Process Control — Emergent Source of Economic Development and Social Welfare

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1. Brazil, Nineteen-Eighties

The keyword of this conference, Brazil in Nineteen-Eighties, does not imply prognostications, such as have of late become so fashionable in science fiction; nor does it imply projections in the more serious economic or sociological style. Yet it implies the future as a subject about which knowledge can be acquired, with various degrees of confidence.

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Interestingly, this foreseen knowledge tends to invalidate itself. From this tendency, of the knowledge of the future to contain the seeds of its own invalidation, once exposed, derives the practical significance of this conference. That is, in this context the importance of knowing the future rests in the capacity to influence and modify by planning and budgeting anticipated future courses of events.

Now, the future of Brazil is not discussed here as such, nor do we speculate about the future state of its social or industrial organization. These lectures, rather, merely indicate an emergent mode of technological organization and industrial management. It is left to us to ponder its implications and reason out whether some of the new ways of producing goods and services could possibly be also applied here.

But why should our improving modes of production be modified? The reasons are well-known: so that the gloomy pictures painted by economists or sociologists for Brazil in the year 2000 shall not become true; so as to prevent the relative decline in the social and individual welfare that is inevitably foreseen on the basis of the disheartening projections of per capita gross national product. The ways in which this can be attained are numerous, and they have been extensively discussed in the literature. The way here suggested is to redirect the course of our economic development from, simply, mechanization toward a state of industrial organization characterized by the word *automation*.

Therefore, the purpose of this conference is to explain the meaning of automation, and its manifestations in process control. The conference does not describe Brazil as it is anticipated to become in ten years hence or so, but rather as it could emerge if we all try, and try hard. And if we do, then the gloomy predictions for the year 2000 and the depressing projections of the volume of national production will also be modified. The first step in this direction is to recognize that the computer or automation is not something beyond our reach. This attitude, too, is sought in this conference. It can be attained by the *thorough knowledge* of the subject, in all its aspects.

For this reason, the subject of process control is divided into two major parts. The first part is concerned with scientific and technological aspects of the new phenomenon, and the second part with its administrative and managerial aspects. In the former sense, as science or technology, process control embraces problems of logic and mathematics, and
questions of engineering and equipment. In the latter sense, as a management subject, current and potential applications of process control must be explored, and its economic implications, questions of profit or loss, must be evaluated.

2. Technological View

A new source of economic development and social welfare has been emerging during the last decade in the United States and other developed countries. This phenomenon, a technology and science of its own kind, is called process control. It has a dual nature: it is a set of ideational entities, that is, logico-mathematical theories and algorithms; and at the same time it is a set of physical devices, electronic computers, electronic and electro-mechanical servo mechanisms, and other automata.

Process control is also bound to affect, sooner or later, Brazil; and some indications thereof have, indeed, already been appearing here and there in the country. Hence, business or industrial leaders and educators of business administration should understand its scientific and technological meaning. They should also understand the actual and potential applications of the new phenomenon, and its economic implications.

To convey some of this understanding is the objective of the two parts of this paper.

2.1. Automation

2.1.1. Introductory Definition

As a working definition, process control is understood to be the direction or control of physical or other processes with the objective of obtaining from them optimal results. Such control takes place, ideally at least, in real time, simultaneously with the occurrence in reality of the related events. It must therefore be exercised with the aid of real-time electronic computers.

The operating principle of process control is closed loop: feedback from the system of data sensed by automatic sensing devices (Figure 1), or feedforward of sensed data that has as yet not affected the system (Figure 2). What is ultimately desired is a cybernetic system, a system that is self-directing in accordance with preestablished criteria. In such a system, the sensed readings control the future course of the process
Figure 1: Feedback

CONTROLLER

PROCESS

Data Flow

Control Flow

Physical Flow

Input

Output
Figure 2: Feedforward

Data Flow

Control Flow

Physical Flow
Figure 3: Cybernetic System

- Controller
- Feedback
- Feedforward
- Input
- Output
- Data Flow
- Control Flow
- Physical Flow

PROCESS CONTROL
Figure 4: Interactive Control System
From JOHNSON, C. I. Interactive Graphics in Data Processing. IBM Systems Journal, v. 7, ns. 3, 4
1968, 167

Host Computer

Operating System

Host State
Controller

Analysis

Communication
Routines

Data Base

Associative Data
Structure
Manager

Data Structure
Management

Host State
Controller

Communication
Routines

Graphics Computer

Display Data
Structure

Image-
Generation
Routines

Geometry
Package

Data Structure
Update and
Fetch Routines

Graphic State
Controller

Transient
Routine Loader

Attention
Handler

Data Datatate

Data Flow

Control Flow

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fully automatically (Figure 3). Until and unless a system is self-directing, it cannot be said to be automated. Thus automation or cybernetics means self-direction, while without self-direction there is merely mechanization.

