Possible Consequences of the Intensive Computerization of Industrial Production and Management: A Scenario and Annotated Bibliography

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POSSIBLE CONSEQUENCES OF THE INTENSIVE COMPUTERIZATION OF INDUSTRIAL PRODUCTION AND MANAGEMENT

A Scenario and Annotated Bibliography

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PREFACE

This scenario was written in 1978 by J. Hatvany of the Computer and Automation Institute, Hungarian Academy of Sciences, and an IIASA alumnus. It was intended as an input to the Institute's own thinking about a future research program. It is just one scenario in a wide spectrum that needs to be taken into consideration in future studies when studying the possible impact of computer developments on management, organization and society.

J. Hatvany has a broad perspective on societal development. In the introduction of this report he commits himself to the "school" of futurologists following Daniel Bell in their investigations of the "post industrial society." Herman Kahn is another major influence. He heavily opposes the other school as advocated by Schumacher, Schwartz, and others.

With this perspective, he investigates his scenario of the future characterized by intensive computerization of industrial production and management with an emphasis on far-reaching vertical integration of computer use in organizations, industry and society. He sees different characteristics in this report within discrete manufacturing and in continuous processes. Managers will have to adapt smoothly into a larger hierarchical power structure than ever before--just as any other component of the gigantic system. The author finds the key to his future scenario in the development of powerful systems analysis and synthesis tools to design highly integrated and a far-reaching computerized control system encompassing industry and societal planning. He holds that such a development must be made through international cooperation.

In the "factory of the future" the author paints a picture of a super-developed society based on such computerized procedures. He dwells on the societal effects within this scenario; on decision-making, education, employment, human settlements, environment, resources, R&D and monetary circumstances. He sees the society where money itself will gradually recede from the everyday citizen level sphere to the accounting and planning of society only.

An extensive bibliography partially annotated with the author's values and comments concludes the report.

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A Scenario and Annotated Bibliography

J. Hatvany

INTRODUCTION

> "It is agreeable to see various indications that the absurd old prejudices against industry are certainly declining." From "Letter to a young Etonian who thought of becoming a cotton spinner" by P.G. Hamerton, 1873.

It has become an acknowledged need for the government of countries, regions and cities and even for the managers of large or medium enterprises to look some twenty or more years ahead in formulating their major policy and investment decisions. In consequence a relatively large body of literature has been generated and while some of it (European Cultural Foundation, 1972) sees the future exclusively in terms of culture, politics, the environment, work, leisure and other sociological characteristics, a fairly large section (Ayres, 1969; Bachurin, 1976; Bauer, 1969; Blohm, 1972; Cross, et al. 1974; Flueckiger, 1971/72; Jantsch, 1967; Lanford, 1969; Martino, 1972) has been concerned with the development of forecasting methods that will help determine the probable course of science and technology (particularly the latter) in the coming decennial. The aim of these endeavors has been to develop analytical and extrapolative apparatus which can be applied to the statistics of the present and the recent past to yield those of the future.

Unfortunately, forecasts in science and technology lend themselves only to a limited extent to the application of continuous extrapolations, since the essence of technological change is innovation and this is by nature amenable to only a very general and only globally significant statistical treatment. No statistical analysis and no extrapolation of trends in the first half of this century would have led to a forecast of the computer industry in the third quarter. Developments in hydroelectric power generation, in the use of the railways, in coalmining, in shipbuilding, television production and a host of other technology-based activities have shown drastic divergences from all trend extrapolations and scientific forecasting expectations. Retrospective analyses of most statistically-based forecasts using explicit scientific techniques have shown a complete failure to foresee the emergence of new science-based technologies and industries and also the consequent decline of superseded ones.

Yet many relatively good forecasts have been made of future--as yet unknown--technologies. Most of these have been due to novelists, of whom Jules Verne is the most brilliant example. Verne was in his day a rare, but not unique phenomenon; a polyhistor with a soaring imagination, a good sense for basic technical limitations and a suitably receptive environment. Today's plethora of science fiction has probably also produced its Jules Vernes--some of the works of Lem, Asimov, Tolstoy, Semitjov, (1975), and many others might retrospectively well be shown to have been prophetic--but the very multitude of them excludes their use as a prognostic source. Let alone the obvious and justified reluctance of administrators to base their actions on what can rationally at best be described as the inspired guesses of gifted amateurs. (See Figure 1 for an example of forecasting.)

Having thus discarded both quantitatively based forecasting methodologies and the intuitive prophecies of the writers, what remains is something that is between the two: the subjective opinions of widely learned and read people, who have devoted much time to thinking about the future and discussing it with people of various disciplines, have most of the relevant data at their fingertips and are ready to revise their forecasts frequently in the light of new facts. They may work singly (Kahn and Bruce-Briggs, 1972; Kahn and Wiener, 1967), in small groups (Almon, et al. 1975), or in collective bodies (Hodges and Kelly, 1970; the NAS "Year 2000" Committee, the USSR Academy of Sciences forecast, etc.)--usually the latter.

Subjective opinions, however, are partly based on personal beliefs and prejudices. In matters of the world of the future, some of these can be so basically different as effect-to preclude any attempt to synthesize extant forecasts.

The most extreme case is the attitude of "cosmic pessimism" which it has become fashionable for some of those in very prosperous environments to adopt. "The universal dream of a coming Age of Affluence <u>modern style</u> has been shattered," writes Schumacher (1975), proposing that mankind should instead strive for smallness, simplicity, low capital utilization and nonviolence. Schwartz (1971) goes even further. "Science and technology," he declares, "cannot help to solve the

