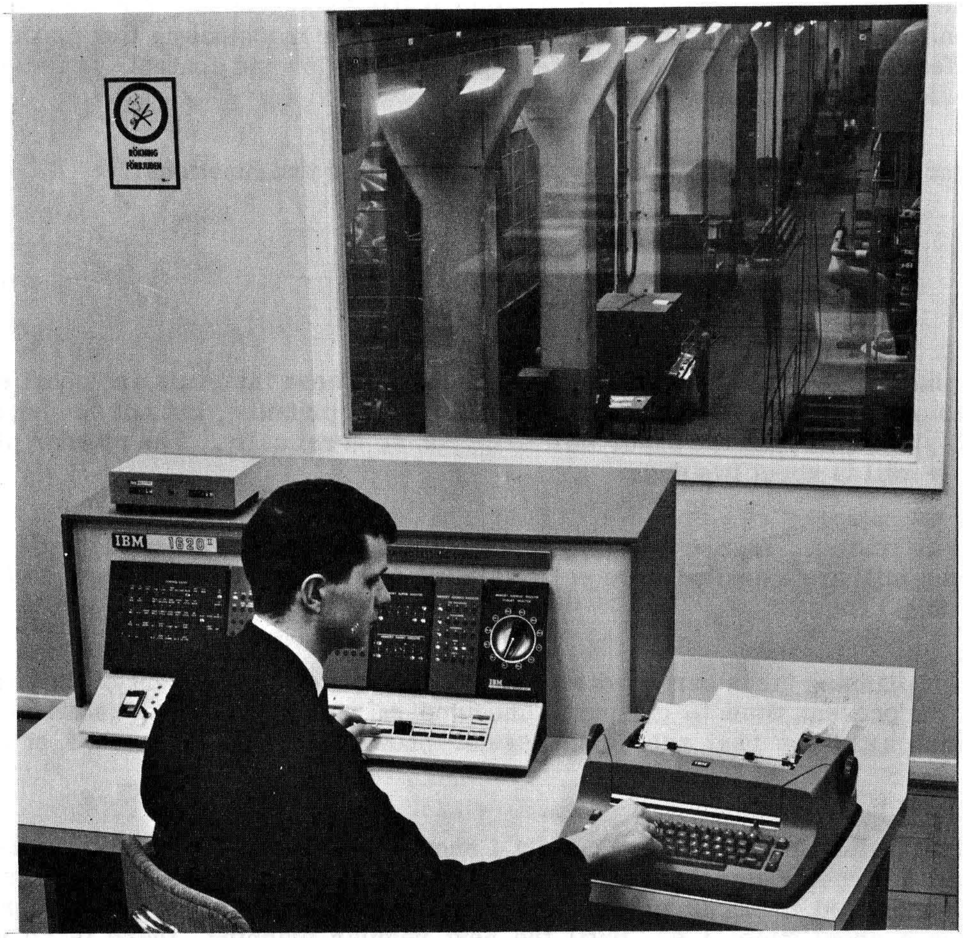
Emergency planning takes care of disturbances affecting the increment of the production plan extending from the present time to the next scheduled regular planning. Disturbances affecting the production plan after the next scheduled regular planning can be taken care of in the regular planning.

In emergency situations there is normally a shortage of time for replanning. It is, therefore, important that the emergency planning function be designed to keep replanning at a minimum. Since disturbances are expected to occur infrequently and any replanning caused by disturbances need only be valied for a short time, i.e., until the next regular planning, there is no need for any sophisticated form of emergency planning. The only optimization included in emergency planning is trim-optimization of affected "sections." Reoptimizing the production sequence is not included since it takes too much time without yielding any significant revenues.

Before actual planning can start, the order material must be prepared as follows. Each customer order arriving at the Billeruds head office in Saffle is entered onto special forms, either for roll orders or sheet orders. There is space on the forms for information comprising a complete description of the customer order including all grade properties, dimensions, dates, etc. At the head office that portion of the information which is known is filled in.

The forms are collected and sent to the Gruvon mill in batches. Upon arrival, the mill planner sorts them into priority levels. Those with the highest priority are handed over to the mill foreman. He completes them by filling in any missing information (normally grade information) and sends them to the punching department.