But fully automatic process control is not always feasible, if the process cannot be defined in full detail along its entire course. In such cases, interactive computing (known also as conversational computing or conversational graphics) may be employed to obtain a high degree of automation. This technique employs devices capable of displaying instantaneously, data or information obtained at various stages of the process. They are also capable of receiving commands by which to redirect the process in progress. For the displays, cathode-ray tubes (television screens) are used; and for the process redirection, light pens are applied to the television screens (Figure 4).

2.12. Formal Statement

The dialog that has been brought about by computing and electronics between the world of technology and the world of business management requires that business or industrial executives should also know something about the logico-mathematical foundations of the new phenomenon. One reason for this is that symbols used in the mathematical treatment of process control, constants or variables, stand for physical or economic quantities of the real world.

Mathematical functions that relate these symbols or transform them from one logical array into another lead to the insight into management problems or generation of new information, which is used for management purposes. The functions represent devices of various categories by which the real quantities are transformed from one physical state into another, and consequently the flow of real-world variables can be controlled.

The general objective of such control is, in formal terms, to optimize some objective function over a specified period of time.

For example,

when the objective is optimal profit \( \int_{0}^{T} f(u(t))dt \) is maximized\(^1\) over a period T, starting at the initial time, 0; or

when the objective is optimal traffic, 
\[ \sum_j \int_0^T q_j(t)dt \]
is minimized,² where \( q_j(t) \) is the length of the queue at any of the system's intersections.

In the case of profit optimization, as stated above, it is necessary to maximize some function of adjustments, \( u \), of some variable quantity, that particular quantity which is under control. These adjustments are brought about by changes in another variable, \( m \), called the manipulated variable (or variables). The function, \( \phi \), applied to the changes in the manipulated variable, is called the control law; so that the manipulated variable is a parameter in the control law. Changes in the manipulated variable, in turn, are a function of a variance between the actual or observed measure of the controlled quantity on the one hand, and its ideal, theoretical, or desired value, on the other hand. Hence,

\[
\text{OBJECTIVE} = \int_0^T f(u(t))dt \quad \text{MAXIMUM}
\]
\[
u(t) = \phi(\Delta m(t)),
\]
\[
\Delta m(t) = \phi(v(t)),
\]
\[
v(t) = a(t) - b \quad \text{MINIMUM}.
\]

That is, the working objective of a process control system is to keep the variance between the desired and observed values as small as possible.

Sometimes even the desired value of the controlled quantity itself is treated as a variable rather than a constant; or, which amounts to the same thing, the control law may vary. If so, an adaptive-control system comes into being, in which an external adaptive loop is superimposed over an internal process-control loop (Figure 5).

2.1.3. Example from Cubatão

Now, an example will be useful, perhaps from the petroleum industry. There is in Cubatão, São Paulo, an automatically controlled unit within the refining installation of the Petrobrás. The general objective of the system is to produce a maximum of a certain product mix — benzene, tuluene, and xilene — within a certain quality range. This is, in this case, the objective function. This function is maximized, among other

Figure 5: Adaptive Control

PROCESS CONTROL
things, by maintaining the flow from tanks to the tower of a petroleum distillate at a certain optimal rate, which is the desired or ideal value, be.

The flow of distillate must therefore be adjusted whenever the actual rate has departed or tends to depart from this preestablished level. The successive adjustments are a function of a change in a gate opening, a diameter of an orifice within the pipe. This function is the control law of this example, while the diameter is the manipulated variable. The change in the orifice, brought about by mechanisms called actuators, is a function of the difference between the desired flow rate and the rate actually measured, $a$. To minimize this difference, $v = b - a(t)$, is the working objective of the system. Again,

$$0 := \int_0^T f(u(t))dt \quad B, T, X = \text{OPTIMUM}$$

where $B = \text{Benzene},$

$T = \text{Tuluene},$

$X = \text{Xilene}.$

$u(t) = \text{Adjustment of Flow Rate, such that}$

$u(t) = \phi(\Delta m(t)),$

$m = \text{Orifice Diameter, and}$

$\phi = \text{Control Law}.$

$\Delta m(t) = \phi(v(t)),$

$v(t) = b - a(t),$

$b = \text{Optimal Rate of Petroleum Flow, and}$

$a(t) = \text{Actual Rate of Petroleum Flow}.$

2.2. Theory

2.2.1. Stochastic Control Theory

Mechanisms of process control rest, in the final analysis, on the stochastic control theory. The theory is concerned, as the name indicates, with stochastic, that is, conjectural or statistical variables. They are the dynamic factors of the business or industrial life, dynamic because acted upon by forces. Thus they change in time, with random fluctuations or *noise* superimposed on them. They flow literally or figuratively through lines channels (and Karl Menger called them "fluents"), and their flow may
be fully or partially subject to management control. Hence the term *fluid dynamics* introduces itself into business administration as another contribution of physics or engineering to its conceptual wealth.