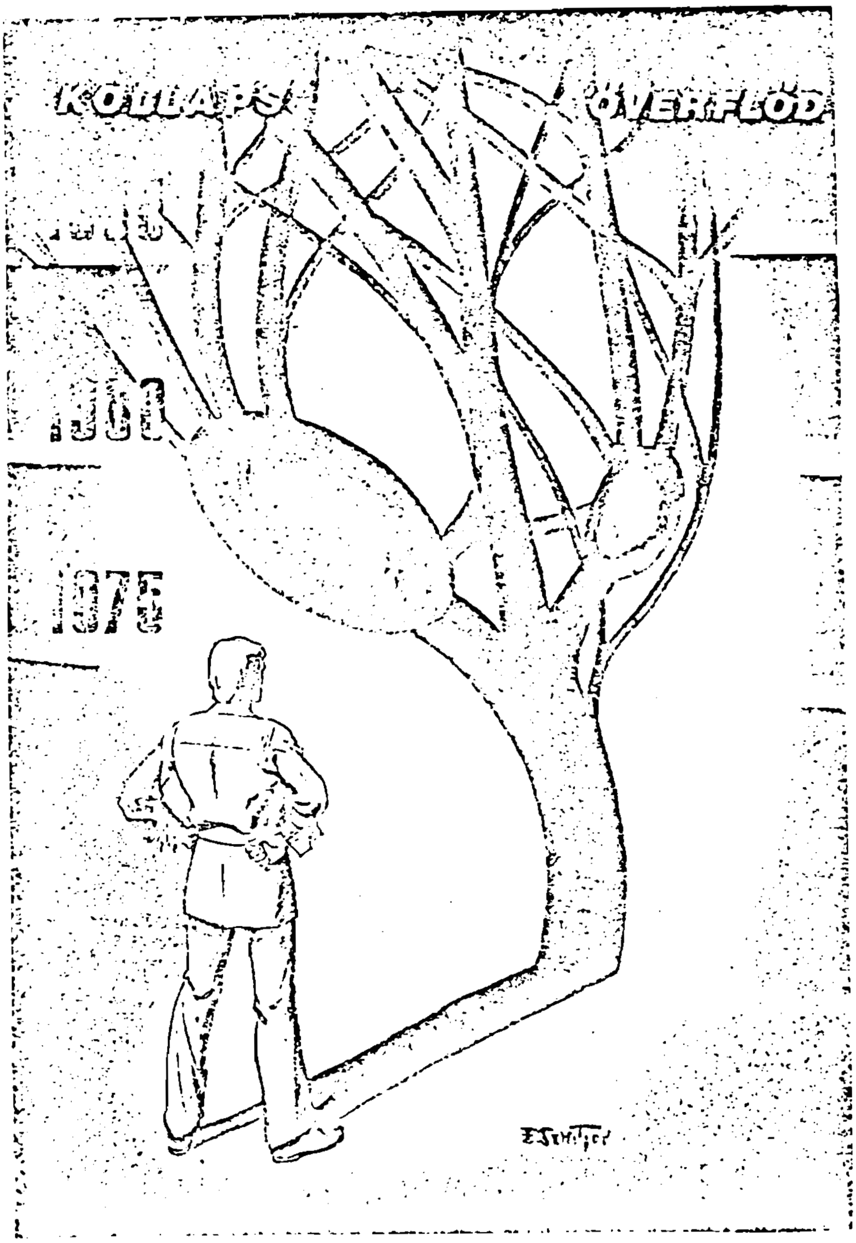

Figure 1. Forecasting: Catastrophy or Affluence.
(Source: Semitjov, 1975)

problems that confront the world, because they are major contributors to the problem." Similar defeatest literature (Bruckmann and Swoboda, 1974; Dickson, 1974; Etyioni, 1973; Farmer, 1973; Lustig-Arecco, 1975) has appeared in considerable quantity and has had a surprisingly large readership. Most of it has emerged in the wealthiest cities of the world and is read by people whose homes are full of the million energy-consuming science-based gadgets against which the works themselves polemicize. The existence of this environment is taken for granted and the impracticalities of persuading a largely undernourished, precariously living mankind to freeze its development at a completely different level are not seriously considered. This neo-Rousseouan "Alternative" school is, therefore, not that which will give us the realistic weaponry to adjust to the challenges of science and technology in the future.

A very much more profound approach is that represented by Bell (1973) and his followers (Morley, 1974; OECD, 1975). Bell's "venture in social forecasting" is based on a trend which is well supported by statistics (The Economist, 1975; OEDC, 1975), indicating that while in the most developed countries the second half of the nineteenth and the first half of the twentieth century showed a swift relative growth in the industrial population and a corresponding (or even faster) decline in the agricultural, the second half of the twentieth century is seeing an equally swift relative growth of the services sector and an equally fast (or even faster) decline in the relative size of the industrial population. It is on the basis of these trends that Bell formulated his characterization of a "post-industrial society" which has changed from a "goods producing to a service economy". This, however, does not appear to be an adequate formulation of the basic characteristic of tomorrow's economy, just as today's is not a "post-agricultural" society. The basis for a thriving industry is an agriculture that provides enough food. The basis for a society with highly developed services, is an industry that will produce an adequate quantity, variety, and quality of goods to render the services available.

The set of "prejudices" for subjective forecasting which are most sympathetic to this author, are, therefore, those which assume:

-- a high and rising level of industrial activity, adequate to the needs of society,
-- a swift increase in the service sector rendered possible by the high level of industrial and agricultural automation,
-- a more rational integration of the functions of production and distribution,
-- a rapid increase in the intellectual content of labor,
-- a more rational and conservative use of natural resources.

These, or similar "prejudices" have also formed the basis for a number of forecasting activities in very differing social environments (Albus, 1975; Fischer, 1974; Kahn and Wiener, 1967; Kuznetsov, 1969; Lavallee, 1972; Modrjinskaya and Stepanyan, 1973; Norman, 1975; OMFB, 1969).

It is from the works of this latter category that the most important features of industrial development in the last quarter of the twentieth century may be formulated as being:

1. The general application of computers to the organization, planning, management, and control of production.
2. The scales of production will be polarized towards very large units on the one hand and the production of a very large variety of small batches (or one-off) at the other--both rendered possible by wide-spread standardization and computer-based automation.
3. The role of chemical products will continue to increase.
4. Requirements on product quality, component accuracy, maintainability, environmental qualities, will increase.
5. There will be increased specialization, increased division of labor, increased international industrial cooperation. The differences in national levels will tend to decrease, technology, transfer will be more efficient.

This paper will be concerned mainly with feature 1., of which Kahn and Bruce-Briggs (1972) have written that "as far as the last third of the twentieth century is concerned (this is) the most important, exciting and salient aspect of modern technology".