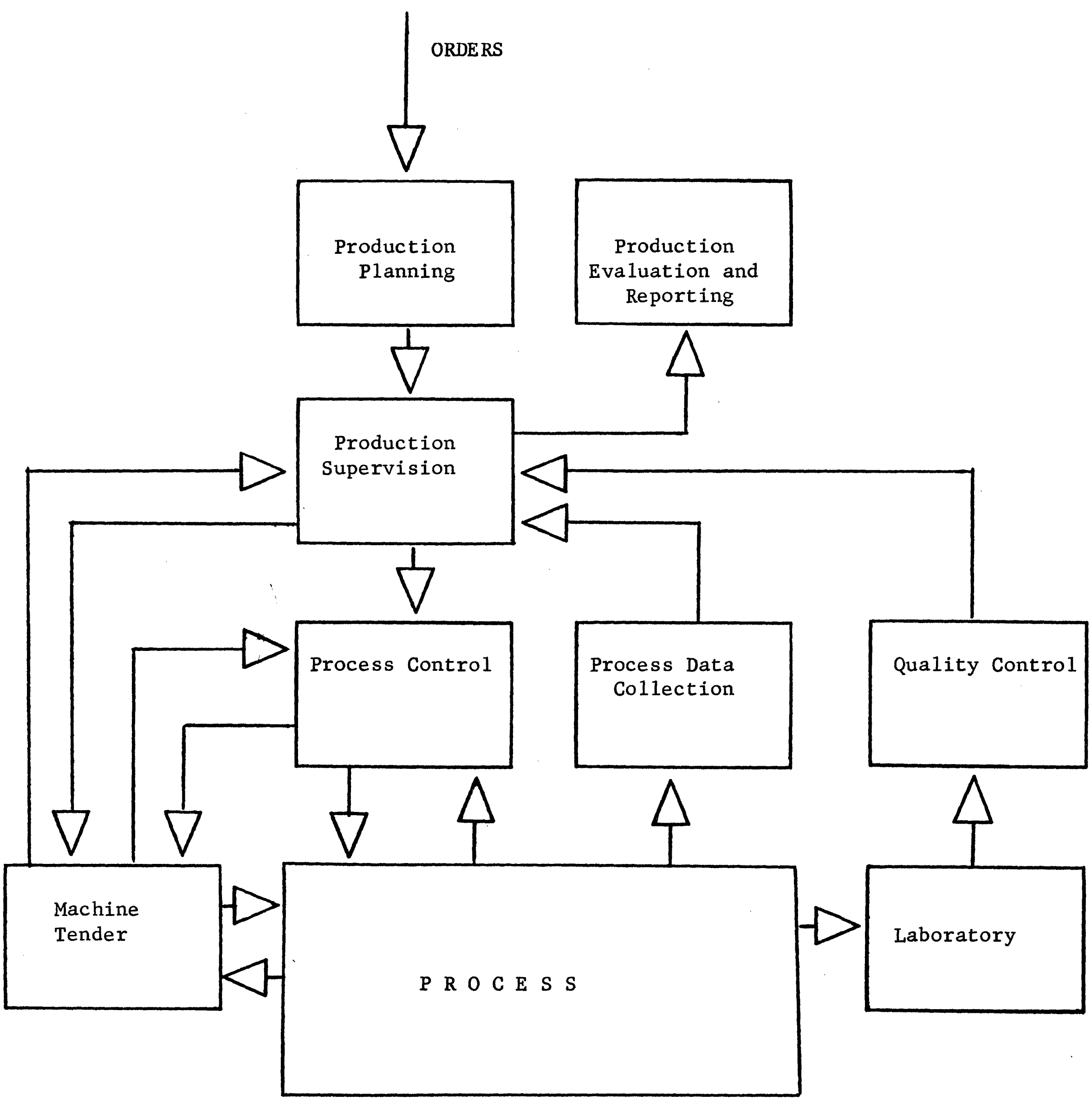
The orders are punched onto cards, one master card for each order and one slave card for each order item. Since it is extremely important that the information be punched correctly, the cards go to the mill planning department and are kept there until it is time for the next regular planning.



OPERATOR AT COMPUTER CONSOLE. PAPER MACHINE ROOM IS IN THE BACKGROUND.