Control of random variables or the dynamic "fluents" is accomplished, generally speaking, on the basis of *two categories of algorithms*: of these, one group is concerned with process identification, and the other with process optimization.

### 2.2.2. Process Identification

The problem of process identification is essential, and its solution leads eventually to the construction of a process model. There are two general categories of models: the initial approach was to create *ordinal descriptions* of a process; but the most recent research is concentrated on *neighborhood descriptions*, or Markov chains. There are also combinations of ordinal and neighborhood descriptions.

In the ordinal sense the process is identified along its entire course as a straight line or curve of some sort. The line or the curve may be a function of time or some other independent variable. In the Markovian sense, on the other hand, the identification is expressed as after effects of the first, second, or *n*-th predecessor within a sequence of segments.

Process modelling consists, essentially, of averaging of some kind or another: the average value may be a constant, a linear function, or a curvilinear function. These functions are produced by (Gaussian) least-square errors criteria, or (R. A. Fisher's) criteria of maximum likelihood. Some systems use combinations of Gaussian and Fisherian techniques; others use stepwise linear regressions, time-integrated versions of regression analysis, curvo-linear regressions, and so on.

### 2.2.3. Process Optimization

Process optimization, on the other hand, leads to optimal utilization of available resources. These resources, of an *identified* process, are controlled under specified contraints. It is necessary, in other words, to devise an optimal strategy by which to obtain different combinations of input factors, so as to optimize the objective function.

For this various elaborations of linear programming are available. They may also be applied to nonlinear cases by the simple expedient
of linearizing them: for example, by dividing an overall program into subregions, or by deriving linear partial derivatives of quadratic relationships.

In the nonlinear category increasing use is being made of dynamic programming, treating variation problems as multistage decision processes (repeated decisions to yield a sequence of state vectors representing the states of a physical system). Other methods use Lagrange multiplier devices; Monte Carlo and similar methods are employed to understand a problem without providing its solution; or, as another example, constraints of an optimized problem may be temporarily set aside.

2.2.4. Characterization

In a word, process identification reflects the working objective of the process, and is characterized by least-squares analyses. Process organization, on the other hand, reflects its general objective, and is characterized by linear programming. In the past, process identification was essentially an ordinal proposition, but in the future increasing use is expected of sequential models. Similarly, whereas in the past process identification was based mainly on linear programming, an area for future research is seen in dynamic programming. An affinity between the Markovian analysis and dynamic programming has been acknowledged in the literature.3

2.3. Engineering

2.3.1. Hardware

There is, of course, also an engineering view of process control, which must here be treated with extreme brevity. That is, inputs and outputs of the controlled system are sensed by transducers (Figure 6). They generate signals that are conveyed by coaxial cables to physically separated computers. The transducer output is converted from analog to digital signals, so that it can be handled by the central processing unit of the computer. Multiplexers, large electronic switches, permit direct communication of a computer to another device with a number of input or output channels.

Hence quality-control system using 100 terminals have been in operation for more than two years; and multiplexers of 200-terminal capacity, reported under development some time ago, have probably by now been installed. The working storage (core memory) of the central processing unit may range from 40,000 to 400,000 characters; and the system should have an extensive disk storage, up to a few million characters, as required in extensive computer-operated manufacturing and testing systems.

**Figure 6: Typical Input and Output Channels**

- **Input Channel**
  - Video Display

- **Output Channel**
  - Open Loop Control
    - Closed-Loop Control
    - Multiplexing
      - Actuators
        - Set-Point Adjustment
The digital computer output is then converted into analog form and transmitted back to the process under control. The signals affect actuators, such as positioning valves or plugs, by which finally the desired position is imparted on the process itself. And thus the control loop has, again, been closed.

2.3.2. Interaction

A few words should also be said about the most recent nonanalytical control techniques of the interactive category. Some came into being, literally, within the last few months while others are still in the process of being created. These developments should be closely followed by business executives, because of their extraordinary promise as tools of business management.