COMPUTERIZATION

The intensive computerization of industrial production and management involves the creation of an integrated material and data processing system, wherein all the data relating to a product (from those required in the decision to manufacture it, through to its routing, scheduling, storage, costing, and delivery) are processed in one set of inter-related and interdependent components belonging to the same overall system that processes (i.e., machines, distills, casts, rolls, etc.) the material itself. This is necessarily a complex, synthetic entity, involving the harmonization of file sets and other data bases to make them mutually accessible and clearly reflecting the particular decision-making hierarchy under which the users wish to run the system.

Integrated systems of this type all have certain basic identities, but they may conveniently be divided into the major classes: those intended for the discrete product industries (e.g., machines, shoes, clothes, electronic equipment, etc.), and those for the continuous process industries (e.g., chemical, petrochemical, metallurgical, etc.). We shall discuss intensive computerization of the technological aspects of these two types of industry separately, then uniting again to discuss computerized management systems.

Discrete Manufacturing

The mechanical engineering industry plays a key role in the development of the economies of most industrial nations. It has been shown that the growth rate of all industries is greater in those countries where the mechanical engineering industry has had a high growth rate (Bekker, 1970). At the same time an analysis of the world market has concluded that there is a marked trend towards the purchase of more complex units and services, including turn key manufacturing systems (Horacek, 1975).

The International Institution for Production Engineering Research (CIRP) has conducted an extensive Delphi-type forecasting project on the future of the industry (1971) and while concluding that full computerized automation will not become general before the twenty-first century, has found that all the major components will be extant before 2000. By 1990, 50% of all machine tools produced will be parts of flexible manufacturing systems under computer control.

The essential features of computer-based discrete manufacturing systems have been extensively described in the literature (Anderson, 1973; Crestin and Gillet, 1975; Feilden and Williamson, 1973; Kamrany, 1973; Merchant, 1975a; Spur, 1975; Spur, et al. 1973) and governments in several countries have commissioned surveys (e.g., The Rand Corporation), which have received considerable publicity. Figure 2 is a schematic illustration (modified from The Rand Corporation Report of 1972) of the major components that go to make up such systems, though their interconnection would in real life certainly not be as simple as this radial structure might suggest.

Starting at the top of the figure and proceeding clockwise, the first major component, marked "programmable machine tools," denotes metalcutting or forming machines each of which is under either an individual computer control (CNC) or part of a group control scheme (DNC). Typical, presently commercially available, DNC systems will have local on-line scheduling, program editing, program retrieval, production logging and other capabilities which are in complex hierarchical relationships with the other major components around the figure.

The "programmable assembly machines" component is, in contrast, not yet an industrially available one. Although very great progress has been made in recent years in the development of computer-controlled manipulators (robots), the necessary perceptory and decision-making processes are still

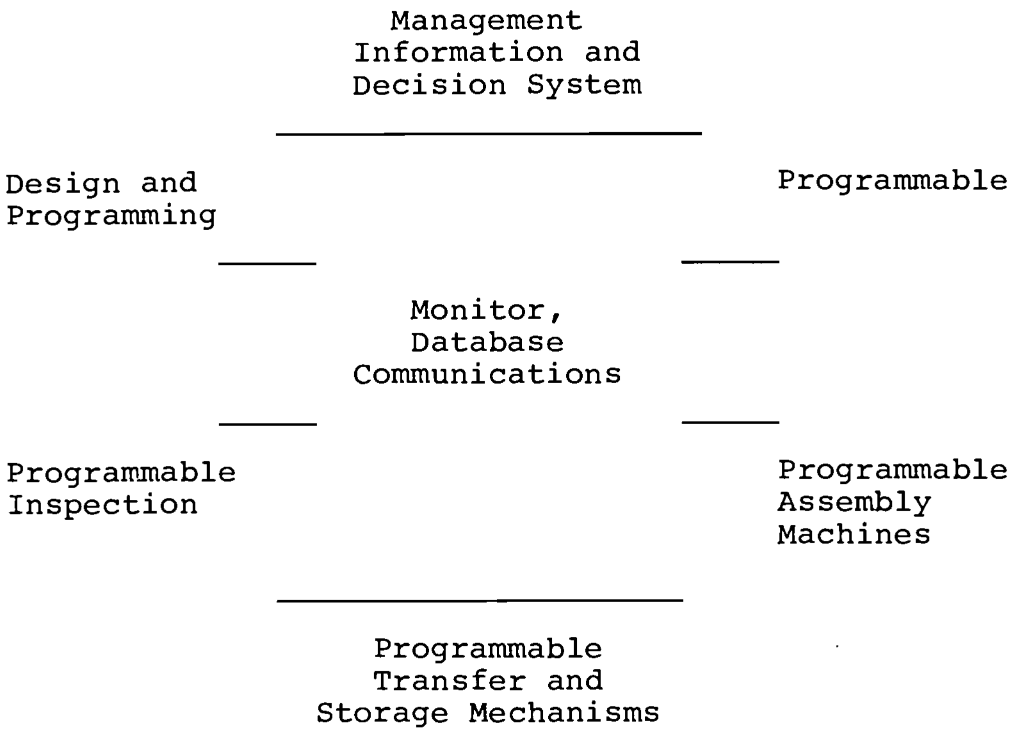

Figure 2. Major components of an integrated discrete manufacturing system.

in the Artificial Intelligence research laboratories and the interface between this component and the others has not yet been developed.

"Programmable transfer and storage mechanisms" are in use with a number of DNC systems in the GDR, USA, Japan, Czechoslovakia, USSR, and other countries. It is mostly these two components together that are regarded as the nuclei for subsequent broader integration.

"Programmable inspection" is another of those components, where only the rudiments have so far been developed. Excellent digital measuring machines are available, some with their own computer systems to evaluate measured data, a few with the ability to carry out a series of measurements automatically under program control. What we do not have, are software systems that will automatically extract from the preceding machining programs and design data, the points, contours or surfaces which it is necessary to measure, or that will link the results of the measurement to corrective action in the requisite parts of the other components.

"Design and programming" covers a very large area, ranging from Computer-Aided Design of the product to establishing and programming the detailed machining technologies appropriate to each of the parts on each of the machines on which it is to be processed. While many of the necessary system components (interactive graphic techniques, high-level, problem-oriented part programming languages, etc.) are available and some have been in general use for over ten years, no broadly accepted systems concept has yet been introduced.