The production planning system revolves around the following incentive areas:

1. Trim losses.
2. Grade change losses.
3. Machine costs.
4. Pulping costs.
5. Storage costs.
6. Late delivery costs.



FUNCTIONS AND INFORMATION FLOW

Since a paper machine represents a large amount of invested capital, optimum production rates must be maintained insofar as possible. As a result, the full width of the paper machine must be utilized. The orders, however, call for rolls of paper of various widths, and sheets of paper of various lengths and widths. The problem is, therefore, to cut the ordered amounts of rolls and sheets of paper from the paper produced in the paper machine in such a way that the total amount of narrow strips left over (the trim loss) is minimized.

The grade of a paper is characterized by a number of factors. These include the way it is glazed, its color, its weight per unit area (basis weight), whether it is bleached, semibleached or unbleached, etc. Changing the grade of paper on a paper machine involves a number of adjustments; these include valve setting changes, speed changes, engaging or disengaging rolls, adding chemicals or color, etc. Many changes can be made without stopping the paper machine. Certain changes involving, for instance, colors or different grades of pulp may necessitate stopping the machine to clean it.

Each adjustment consumes a certain amount of time. Furthermore, there is a transient period during which the adjustment takes effect. During this period the changing grade may not fulfill either the old or the new grade requirements. Such paper has to be scrapped and consequently represents a loss.

Production planning also takes into consideration machine costs, pulping costs, storage costs and late delivery costs.

The general problems of production planning were defined to minimize trim losses, grade change losses and machine costs subject to the following restrictions: delivery times, pulping capacity and storage space.

Eventually, the problems of production planning were broken into three sub-problems:

1. Allocate the orders to the different paper machines in such a way that the machine costs are minimized, and group the orders roughly within each machine so that the total pulp requirements at any time do not exceed the capacity of the pulp mill.

2. Sequence the orders within each paper machine so that the total grade change time within the paper machine is minimized and so that delivery times are not exceeded.

3. Optimize trim within each machine.

Since sequencing and trim can be programed using existing optimization techniques or modifications of such techniques, these two sub-problems are handled by the computer.

Some of the factors involved in the allocation of orders were judged to be too complex to allow them to be consolidated into a form suitable for computer handling. It was, therefore, decided to handle allocation and pulp checking manually for the present.

Production Planning Programs

The Production planning programs which have low priority are written as low-level main-line programs, i.e., they may be interrupted by programs of higher priority such as process control programs. These programs may also be called off-line programs since they are not directly connected to any process but are called in by an operator for execution. The system consists of a large number of programs occupying a total of 0.3 million positions. These are normally stored on discs and called in to core storage when they are executed. Moreover, a number of disc-stored tables occupying about 0.5 million positions are used as input areas for new order information, data processing work areas and storage areas for planning-result data.

PRODUCTION SUPERVISING

The integrated system implemented on the IBM 1710 process control computer includes a complete line of functions such as planning the production, controlling the production, controlling quality and reporting the results. A number of routines which serve mainly as linkages between the different subsystems has been grouped together in another subsystem called the Production Supervising system.

The main functions of the Production Supervising system are:

1. To supervise production, i.e., to set new reference values for the Process Control system, and to start grade changes at the proper time.
2. To identify and store collected process and quality data.
3. Supplies input information for the printing of management reports.

The first function determines suitable settings for important process variables such as moisture content, basis weight and machine speed based on given specifications for each grade. New reference values are fed into the process control system in due time before a grade change, and the change is initiated at the correct time and in a suitable sequence, starting with the refiners and ending with the drying section.

The objectives for the identifying function are closely related to the fact that the desired quality control system requested a complete identification of each individual roll, i.e., information about how the reels were cut into rolls including the corresponding order identification number. This was also desired for production reporting purposes.

It was determined to let the computer determine how the paper should be produced, rolled into reels and how the reels should be cut into rolls at rewinding. The computer also assigns order identification to each produced roll. All this information is printed out to the winding crew. The crew operates according to this information or, when it is necessary to operate in a different way, inform the computer system about the changes.

In the following description of the supervising system, the grade change routines are discussed first, and then the normal supervising functions during the production of one grade.

GRADE CHANGES

At a grade change, the production supervising system performs most of the identifying work by forming the supervising tables for the new grade. The new reference values are calculated and the actual grade change is initiated in the process. Three different grade change programs are used for this purpose.