With interactive graphics complex processes can be displayed on television screens, in the most simple case as point readings, the underlying curve shapes being approximated by connecting, with light pens, short-line segments of the plotted data. At the same time rapid computations by computers can derive functional identification of these curves or processes (with algorithms such as parametric cubics or rational polynomials).

A special feature of such modern display-oriented devices is the ability to produce, by print or photography (reprography) process history for review and analysis. The data may be continuously displayed as alphanumeric characters (numbers or formulas) or other images for which canonical forms are available. The other images include geometrical entities and entities not thought of as geometrical. In the nongeometrical category are plots of functions, polygons, histograms, scatter diagrams, flow diagrams, and as the most recent development, holograms.

Holograms present three-dimensional pictures on two-dimensional screens (as initiated in 1937 by Gabor for x-rays but made more recently operational with laser beams). They have been used recently in the petroleum industry to create three-dimensional pictures of earth structures, thus enabling gas and oil researchers to visualize subsurface configurations.

Now that the various formal and technological aspects of process control have been explored and understood, its administrative and management aspects can be treated and well-appreciated.
3. Management View

3.1. Applications in Manufacturing

3.1.1. Categories

Currently, thirty-five hundred fully automated process-control installations are in operation in the United States. Four distinct categories have been emerging with, generally speaking, typical logical and operating characteristics of their own: process control for manufacturing industries, traffic and transportation, scientific laboratory, and business administration.

The majority of the installations falls into the first category, of production, of which two thirds are in industries characterized by a continuous process or some sort of hand-off control. Here belong petroleum and gas industries, pioneers of process-control automation. Five categories of applications have been developed: exploration, oil-field or gas-field operation, refining, transportation, and distribution.

Another group consists of chemical, paper, glass, cement, textile, and rubber industries. The control functions here include product mix, kiln or furnace operations, and various categories of finishing operations. Early in 1967, for example, control of a few basic functions of a kraft paper machine, in a Swedish plant, was reported as the most successful installation of this type to that date (Figure 7).

Yet another group contains electrical utilities, steam and power generation, including nuclear-power plants; while the fourth group includes metallurgy and steelmaking, and nonferrous metal industries.

However, in heavy industries characterized by fabrication, assembly, and large labor forces, applications of closed-loop control have been rather limited. The reason for this is mainly the lack of automatic sensors, so that human process sensing cannot be avoided. But this is expected to change before long with the new economic and technical possibilities created by the latest types of servo mechanisms and third-generation computers.

3.1.2. Petroleum Industry

A few examples will illustrate in broad-brush terms the progress of the last decade or so within the petroleum industry. For field operations and guidance of drilling procedures, computers are used for data acquisition and analysis, with teletype terminals and voice-grade telephone (Union
Oil of California, 1969, for tens of thousands of wells as remote as hundreds or even thousands of miles). Mathematical models were developed to shape optimal field-development policies and minimize cost of production-handling equipment (Groeningen gasfields, 1969).

Again, more than ten years ago automatic control of petroleum liquids fractionation columns was introduced (Phillips Petroleum), as well as production of styrene from the catalytic dehydrogenation of ethyl benzene (Dow Chemicals). Mathematical models were announced for vinyl-chlorid (B. F. Goodrich) and polymerization (The Texas Company) processes. The first automated catalytic control system dates back to 1961, for a 60,000 bbl-per-day operation (Philadelphia refinery of Gulf Oil), while in 1962 there was started an on-line closed-loop control of a 85,000 bbl-per-day three-stage crude oil distillation (DX Sunray Oil Company, Tulsa, Oklahoma).

In the meantime, control of pipelines with microwave-communication channels has become wide spread (1961, a 14-station and 931-mile crude-oil pipeline of Mid-Valley Pipeline Company of Longview, Texas); adaptive-control techniques have been applied for gas distribution to limit peak-load demand (Public Service Company of Colorado).

The API (American Petroleum Institute) also indicates an accelerated tendency toward pipeline automation, for petroleum and petroleum products (the controlled functions rose from 6,622 at the end of 1964 to 13,370 at the end of 1969); from a sample of 76 systems (in April, 1969), 24 were 90% automated.

And at Fawley (near Southampton, England), computers of an Esso's refinery control virtually all fuel production (through primary plant variables such as temperatures, levels, pressures, or flows, sending instructions directly to over 400 control valves), together with administrative functions such as production and inventory accounting. In a word, automation today embraces the entire spectrum of petroleum or gas industry.