The "management, information and decision system" component is expected to contain all those subsystems concerned with order processing, scheduling, stock control, purchasing production control, costing, invoicing, etc., of which many are already operative in most larger plants. In this context, however, they must be in a form that can be readily interfaced with the other major components--another problem which has so far not been solved with any general validity.

And finally, there is the major component at the center of the figure--one that will monitor the operations and intercommunications of all the others and maintain data they generate in a form accessible to those of the others which need them. Such a component could evidently not be built to any degree of perfection unless the overall system was first designed in some considerable detail. This has (as far as the literature indicates) not yet taken place anywhere.

As the above survey shows, this CIRP forecast for the development of all the necessary components of computerized manufacturing systems before 2000 will require much work and their synthesis into large, integrated systems will need both new skills and probably also some very large and expensive experiments.

Realizing this state of affairs, proposals have been prepared in a number of countries for the establishment of government-backed pilot-plant projects to this end. Perhaps the best known of these is the Japanese venture for an "Unmanned Metal Working Factory" (Bull of MEL, 1974). This plan envisages a factory of about 20-30000 m^2 staffed by a control crew of 10, compared with a normal complement of 700-800 workers, producing about 2000 different components in batches of 1-25 and assembling them automatically. The cellularly organized plant will have tool and workpiece transfer by computer-controlled vehicles. It will be capable of parallel and mixed production of items of widely differing kinds.

In the United States, the American Automation Council made similar, though somewhat less ambitious proposals (Bennet and Williams, 1974; Bernard, 1974). At the same time a number of United States engineering firms, acting through their joint research and development organization CAM-I (Computer-Aided Manufacturing-International) have drawn up a detailed program of action (1975), envisaging the development of 23 software systems components by 1985, with an investment of over 400 man-years of effort. While a number of these components are very ambitious of their kind, they still do not attempt to provide full coverage for the "major components" of Figure 2 .

In the German Democratic Republic, several computer-controlled metalworking systems have been built, of which the ROTA-FZ-200 is perhaps the best known (VEB Werkzeugmachinenkombinat, 1975). In this pilot plant, comprising over 20 machine tools with programmable workpiece changing and transport, 20 people are now producing the former output of 200.

The main-bottleneck in the development of the integrated manufacturing systems of the future is everywhere that of software production (Bjørke, 1975). Software is still being produced by inefficient, undisciplined and uncoordinated methods, leading to repeated commissioning delays and extremely high software maintenance costs. Moreover no broadly accepted method has yet been proposed for the registration and synthesis of extant system modules in some standardized and available form.

While most of the above discussion has been concerned with metalworking systems, the same remarks apply basically also to the other discrete manufacturing industries, to shipbuilding (Lighthill, et al. 1972), electrical machinery (Yamanaka, et al. 1974), and, of course, electronics, including the computer industry itself.

Continuous Processes

The continuous process industries are today much more highly automated, their control, scheduling and management functions better integrated, than in the case of discrete manufacturing (Cheliustkin, 1975; Cockerill and Silberston, 1974; Murrill, 1976). There are, however, internal differences, and the effects of automation will be greater for the textile, food, drugs and paper industries than for, say, petroleum or the petrochemicals.

A major item in facilitating the computerization of continuous process plants is the swiftly developing trend towards plant design standardization, due to the fact that the enormous new equipment now being used is simply too expensive to custom design each time. (This increase in plant size will probably continue for a time, though not as dramatically as hitherto.) The aim of integrated systems development is through firmer overall control to require less intermediate storage and to be able to run processes with faster response characteristics (and, therefore, more difficult to control).

In the case of continuous process control it is more the existing features that will be enhanced, rather than new ones created. There will probably be a continued centralization of control rooms, but this will be accompanied by a parallel trend to more field hardware, particularly microprocessors. While becoming functionally centralized, the control rooms will shrink in size as the display of measured parameters is concentrated on one, or a very few display devices, operated on the principle of "management by exception". Radically new additions to the extant system are to come mainly from the Artificial Intelligence side, leading ultimately to fully automated process diagnostics and remedial action. This field, moreover, is expected to heal the many years' rift between the control theoretician and the systems designer. Such devices as on-line mathematical modelling will make optimization--incorporating production, market forecast, sales trend and corporate strategy criteria--a widespread, feasible practice. Process controls will be adaptive and able meaningfully to cope with stochastic information.

A significant trend appears to be developing towards the use of more discrete devices and operations where analogue ones used to be universal. While this is due largely to changes in hardware costs and availabilities, it also means that controller algorithms will be more flexible, and in hierarchical systems will be amenable to on-line modification. In the very complex multi-level hierarchical (digital) control systems which will thus develop, multivariable control using strictly discrete methods, deadtime control, feedforward and predictive techniques will be widely used. Data communication within continuous process plants will be along digital data highways. This will permit the establishment of more meaningful man-process interfaces using more graphics and possibly audio input/output. Heuristic techniques will be used to facilitate the operator's situation recognition process.

Since, as has been pointed out, much of the continuous process technology will become increasingly standardized and the sophisticated know-how to control the new, critical, high speed, high pressure, high temperature processes will be increasingly incorporated in relatively readily transferable digital computer programs, the technology gap between nations will continue to close. The emerging, fully integrated systems will have fewer operators, more and better information channels between processes and the higher decision-making forums.

Management

The most important trend in the development of computerized management information, data processing and decision systems will be their increasing linkage with the technically oriented components previously discussed.

Computer-Aided Design, for instance, provides a means for on-line interaction in the nascent stage of product development, between the engineering design activities on the

Schoeman, 1973; Cetron, 1969; Diebold, 1970; Fischer, 1974; Jantsch, 1972). None of these sources, however, attempted a more detailed analysis of how such techniques can subsequently be organically combined with the product design and scheduling functions for which they, after all, should provide the primary outputs.*

Problem Areas

While many forecasts have been made and are being made of computer-based integration in a variety of industrial and commercial activities (Gabor, 1971; Howard, 1975; Lighthill, et al. 1972; Moszkovicz, 1974), the work of designing such systems in detail has proved far greater than was estimated. Even those individual subsystems where specifications were quite clearly envisaged many years ago (Krasovsky, 1970), have failed to develop in a sufficiently flexible form to enable them to be easily linked to other subsystems. And for larger system-complexes containing several of these subsystems (e.g., Garrocq and Harley, 1975), the synthesis procedure has been very painful and so far not very effective.