Normally, grade change program 1 is called when there are about two-and-a-half sets of one grade left to produce. From tables supplied by production planning, information about the next planned grade is collected. The machine tender is then informed when the grade change will take place and of the specifications of the next grade. He is also asked to accept the new grade within a specified time. He accepts the new grade by turning on a switch on his Sense Switch Unit. If he does not accept the new grade within the specified time, a message is printed out and grade change program 1 is called once more. Grade specifications for another grade are then printed out and acceptance of the new grade is requested. This may continue until acceptance is given or until the grade under production is finished. If no acceptance is given at that time, the supervising programs are disconnected and a message about this is printed out to the machine tender.

When the new grade has been accepted, grade change program 2 will be called about 12 minutes before the present grade is finished. This program forms the important supervising tables. Two tables are produced. One, the supervising head sector table, contains grade specifications, information about the orders that are included in the grade and other general information. The other, the set table, contains the following information:

1. Set identification.
2. Section number and length.
3. Set length.
4. Roll distribution of the set.

The following information is supplied as the production of the grade proceeds and quality data is entered:

1. Date, start time and end time.
2. Sorted rolls in the set.
3. Mean value of basis weight and moisture content for the set.
4. Quality data from reel and set tests.
5. Process and production data.

A message is printed to the machine tender specifying the orders and order positions included in the group. From the grade specifications in the tables, the program then calculates new reference values for the process control programs. Some of these new values are also written out together with the latest measured values of the same variables. This indicates the approximate change in the running conditions. Finally, grade change program 2 will initiate the process control programs to start the grade change in the refiners.

The changes in the remaining part of the process are not started before the bank tender turns off the sheet length meter and thus indicates that the grade is finished. Then grade change program 3 is called. The reference values for the new grade are transferred to the process control programs and the grade change on the paper machine is initiated. When the machine tender finds that the paper has reached the new specifications, the sheet length meter is turned on and the reel must be changed. The grade change is then completed and production of the first set in the new group starts.

NORMAL SUPERVISING FUNCTIONS

During the production of one grade, the supervising programs follow the production of each set by reading the sheet length meter. Paper produced when the sheet length meter is off is considered off-grade paper.

At reel change, process data is collected. An important function of the reel change program is the collection of basis weight and moisture content data which is used for calibrating the instruments. These are placed in the set table. Finally, the number of sets on the next reel is calculated and printed out to the machine tender.

Some time during the production of the last set on the reel, the back-tender demands a printout about how the reel will be divided into rolls.

SHEET LENGTH METER INTERRUPT

The sheet length meter is a most important instrument for the supervising system. It is with this instrument that the production is measured. Only the paper produced when the sheet length meter is on is considered on-grade paper. Paper produced when it is off is considered off-grade paper. An interrupt signal is initiated each time the meter is turned on or off.

The program called for when the interrupt signal occurs always updates the total length of the paper on the reel and the length of the grade paper on the reel. Each time the meter is turned on, a process data collection program calculates the length of time it has been off.

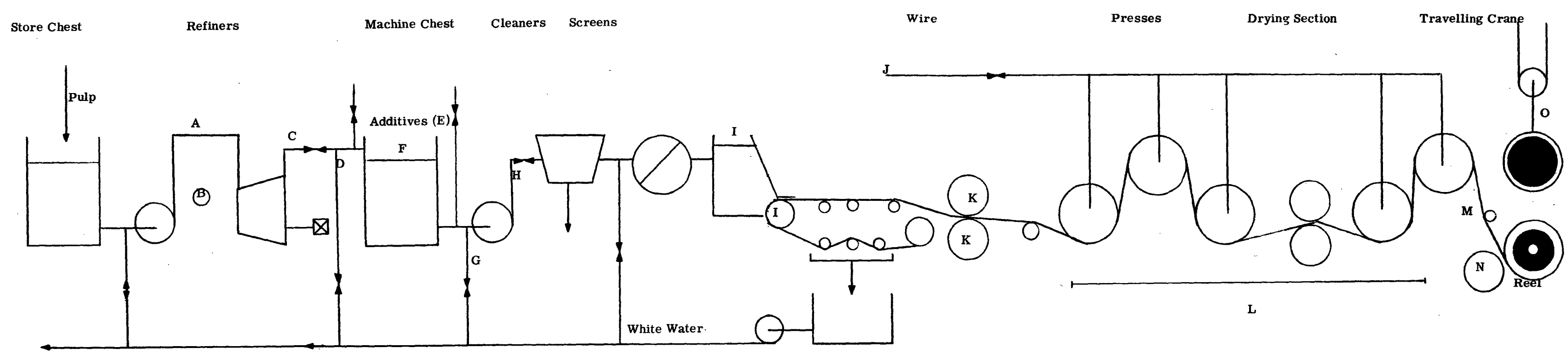
The program identifies the reasons for disconnecting the meter. These include grade change, sheet break, paper machine stop and off grade production. This information is used for management reports.