32. Applications for Traffic and Transportation

32.1. Automobile Traffic

The second category of applications is concerned with traffic management, to synchronize traffic signals in an arbitrarily connected network. They
operate on mathematical models derived from data obtained directly from traffic sensors located in the pavements, or from data sensed by radar. Their purpose is to devise optimal control strategies: patterns of green-and-red-light periods within the network and, of course, automatic control of the lights.

Such systems have been installed or are being installed in about a dozen American cities, in Canada, and in Europe. There remain some mathematical problems to be solved, but nonetheless computer control is anticipated to emerge within one or two decades as the dominant mode of traffic management on North American highways and byways (Figure 8).

Figure 8: Traffic Lights Under Computer Control in downtown San Jose, California

3.2.2. Transportation Variants

The principle of automobile-traffic control has been recently extended to railroad transportation. Programs have been written in terms of stations, train schedules, costs, requirements, and, availabilities. The problem is common to other areas and modes of transportation, such as bargeline operations and warehousing.

Now, here is a good opportunity to demonstrate how analogy becomes a source of creativity. Once, a petroleum engineer and a traffic engineer, observing the flow of cars at a busy intersection of a Floridian metropolis, came to the conclusion that their problems were essentially the same. Hence, the concept of controlling the flow of petroleum through pipelines was generalized and further elaborated, until finally the concept of controlling the flow of cars through metropolitan arteries arose.

From traffic control the logical path leads to railroad transportation, and from train schedules there is but a short step to barge schedules. Interestingly enough, from barge schedules the path leads to the tanker fleet of the Brazilian petroleum industry. That is, a variant of process control application has been created by operations researchers of the Petrobrás, to guide movements of the ships to points of optimal destination (Figure 9).

3.3. Applications for Scientific Experiments

3.3.1. Nuclear Physics

The latest category of process control applications is for laboratory automation, which has been made possible with the advent of interactive computing. Interactive terminals are used by experimenters to monitor processes the detail courses of which cannot be anticipated, and to modify experiments in progress.

Nuclear physicists have, from necessity, been among the first to use computers in their scientific explorations. At the Yale University’s Wright Nuclear Structure Laboratory, the graphics terminal for low-energy nuclear-physics data acquisition is capable of plotting 200,000 points per second with variable intensity; at the Bell-Rutgers nuclear physics laboratory it is used for all experiments run on an accelerator; and at CERN (European Organization for Nuclear Research), for processing bubble-chamber data in the laboratory of high energy nuclear physics.
Figure 9: Source of Creativity

FROM THE GULF OF MEXICO TO BRAZILIAN COAST

\[ \text{Petroleum Flow Control} \]
\[ \downarrow \]
\[ \text{Traffic Control} \]
\[ \downarrow \]
\[ \text{Train Schedules} \]
\[ \downarrow \]
\[ \text{Barge Operations} \]
\[ \downarrow \]

Petroleum Tanker Fleet of Petrobrás
3.32. Other Sciences

Again, life scientists at the California Institute of Technology use the computer to analyse functional behavior of neural systems; while in chemistry or solid state physics, experiments with interactive graphics present currently great expectations, mainly in x-ray diffraction and fluorescence, kinetics of chemical reaction, lens testing, electron paramagnetic resonance spectroscopy, nuclear magnetic resonance, or chromatography.

3.4. Applications for Business Administration

3.4.1. Management Control Center

But the greatest promise exists in applications of process control for administrative functions and management decisions. Many routine operations and middle-management decisions can be redefined in mathematical terms and delegated to computers. So striking have been the promise and the initial payoffs that in the early sixties predictions were made that "by 1970 nearly all electronic data processing systems will be of an on-line-real time variety." 4

Meanwhile, two distinct categories of effort are observed: of these, one is concerned with data acquisition, information retrieval, and coordination of different categories of operations; while the other stream of endeavors leads toward automation of operational planning and budgetary control.

3.4.2. Information and Coordination

For data acquisition, administrative terminals have been developed to cope with file maintenance at frequent intervals or in real time. Order tracking, expedition, and control is another example. This system serves the purpose of effort coordination: it monitors the progress status of an order or a number of orders for a customer through the various stages of manufacture, until completion and delivery. One wonders whether, as another creative analogy, the numerous phases of a major developmental undertaking could be treated in the same manner as the various orders of a customer. In other words, the question that comes to mind is that of generalizing and adapting order tracking so as to control such projects as construction of a new refinery or a new pipeline.

In this category belongs also economic dispatching. It consists of assigning work loads to individual production units, so that the overall operating costs are minimized. Sometimes called dynamic dispatching, such a system leads to routine decisions based on order specifications, machine queues, setups, efficiencies, or availabilities.