The attempts now being made, therefore, to develop systems analysis and synthesis tools of sufficient power to cope with these problems (e.g., SofTech, 1976; Thomas, 1975), are, therefore of paramount importance in creating the tools for the intensive, integrated computerization of industrial management, design, production and distribution. It is especially regrettable that although the wish to engage in real international cooperation in this respect is very widespread, no appropriate organization has yet been found to host such an effort.

THE SCALE OF INDUSTRY

The first Industrial Revolution and the subsequent introduction in this century of mass production technologies, have involved over the past 150 years an almost monotonous progression from scattered craftsmen's shops to large factories and then to the technologically highly concentrated production facilities of today. There are, in fact, a considerable number of technological processes, where this trend will undoubtedly continue--though possibly at a somewhat reduced pace--during the last quarter of the century. Predictions in countries of very differing backgrounds (Leicester, 1972; OMFB, 1973) agree in this respect.

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*Not that the role of the forecaster is easy. One team of authors (Martin and Norman, 1970) was recently (five years after the publication of their book) hauled over the coals by a critic (Tullos, 1975) who rightly reproached them with, for example, overestimating the future of the picturephone, while failing to see that of the pocket calculator.

one hand, and the market assessment and corporate strategy activities on the other. While at present these communicate loosely and at long intervals of time, their on-line mutual liaison could cut design and development times, reduce the number of alternatives that are elaborated into formal proposals, and at the same time enhance the range of real choices open to management.

In the continuous process area, management will be able to gain instantaneous information on the optimization criteria currently being used and will be able to modify them as rendered necessary by higher-level economic or other considerations.

At the same time this integration is requiring a basic readjustment of management attitudes, training, and techniques (Boura,et al. 1975; Kirk,1973). The manager who is given increased power due to his possession of a management information system and to his key position in it, will have to fit smoothly into a hierarchical power structure that requires of him (just as of its other components) a flexible, adaptive and sophisticated response. Many of the present-day administrative practices will have to be radically revised, though in fact it has been suggested (Weizenbaum, 1976) that some particularly outdated ones are presently being kept alive precisely by the availability (and misuse) of computer technology!

A recent paper in a series of "management of change" studies (Kozmetsky and Ruefli, 1972), makes the following points with respect to the implications of computerization for management:

-- increased range of choices,
-- multi-objective goals and programs,
-- new policy-formulation centers and decision-making information networks,
-- a new kind and quality of business management, able to use the new means at its disposal,
-- a new concept of "profitability," involving the value of a company's knowledge contribution to society,
-- more effective means of identifying and developing new products and services to help solve societal problems,
-- greater consumer participation,
-- highly skilled employee requirements,
-- information as a form of wealth and a national resource will require new legal definition.

One of these, the means for identifying future developments and developing timely products and services, making the right investment decisions to produce and market them, has received particularly extensive treatment in the forecasting literature (Beckmann, et. al. 1972; Bright, 1970; Bright and

The industries where the growth in scale will be assured are those where technological efficiency is directly related to the size (throughput) of the plant. Familiar examples are thermal power generators, blast furnaces, cement kilns, petroleum refineries, and fertilizer plants. In these and similar plants there is a constant and homogeneous product, unvarying over many years, whose production costs are inversely related to the size of some technological unit (e.g., a turbine generator). In these cases the role of computerization is to promote increases in plant size. This is rendered possible, because the operation of larger technological units is generally very much more critical and dangerous than that of the smaller ones and such regimes are not amenable to manual control.

In the case of very large units it is no longer possible for human operators to observe and supervise the many thousands of parameters they should be checking, nor if they have observed them, to evaluate them, or to deduce and order the corrective actions required to set them right. Before the advent of industrial computers, it was necessary to limit the units to "manageable size". The bounds of this limit will now be rapidly extended by computer-based process control, which will be able to collect, evaluate, display, and if necessary act on the plant data. Fears that have hindered this type of development, have been centered on the reliability of the control computers to be placed in charge of the very large units, particularly where these are operated in critical domains. These fears will be increasingly allayed by the introduction of high-reliability parallel processing techniques, of hierarchically structure, decentralized, multiprocessor control systems and by the development of more efficient human supervision facilities based on the "management by exception" principle. The very low labor requirement of these super-scale, computerized plants will enable them to be located at economically and environmentally optimal sites.

In many branches of discrete manufacturing on the other hand, the trend will be the very opposite. The development towards mass production in the first half of the century has undoubtedly given us cheaper goods. It, at the same time, drastically reduced variety, choice and quality, leading to an enforced consumer conformity and stablizing bad product lines as well as good. The flexibility and convertibility of industrial plant was diminished and inflexible productive facilities became unduly dependent on market fluctuations whose effects they could not circumvent. At the same time the mass production environment has had deleterious social effects, often causing grave adjustment problems.

Computerization effectively offers means in discrete manufacturing for conducting small-batch or even one-off production (Anderson, 1973; Merchant, 1975a; The Rand Corporation, 1972). This means that a multitude of relatively small plants, working with only a few tens of operators each, will be able to produce a very large choice of goods, will themselves be very flexibly reorientable towards the production of a completely different line of commodities, and will do all this at unit costs that will compare favorably with those of mass-produced products. One interesting consequence of this will be that since the machine tools are themselves produced in very small numbers, the introduction of methods which will automate their production will in turn lead also to reduced costs where mass production does remain (Albus, 1975).

The return to many relatively small manufacturing units open up new possibilities in siting, labor supply, and subjective matters such as personal job-satisfaction.

A further factor in determining the scale of production will be the continued trend towards specialization and the division of labor both on a national and--increasingly--an international scale. This trend will be manifest both in the mass-production sphere, such as the manufacture of semi-finished components of electronic or engineering products, and also in the specialized end-product field. Some good examples of the former may be seen in the current cooperative road vehicles program of the European Socialist countries, where the large scale mass production of items such as ignition systems, motors, brakes, rear axles, etc., is decentralized in plants located in several countries, enabling on the other hand, the relatively small scale production of special purpose vehicles to be conducted with favorable economic indices. The efficient utilization of such possibilities requires the establishment of large design data bases which can be accessed by product designers both to incorporate extant semi-finished products in their end product, and also to influence component design to fit their special needs. (This type of computer-based interaction is now developing in the electronics industry, particularly within large, multinational corporations.) Another computer-oriented requirement of the further rapid development of specialization is, of course, efficient order-processing and delivery scheduling.