When the sheet length meter is turned off at the end of a grade, a special data collection program will organize and store production and consumption data gathered during the production of the grade just finished for use in the reports.

ADJUSTMENT OF SET LENGTH

Many customers specify certain roll diameters in their orders. From the roll diameter, production planning calculates the set length, using a certain value for the apparent bulk or thickness of the sheet. This value varies, however, and to obtain a correct roll diameter despite the variation in thickness, the apparent thickness is measured on-line and the set length is adjusted according to the measurement.

The method for measuring the apparent thickness is as follows. During the production, when the reel has reached a certain diameter, an interrupt occurs and the sheet length on the reel is determined and stored in the computer. Some time later the reel reaches a new specified diameter and a new interrupt occurs. The sheet length on the second reel is determined and the apparent thickness of the sheet is calculated by equating the area determined as length of sheet times apparent thickness and the area between the two specified diameters.



A. Stock consistency before the refiners
B. Refining power
C. Stock flow through refiners
D. Flows of dilution water
E. Flows of additives
F. Level in machine chest
G. Flow of dilution water
H. Thick stock consistency; Thick stock flow
I. Headbox level
J. Total steam flow, temp., pressure
K. Pressure; Speeds
L. Cylinder steam pressure; Cylinder speed
M. Basis weight; moisture; paper length; width of the reel
N. Speed at the reel
O. Weight of the reel

THE CONTROLLED PROCESS WITH THE PRINCIPAL VARIABLES.

Actually, there are three different diameters on the reel that gives interrupts. If a sheet break occurs, or off-grade paper is produced between two of the interrupts, the calculation of the sheet thickness between those two diameters is bypassed. Exponential smoothing of the calculated values is used to minimize the influence of random measurement errors.

MANAGEMENT REPORTS

Two reports are printed in the computer room at Gruvon on demand from an operator:

1. The rejection report.
2. The daily report.

The rejection report gives a list of all the rejected rolls. For each roll the most important quality properties are printed together with the reason for rejection. The latter is given as a code number.

The daily report gives management an overall view of production and paper quality during the last 24 hours. Quality data determined at the end of each reel is printed as curves showing the variation about fixed values, Each grade starts with a line giving start time for the grade, the time for changing grade, ordered basis weight and, if it is extensible paper, the desired tensile stretch value in the machine direction. At the end of each grade, the mean value of the basis weight is printed out together with the standard deviation.

At the end of the report, information is given about the total amount of on-grade and off-grade paper produced during the period. Total stop time and the time for sheet breaks are given, and finally, the different sheet breaks are listed separately.

Other reports to management are printed out at the Billerud data center in Saffle. The supervising tables will, on demand, be punched on cards which will be transferred to the data center.

A special program collects quality data from the tables for any specified order position and prints out the data. Tensile stretch and tensile strength are printed for each roll in the set. Other properties of the sheet are measured at the end of each reel and these values are printed out only for the last set on the reel. Mean values and standard deviations for the different properties are also given in the table.

Sufficient data is collected in the supervising tables for printing out a monthly report. This will present the efficiency of the paper machine and a survey of production during the last month. Consumption data for electricity, steam and some chemicals are also included in the monthly report.

Quality data in the supervising tables is used to update the statistical models used in quality control for estimating purposes, and the process data is used for optimizing the running condition of the paper machine.

PROCESS CONTROL

Control Objectives

On paper machine number four, the objective is to produce the maximum amount of paper during the available time while consuming minimum amounts of raw material and energy and maintaining acceptable quality. The production rate is limited by the physical constraints of the plant and by pulp availability. Moreover, production is reduced because of time lost due to rejected off-grade production or paper breaks.