3.4.3. Planning and Budgeting

The most interesting in this context are applications for operational planning and budgetary control, because they tend to integrate business administration and industrial operations into one total system. The various functions of budgetary control may be performed, at reduced cost, on a continuous basis. It is felt that management information requirements of larger organizations cannot be met by batch-processing methods. Rather, data processing and evaluation should take place in short intervals, their length depending on the nature of the business and the budgetary system.

Despite the predictions, these applications are still in their early infancy, even though the possibility of such operations was conceived of more than ten years ago under the concept of MAPS, Management Analysis and Planning System (Figure 10). It is essentially a cybernetic system consisting of two sets of functions, one tracing the budgeted and the other the actual stream of money expenditures or physical effort, and analyzing the detected differences between the two variable quantities. It comes immediately to mind that these are the desired and the observed variables of a self-directing system as discussed earlier.

Indeed, budgetary control of a petroleum refinery and the control of petroleum flow through its pipelines can be generalized, in formal terms, as identical propositions. That is, the concept of petroleum flow that once became the flow of cars in metropolitan arteries, and then the movement of tankers along the Brazilian coast, now becomes also the flow of money and productive resources through administrative channels of a modern business or industrial organization.

MAPS introduces the principle of instantaneous control and adjustment instead of the traditional control at discreet intervals. But it is necessary to realize that in any physical realization of the system certain instances will always be relevant, while others remain irrelevant. Hence there will be a variable sampling interval, lapse of time between successive
budgetary reviews. The duration of this sampling interval depends on the capacity of the hardware configuration within the system.

It should be stressed, however, that the implementation of the system does not depend on any particular hardware sophistication. It is mainly
the matrix of thought itself that leads to new analytical insight, and from which appreciable payoffs may be derived.

3.5. Benefits of Process Control

3.5.1. Tangible Benefits

Finally, what interests business executives most is, of course, the profit aspect. Engineering studies indicate that if 100 loops can be replaced by a digital control system, the total installed cost of the system equals approximately the total cost of the conventional loops. Hence for plants of more than 100 loops computer control is feasible on that account alone. But a typical processing unit in a typical plant may have as many as 400 loops.

There are also reductions in operating costs, raw materials, fuel, energy, and other utilities, and in operating supplies of numerous categories. Again, reductions in impurities, blemishes, and other improvements in quality are due mainly to reduced process variations, more uniform testing and processing procedures, or to improved standard settings.

Lowering of incorrect output rejections is attributed to better estimations of quality variables. With testing under computer control, costs of testing equipment, materials, and wages are reduced: 10,000 man-hours have been reported saved by a typical chemical plant due to unattended operations, fewer tests, and readily available informations.

Besides reductions in direct costs, there are analogous savings in selling expenses, mainly because of improved inventory, warehousing, and transportation techniques. Similar reductions have been achieved in almost all other categories of general and administrative expenses.

In petroleum industry, for example, holding of temperatures, pressures, or flows close to constant or optimal values led to reductions in maintenance and operating costs. Computer control of fractionation columns (at Phillips Petroleum) produced sizeable reductions in reboiling steam consumption and more uniform compositions of valuable products. The potential of computer control in catalytic cracking is said to be tremendous, operating efficiencies having been increased (at Gulf Oil in Philadelphia) up to 95 per cent of theoretical perfection and beyond. In Groeningen (at Nam), the average number of days to drill a 10,000 ft.
well has been reduced from 37 to 15 days, bit hours on bottom cut from 324 to 137, and the number of bits used from 16 to 9. In a word, computer control tends to have a twofold effect: it tends to increase net revenue per any given volume of sales, and it tends to promote sales.

Benefits derived from computerized applications in the category of traffic control are measured by car delays in networks. These have been reduced by about 10 per cent, as compared with conventional methods of traffic engineers. Systems designers claim, for example, that in Wichita Falls, Texas, the number of times a vehicle travelling in the streets must stop has been reduced by 8%, the delay as stopping reduced by 18%, accidents cut by 8 1/2%, mostly rear-end collisions, while the average rush-hour speed on the main arteries has risen from 20 to 30 m. p. h.

The argument, as summed up by the United States Academy of Science, is that "in continuous processes that were already under automatic control, such as paper mills and oil refineries, "a process improvement of 2 percent to 5 percent has been experienced quite generally upon the introduction of process computers. Any product line having more than US$ 6 million annual volume is then a likely prospect because the DDC system can be paid for out of savings". This means that on the score of process control alone the minimum economic size of an oil refinery or any other continuous-process unit must be Cr$ 25 million of annual output.