THE FACTORY OF THE FUTURE

There is no need to stretch our imaginations too far to obtain a picture of a computerized factory in ten, or even twenty years' time, though perhaps towards the end of the latter period some new features hitherto unenvisaged might begin to appear. For the intervening period, "blue prints"--and to some extent "prototypes"--for the factory of the future have already been published and are today available for detailed study. Partly they are the concerted programs for pilot plants of advanced manufacturing facilities which have been proposed and widely discussed in recent years (Bull of MEL, 1974; CAM-I, 1975; Crestin and Gillet, 1975; Garrocq and Harley, 1975; Merchant, 1975a; Spur, 1975; The Rand Corporation, 1972), partly they are extant (mostly experimental) plants where considerable contiguous domains of activity have already been integrated into computerized systems.

The first widely publicized computerized manufacturing system design was the Molins 24 System of DTN Williamson (Feilden and Williamson, 1973) which for several years served as the point of departure of most integrated discrete manufacturing research and development. The focus of attention in this area at present is the Japanese project for an "Unmanned Metal Working Factory" (Bull of MEL, 1974; Merchant, 1975a). This project envisages the construction and operation of a prototype plant by about 1980. The plant will have a floor area of 20000-30000 sq. meters and will, as has been pointed out, be staffed by a control crew of 10, compared with a normal complement of 700 to 800 workers. It will be directly linked to a remote technological data bank and will have the following major components:

- control center,
- operation department,
- machining department,
- pollution disposal department,
- warehouse department.

Of these all but the first will be fully automated.

The factory will produce small quantities (batches of 1-25) of a large assortment of products (some 2000 kinds of parts, making up some 50 kinds of functional, assembled units, such as gearboxes, spindle heads, hydraulic motors). The plant will use some 400 kinds of raw materials and will automatically conduct operations such as metal cutting, forging, heat treatment, welding, press work, coating, assembly and inspection. Current cost estimates for the project are at around 40000 million Yen.

The overall concept for the system is based on the provision of group technology cells. Such a cell incorporates a four-sided structure, on which various machine tool modules can be mounted in a manner such that each face becomes a different type of machine tool. Robot arms are provided for handling and changing tools, workpieces and machine modules. Each face of the cell will be controlled by a built-in minicomputer. The computer system for the plant will be of hierarchical form with middle-level computers controlling and coordinating the operation and work scheduling of one or more cells and the entire system being controlled by a central computer. Each cell, interfacing with the overall system, will be capable of self-diagnosis and self-repair. The tool and workpiece transfer system will be of the computer-controlled vehicle type. These vehicles will have an independent driving and control system and will run freely along routes determined by a computer graphics system.

In effect, we are to envisage a building of, say, 100 by 200 meters, which by very careful environmental control (c.f., "pollution disposal department"), emits only negligible amounts of deleterious substances. Within the building there are no "dirty jobs". All material is stocked in fully automated warehousing facilities, where a fork-lift arrangement removes it from its shelf and places it on an automatic vehicle. The vehicle will--in accordance with an optimalized "salesman problem" solution--make its rounds and deliver the material to the requisite group technology cell. The latter, using its robot arm, will restructure itself for the job, take the piece, equip itself with the right tools and conduct a technologically optimized machining operation. When the job is completed, the computer-controlled vehicle will fetch it, take it to an automatic inspection station, and if it passes inspection, will place it in a temporary storage unit. After all the parts for a particular subassembly have thus been accumulated in the temporary storage, they will be automatically assembled and packed.

Human activities in such a factory will be limited to the functions of top management, computer-aided design and programming, equipment supervision and maintenance, data input, outward liaison and external transport. In order for a highly automated and very complex system of this kind to function smoothly, it will have to possess a much higher degree of flexibility and adaptivity ("resilience") than our present-day systems have. (Self-diagnosis and self-repair are cases in point.) The major factors in achieving this will be the faculties for situation recognition and problem-solving which are now the subjects of Artificial Intelligence research.

The continuous process plants of the future will be very different. They will (Murrill,1976) increase in capacity (throughput), but due to the intensification of the processes involved, this does not necessarily involve an increase in the physical size of the plant. Moreover, the trend will continue of breaking away from the anthropocentric approach of enveloping all process equipment in a building and making all parts easily accessible to human operators at all times. An illustrative example of these processes is contained in Table 1, whose contents were contributed by Prof. G. Hajós of Budapest. Here data are compared for identical output,

Table 1. A comparison of two Ammonia plants with an identical annual throughput of 300000 tons each.

	Units	Old process	New process
-- area	hectares	15.4	0.65
-- internal volume of buildings	m3	280	11
-- weight of machines & equip.	tons	17.78	5
-- weight of structural steel for buildings	tons	0 ,7	0
-- electric power	MY/yr	520000	12000
-- steam consumption	t/h	6 ,2	-
-- number of people employed	-	300	40

which is, of course, rarely found. The new process will generally also be one with a considerably higher throughput.

One rather plausible scenario for this type of activity is that the continuous process plants of the future will be operating in remote localities, with crews of five or ten people in all. The only building in the human habitation sense will be that housing the control computing equipment, particularly the peripherals. The rest of the plant will be technological units running under very critical regimes and housed in the open. All material movement will be under automatic control and the process itself will be monitored, controlled and directed by a complex network of computer technology, involving micro-, mini- and (remotely) very large main frame computers (and their crews) in constant interaction.

These systems will ensure virtually unattended plant operation and will have automated process diagnostic facilities to support operators in detecting the causes of abnormal conditions.

One particularly interesting category for the future factory is what has been called in Japan the "renewal plant" (Yamaga, 1974), where used and discarded industrial products would be disassembled and re-processed to become raw materials for the next production cycle.