High average production rates require that:

1. The process be run as uniformly as possible during the production of a given grade of paper. The advantages of uniform operation include the following:
   a) plant operation near the upper capacity limit.
   b) production of uniform-quality paper.
   c) reduced paper-break risks.
   d) average moisture content can be increased to obtain a higher paper yield per ton of pulp.
2. Grade changes be executed in a short time, but without breaks.
3. The process be efficiently controlled when emergency conditions prevail during paper breaks; for example, in order to restore on-grade production as soon as possible.

MACHINE TENDER OPERATING SWITCH UNIT. SWITCH UNIT AND PRINTER PLACED IN THE MACHINE TENDER'S BOOTH AND ARE USED TO COMMUNICATE WITH THE COMPUTER.

The purpose of the control system is to attain the above objectives by automatic control action and by assisting the machine tender in the execution of manual operations when required.

The Process

The PM4 is a Fourdrimier machine which produces kraft paper at an average rate of 50,000 tons per year. Sack paper with a basis weight ranging from 60 to 140 grams per square meter is produced; for the most part it is unbleached, but semibleached and fully bleached grades are also produced. The speed of the machine varies from 200 to 370 meters a minute. The trim width is approximately 5.3 meters.

The computer-controlled process starts at the pulp storage chest ahead of the refiners and ends at the reel of finished paper.

Paper must be produced within given specifications. These include basis weight, moisture content, resistance to passage of air, tensile strength characteristics, etc. To meet these specifications, certain process variables have to be controlled. The basis weight is determined by controlling the fiber flow and the machine speed. Fiber flow control is obtained by controlling the stock consistency and the stock flow after the machine chest. The moisture content can be controlled by adjusting the temperature (using steam pressure) of the drier cylinders. The porosity and the tensile strength characteristics depend on variables such as refining, formation additives, etc. The principal refining variables are refiner flows and the consistency of stock flowing through the refiners, refiner power and a refining index function of couch vacuum. Formation depends on the consistency in the headbox and the difference between the speed in the slice and the wire speed. The speed in the slice depends on the level in the headbox.

Process control includes more than automatic operations. One must also consider the action taken by the machine tender which, in spite of automation, remains a fundamental part of the process control. The machine tender and the control system collaborate to run the process. Their contributions are complementary. This can be better understood by examining the flow of information between elements having a role in process control: the computer, the machine tender, the instrumentation and the process itself.

Computer control action proceeds via analog controller set-points or, more directly, via valve-drivers or other electric actuators. Computer control action is based on information from:

1. Production supervising program (recommended reference values of variables).
2. Process (actual value of process variables, on/off status of devices, etc.) via on-line sensors.
3. Machine tender (reference value modifications) mainly via binary switch unit.

Machine tender action proceeds via analog controller set-points, motor switches, manually-operated valves, etc. Machine tender action is based on information from:

1. The process, via panel instruments or direct observation.
2. The computer (process data, alarm conditions, notice of automatic operations) via print out or lamp signals.

Before discussing automatic control, a few words on the flow of information from computer to machine tender are in order. This information is supplied in the form of print-out messages or lamp signals. Messages are issued via a printer in the machine tender booth near the wet end of the paper machine. Lamp signals are issued via indicator lamps or legible lighted displays on the instrument panels.

In print-out messages, the use of symbols or special codes is avoided as far as possible. A message may contain one or more of the following types of information:

1. Value of a process variable, if a print-out has been requested by the machine tender. There is no data logging on the machine tender printer.

2. Alarm, for abnormal process conditions, malfunction of instruments, etc. Alarm messages are usually printed in red.

3. Operator-guide recommendations, to carry out manual adjustments on the process.

4. Notice of automatic control actions which are either under way or soon to be executed.

All lamp signals indicate alarm. Their use is restricted to urgent situations which must be brought to the attention of the machine tender or to machine crew members who do not work in the vicinity of the machine tender printer.

Automatic Control

The ultimate objective of process control during production of a given grade of paper is to keep the production rate and product specifications close to the values prescribed by the production supervising system. This is achieved mainly by closed-loop control of process variables.

Control action is based mainly on feed-back signals, i.e., on on-line measurements of the controlled variable itself or on other related variables from which the actual value of the controlled variable can be calculated. Loops can be single or cascade.

Control of Basis Weight

Readings of on-line basis weight and moisture gages are filtered (exponential smoothing) and used to estimate the actual basis weight of the dry paper. The reference value is supplied by production supervising programs but may be modified by the machine tender. Control action is taken on the set-point of the controller of thick stock flow.