3.52. Intangible Benefits

Cost savings are usually called tangible, probably because they are measured directly by statistical methods. On the other hand, the value of improved management informations is usually referred to as intangible.

Control of production by digital computer has proved markedly better than the conventional mode of analog control in terms of speed, flexibility, and display coordination. This improvement leads to an ability to detect sources of inefficiency and waste, as well as new possibilities of economy, savings, or profit earnings.

The time is reduced that a plant requires to accept new products, product changes, or to redirect its research, product development, planning,

budgeting, and engineering efforts. In one application, for example, at least three months were required for an expansion in production because new quality-test stations had to be added and made operational. With a process control computer, such an expansion can now be performed within one month, so that the increase in production is advanced by two months.

Benefits of improved management information are therefore equally tangible: even though in conventional accounting they are, alas, not recorded nor measured. These are savings in opportunity costs of management decisions, costs of better alternatives that have been forfeited. Reductions in opportunity costs are estimated to lead to even greater profit rewards than the conventionally recorded cost savings.

3.6. Impact on National Economy

Clearly, benefits derived from applications of process control are reflected in the total structure of a national economy. This is true of any country: particularly of countries characterized by giant enterprises, such as General Motors or IBM; or by national monopolies, such as the Petrobrás.

It has been demonstrated that improved controls of production, distribution, or administrative functions leads to reductions in the quantity of productive resources required per unit of output. For an individual business unit as well as national economy as whole, this means that a greater quantity of output can be obtained with any given set of cash, materials, plant, or personnel. In other words, process control must be looked upon as a new factor of economic growth.

Perhaps an example will be useful, to emphasize this important point. Let it be assumed that there is an economy consisting of ten large enterprises, and that each of these enterprises, when operated in the conventional manner, requires daily a reserve of cash and other current assets in the amount of, say, Cr$ 500 million. This reserve is required, Keynes tells us, in part for transaction reasons and in part for precautionary reasons is, of course, a direct reflection of the degree of uncertainty within an enterprise or economy.

But process control tends to reduce this uncertainty, and to this extent it also tends to reduce the reserves required for precautionary reasons.
A reduction in uncertainty of 10% may be regarded as easily feasible under any conditions. If, in this example, the reserve is required largely for precautionary reasons, introduction of process control means, in effect, creation of a new capital of a few hundred million cruzeiros for the whole country. Now, the less developed a country the higher the reserves required for precautionary reasons, hence the greater the impact process control is bound to have on productivity of capital and economic development of the country.

Process control tends to reduce not only reserves of input factors required for precautionary reasons, but also reserves required for transaction reasons. This, in turn, leads to the abatement of the destructive forces of cyclical downturns, as long as they cannot be eliminated altogether. Students of business cycles have shown that since World War II ameliorative effects have been produced by improved inventory controls alone. That is, inventory business cycles have virtually disappeared.

A phenomenon similar to the inventory cycle is caused in developing countries by the frequently spasmatic patterns of the developmental processes. These patterns cause alternate abundance and shortage of cash, that is, liquidity cycles, and consequent recessions such as has recently occurred (mildly though) in Brazil. Automation of planning and budgetary controls in these countries will tend to even out these fluctuations, and thus also in this sense it must be expected to become a factor of economic growth.

In a word, it is true that development of process control systems comes at social cost, but consequent reductions in production costs and administrative costs are even greater.

As a closing thought, process control applications have tended to produce a threifold effect on the national economy: 1. increase in capital, 2. betterment of technology, and 3. improvement in business administration. Interestingly, to paraphrase Galbraith, these are the "three things, which the more advanced country has, which can be borrowed by those following it along the line." 6

4. Summary

4.1. Science in Business

The scientific or technological subculture of our society and its business or managerial subculture had for long had little to say to each other, for lack of mutually understandable means of communications. Introduction of the notion of process control into the matrix of thought of business management and into the arsenal of planning and budgeting techniques appears to be a frontal attack on this traditional division of the two cultures.

I recent decades engineers and scientists have been assuming positions next to business-educated personnel at all levels of business and industrial management, and a dialog has been emerging. For this metamorphosis there is a number of reasons, or perhaps one general reason known according to its manifold aspects: electronics, computing, giantism, process control, automation in general, to mention but a few. Hence a seminar on process control must also be viewed as a contribution to this dialog, tending to introduce science into business administration and business administration into science.

In the conference attempt has been made to give precise definitions to a host of concepts that have been known to us by and large intuitively, scattered as they are through the technical and economic literature. They have been logically interrelated and explored from various viewpoints. They are fundamental in nature and increasingly important in the emergent mode of modern business and industrial management. As Plato would say, now that we know the details and the concepts, we should also be able to handle arguments.