In conclusion, let me dwell for a moment on the picture at the end of this section (Figure 3). The author of the book from which the illustration is taken (Marolleau, 1975) writes that these industrial columns may be regarded as sequoias, presenting a vision of the evolutionary mode of the factory-cities of tomorrow, where the biotechnical infrastructures are connected to the psychotechnical superstructures by integrated transfer channels. In a footnote, he adds:

> In our age of sexual liberation many other interpretations are possible, in particular the following: morphologically, mythologically, the cave is feminine. Following this line of thought; the "sequoia-type" factory is a gigantic, collective phallus with industrial activity symbolizing a "coitus interruptus" and illustrating the historically fertilizing role of technology.

EFFECTS

Decision Making

Technically oriented people have long averred that the primary gap in the present-day introduction of computerized management and control systems is the lack of management understanding. Now many economists and policy-makers are also

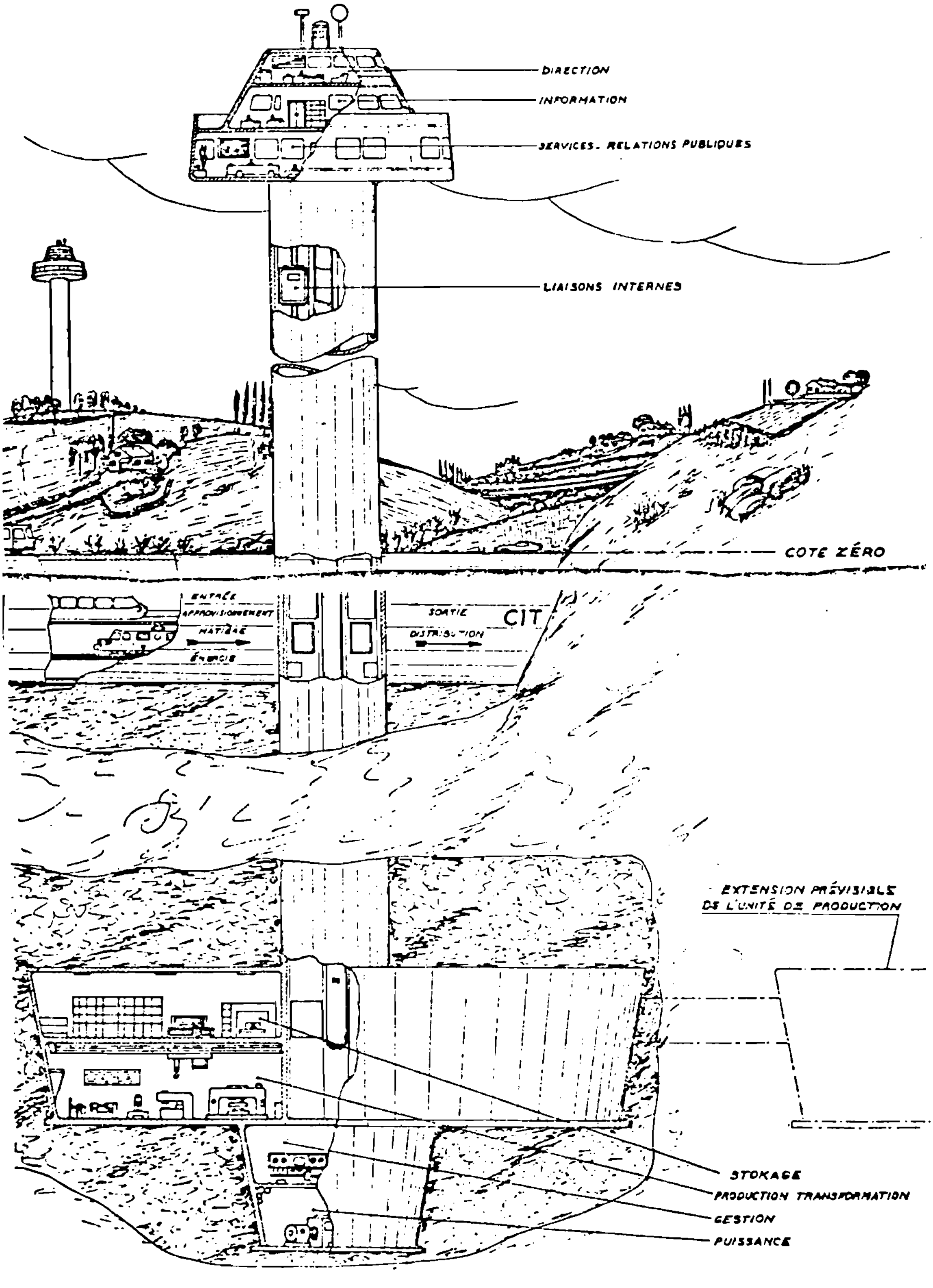

Figure 3. Factory of the Future?
(Source: Marolleau, 1975)

coming round to the view that the implementation of effective decision making in a man-machine environment requires a full revision of management organizations, training and practices (Boura, et al. 1975; Wilensky, 1967; Wills, et al. 1969).

A recent analysis of the critical implications of information technology for decision makers (Kozmetsky and Ruefli, 1972) has attempted a forecast of technological developments into the nineties. These indicate a significant extension of the capability of managers to utilize computer technology to shrink time and distance, structure problems and solutions, extend their perception and creativity, to improve staff functions and to introduce new organizational structures.

The new business manager, in effect, will himself be closely involved with information technology. He will consequently know that a rigid framework is not necessary for effective decision making, if the computer can provide him with a dynamic picture of his firm's activities. Decision making for the new manager should be based on participation and supervisory information, rather than authority. Opinion is unanimous that such new types of managers are needed, but their training is extremely difficult, and the extant structure, into which they will have at first to fit, serves only to enhance this difficulty.