The conversion function for basis weight is calibrated approximately every hour at the completion of each reel with reference to measurements of reel weight, paper width and length.

Control of Moisture Content

In controlling the moisture content, there are two alternatives: analog or digital control.

Analog control is accomplished by an analog controller connected to the moisture gage which governs the set-point of the steam pressure controller in the drier section. This is a typical case of cascade control.

For digital control, the set-point of the steam pressure controller is governed by the computer instead. Readings from the moisture gage are filtered (exponential smoothing) and used to estimate the actual value. The reference value is supplied by the production supervising program but may be modified by the machine tender. Control of steam pressures can be considered as a complement to moisture control. Reference values for these pressures are given by the production supervising program but are automatically changed if necessary to keep the pressure within limits suitable for control. Changes are executed with respect to certain constraints (pressure differences between sections and top limits) and to a suitable temperature gradient along the machine.

Control of Level in the Headbox

Since the headbox is of the open type, the level in the box determines the speed of the thin stock at the slice. The level must be kept constant to ensure a given difference in speed between the stock at the slice and on the wire. This difference influences the tensile strength properties. The reference value for headbox level is calculated from the desired value of the speed difference that is entered by the machine tender. Control action is taken on the set-point of an analog level controller.

Control of the Degree of Refining

Specific refining energy is used as a measure of the degree of refining. This is calculated as the ratio between the power input to the refiners. The reference value for the specific refining energy is supplied by the production supervising program and can be modified either manually by the machine tender or automatically from an external feedback control loop. The deviation of the calculated specific energy from the reference value is used to adjust the desired value of the total refining power.

Paper Breaks

A paper break is detected immediately by photoelectric sensors distributed along the paper machine, and an emergency routine is initiated. Steam pressures in the drier cylinders are lowered and programs for control of basis weight and moisture content are temporarily inhibited. Other control loops continue in the normal way. When the paper web is restored, steam pressures in the variout sections are automatically brought back to pre-break levels, and normal control programs for basis weight and moisture content are re-activated.

Other Controls

In addition to the above controls, consistency of stock is controlled at three points. The level in the machine chest and is also controlled as is the addition of alum, rosin and sulphuric acid. Grade change control has been discussed above.

QUALITY CONTROL

Samples of paper are taken at the end of the reel (reel samples) and at the end of each roll-set (winder samples). (All of the rolls slit side-by-side from a single length of reel paper are called a roll-set.) The samples are sent to the Billeruds laboratory where quality test data is obtained. This data is then fed into the computer system via a manual entry unit located in the laboratory.

Quality control has two functions: (a) to issue information to the machine tender which will help him to control the paper machine; (b) to determine whether the produced paper is within the given specifications and can be delivered to the customer or whether it must be rejected.

The first function is based mainly on test data from reel samples. Information about important quality data is printed out to the machine tender when all the reel-sample test data has been fed in.

The second function, sorting, is based mainly on data from winder samples. Two options are included in the system. The sorting can be done either in manual or in automatic mode. In the manual mode the estimated values are printed out to the shift foreman who has to determine whether the paper is within the given specification. When the shift foreman wants to reject a roll, the computer checks whether all variables are within the customer's specification.

Information about rejected rolls is printed out to the winding crew. The shift foreman can override previous automatic or manual sorting.

All collected quality data and information about sorting are stored on discs. This data is administered by the production supervising system. The stored data may subsequently be transferred to cards for further processing on other computer systems if the operator so requests.

RESULTS AND FUTURE PLANS

The greatest process control profits are expected to stem from the improved settings of key process variables, i.e., from process optimization resulting in improved quality and increased production. The integrated system is expected to provide additional savings. The fact that the computer system has been able to take over many functions previously performed manually and to do them equally well is an important step toward a fully automated plant.

Another factor on which success depends was the acceptance of the computer system by the machine crews. Crews were retrained and were kept informed as the project developed. This, as the system became operational trained personnel were on hand to operate the equipment.

Calculations illustrating the profitability of the system have been omitted because of the relatively short period during which the system has been operational.

Some new attitudes were acquired toward the problem of intercommunication between personnel and computer. At the outset, it was expected that these exchanges would be very limited. However, experience showed that there is a need for frequent personnel/computer intercommunication and that it would be facilitated by a more extensive machine tender console.