4.2. Flow of Petroleum or Money

There is, it is suggested, a close analogy between the world of technology and the world of business management in terms of cybernetic principles. That is, when raised to a sufficient level of abstraction, the flow of continuous physical quantities, such as petroleum in the pipelines, is equated with the flow of cars in metropolitan arteries or flow of money throughout administrative channels of a modern corporation. The same is true of the flow of its productive endeavors. Hence the same general principles of process control that are applicable to the management of
an automated refinery are also applicable to an automated planning — and budgetary — control process.

Stochastic control theory and its identification and optimization algorithms are, therefore, applicable both to industrial as well as administrative processes. If the purpose of controlling a technological process is to optimize, minimize or maximize, an objective function, the purpose of planning and budgeting is certainly to maximize the objective function of a firm.

The formulation of an objective function implies the definition of a systems concept, a way of looking at things. This concept is related to the subsequent systems approach, a set of procedural steps by which to project the systems concept into the operating reality, and thus to secure the optimization of the objective function. Also the working objectives of technological and budgetary processes are the same: the reduction, ideally to zero, of the difference between the desired and the observed values; or, in budgetary terms, of the variance between the budgeted and the actual flows of expenditures. For these reasons it is appropriate that apparently technological phenomenon of process control should be discussed under the auspices of the Planning and Budgeting Section of this Company.

5. Conclusion

5.1. New Capital

Under modern conditions, planning tends to become imbued with cybernetics or process control and process control with planning. In mutual cooperation, planning with process control tend to reduce the level of uncertainty within business, and this is followed by a reduction in the quantity of input factors required for transaction and precautionary reasons. In other words, planning and process control tend to reduce costs, improve quality, and promote sales; and thus they become a source of new capital. Such has been the experience of the developed countries, such as the USA, and that much more it must be true of an underdeveloped country, with much lower productivity of labor.

5.2. Social Progress

But what could be done about the people, if computers replace them? Well, they do not replace them: on the contrary, computers can create
new jobs for Brazilian people; and since the transition does not come evernight, there is no need to send people away.

The same objective is ultimately accomplished as if a redundant employee were eliminated: a greater output quantity is produced without the necessity of increasing the labor force, and thus the additional national product can be channelled into new productive facilities. That is, in this manner new employment is created, jobs of higher categories and better paid than those previously existing. This, then, is the only objective measure of economic development: how much an industry or a society can rechannel into its expansion from its own output.

5.3. Avenues of Advance

Of course there is no rough and ready prescription by which to solve the economic problems of this country, but there are nonetheless many things that can be done immediately. Process control applications, for example. If introduced by one Brazilian company or industry, the benefits will not remain confined to that industry alone. They will accrue to other industries as they spread throughout the economy, upgrading industrial skills and increasing educational levels. There are three avenues of such advance.

The first stream of effort consists of the automation of planning — and budgetary — control functions. An since in the electronic environment all administrative functions tend to be concentrated around a computer, in which we all shake hands, as it were, this initial phase leads gradually to the automation of other administrative processes.

The second avenue of progress is, no doubt, the gradual automation of technological processes, for which purpose the third generation computer is justifiable. If the cost studies presented to the U.S. House of Representatives are true, and there is no reason for doubting their veracity, and if an American continuous process factory turning out six million dollars annually is adept for digital control, then a Brazilian plant producing from one — to two — million cruzeiros worth of goods per month must also be regarded as ready for it:

And thirdly, there is also a scope for interlinking of management and productive operations. When, not if, we arrive at that stage, we can perhaps say, with Voltaire, that "we have indeed made a contribution to the art of marking pins". 
5.4. Closing Thought

The conclusion is clear: development through mechanization alone leads toward underdevelopment. Development for development must lead through automation.

Why? Because underdevelopment is a relative concept, and the countries with which our economic and social structures are compared are transforming their productive patterns rapidly into automated modes. Hence the fantastic increase in the total gross national product and the per capita output anticipated for the United States by the end of this millenium.

To follow suit, therefore, is the only way of escaping the gloomy pictures that have been painted for us, not without justification, by the researches of the Hudson Institute. Without automation, no continuous-process industry, which includes petroleum and petrochemical industries, can possibly be competitive on international markets. And Brazil must be able to export industrial products, in order to promote its economic development. Automation must, of course, be combined with other measures, all of which may be subsumed under two headings: education and patriotic psychology. The result will then be not only a larger cake for Brazil, but also a larger share of it for all.

Bibliography

Part 1:


Part 2:


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