The main structural change which the interlinkage of remote, and hitherto organizationally separated entities will bring, will be the evolution of new policy-formulation centers. The present-day difficulties with inability in many outmoded structures to cope with the simultaneous satisfaction of goals such as profit optimization, environmental constraints, optimal urban settlement patterns, etc., can be obscured for yet another while by tradition, ideology, confused nomenclatures and implicit hierarchical relationships; and to some extent the computer may even aid and abet this concealment (Weizenbaum, 1976) by doing its low-level data-processing chores efficiently. However, as soon as the job of designing an integrated computerized system for a major sector of the economy is undertaken in earnest, the analyst will be confronted with a multi-objective situation, whose rational resolution cannot be to set up separate decision-making hierarchies for each objective. Consequently, any scientifically-based system will have to include timely and effective multi-objective planning, involving a union of the functions of business, national government, local government, consumers, labor, etc., in one informational and decision-making complex. The degree to which present-day societal and business structures can approximate to this, differs greatly--in the market-centered economies it will require, at the least, a reevaluation of the concept of "profitability" to reflect the real value of a company's contribution to society by the knowledge and information it creates and makes available.

One particularly interesting and novel feature of decision-making in relation to integrated manufacturing systems is the possibility of almost direct managerial and consumer/user involvement in design decisions about new products, afforded by the facilities of computer-aided design techniques. These are making it possible for managerial and societal constraints and requirements to be introduced very early in the design process, for the managerial level continuously and meaningfully to monitor and interact with the design process, and for perspicuous, often tangible, models, simulations, prototypes of design alternatives to be presented to managers, governmental organizations, consumers, users, before final design consolidation decisions are made, at practically no extra cost. (This, of course, again implies a decision-making climate very different from that prevalent in many present-day organizations.)

Personnel, Training, and Education

There is a fairly general agreement that computerization will increasingly be "an important means of transforming the nature of labor" (Krasovsky, 1970). The "new nervous system" (Anderson, 1973) thus created will, in some views, go so far that in the future organizations will in fact have no physical location and man's primary activity will not be traditional work. It has even been suggested that a growing number of people may have to be trained for a non-working life (OECD, 1975). As an aftermath of the CIRP Delphi-Type forecast (1971) a Technology Assessment of the Computer-Integrated Factory was conducted (Merchant, 1975b), where there was an overwhelming majority of respondees who claimed that such a development would have a beneficial social impact on the countries and on the production engineers concerned, that the universities would be either not at all, or beneficially effected, but there was a quite significant minority who foresaw a harmful social impact on the factory workers concerned.

In the view of foreward-looking planners society is, because of the time-constants involved, in a good position to cope with this problem. For while innovation and research may be revolutionary, their rate of diffusion into the industrial and social life of a nation is relatively slow and fully comparable in time with the "throughput-rate" of the educational system.

One well-documented long-term plan to meet the labor requirements of a future society (Hungarian State Planning Committee, 1975) starts off from the following basic premises:

1. There will be changes in the ratios of labor categories.
2. The functional role of skilled manpower will change.
3. The difference between physical and intellectual work will decrease.

4. The rate of obsolescence of knowledge will increase so that knowledge will have to be easily convertible.

Applying these general premises to a concrete situation (that of Hungary) the plan proposes to maintain the present high ratio of secondary education and within this to increase the weight of training for transport, commerce, health, education and other services, while gradually decreasing that of classical mechanical engineering. In the training of skilled workers, the trend will be to increase the numbers of those entering the skilled trades in agriculture and in the maintenance of the equipment of the services industries. In university training, a rise in the number of teachers, lawyers, economists and information technologists will be accompanied by a drop in other engineering faculties.

Throughout the educational system much greater emphasis must be placed on fundamental education which can provide a basis for several kinds of specialization in the course of a career. There will be a continuing and increasing demand--connected with the growing mobility of labor--for adult education and retraining. As part of this process, the skilled workers will tend to convert into technicians and there will be a polarization in unskilled work between the remaining "dirty jobs" on the one hand, and the increasing skill (knowledge) required to perform hitherto "unskilled" jobs, on the other. (The proportion of "dirty jobs" will decrease fast for a while yet, but asymptomatically later.)

In higher education the disciplinary specializations of today will be less marked, but the job contents of research and development on the one hand and production control and management on the other will require a different type of education and career goals and values which are more clearly differentiated than today. The role of post-graduate training will be increasingly important in both, to fit people to the intense specialization of a particular field during one technological cycle (of, say 10-20 years).

None of the above proposals is really radical, but implemented together on the basis of a presently relatively well balanced system, they are expected on the time-scale envisaged to bring about the very considerable reorientation in manpower composition that intensive computerization will render necessary. If the base is already out of harmony with present-day requirements, or if the rate of change in the diffusion of computerization is expected to be faster than that envisaged, then, of course, more radical measures will have to be taken.

Employment

Statistics (Almon, et al. 1975; The Economist, 1975; Howard and Lehmann, 1972; Kelley, 1972; OECD, 1975) from various sources are in full agreement in showing rapid increase in the industrial labor force during the period of industrialization, followed by a decrease once industrialization has taken place. The turning point appears to come when about 30% of the labor force is employed in what the ILO statistics call "Manufacturing". Once a nation is past this turning point, a gradual shift of the labor force begins from industry to the services (trade, transport, education, health, etc.). It is more interesting to observe that these trends are more or less independent of whether there is--due to the economic and political conditions in the country concerned--momentarily a shortage, or a "surplus" of labor.

Much emotion has been generated over the "displacement" of workers by automation, and their future, even more rapid "displacement" by computerization. This is perfectly understandable in environments where there is unemployment and organized labor is fighting to retain every possible labor opportunity. The fact is, however, that in the countries with high unemployment figures, only a diminutive fraction of jobs have so far been lost through advanced automation. In light of the statistics, this problem is basically not one of computerized automation, but of the general mass unemployment in some countries, due to a very different set of factors.

In the long term, however, intensive computerization will have very serious effects on the employment situation. First, and most important, it will permit industry to maintain and to some extent raise its contribution to the GNP, even when labor is drifting away from industry into the service sectors. Not necessarily because it is sent away and has to relocate, but often because the service sectors are more attractive places of employment. "There is," says Merchant (1975a), "a steadily increasing resistance by workers to continue to expose themselves to the manufacturing environment." Intensive computerization will have to compensate the drift by raising per capita productivity, and it will also have to make industry more attractive to the worker--by creating better conditions, opening up a promising career pattern and providing job enrichment by allowing much more intelligent participation in decision functions.

The second important effect will be that in the long term, there certainly will be a reduction in the required size of the overall labor force necessary to produce the goods which society needs. This, however, should not be viewed as a disaster, since man's purpose in life is not to spend his waking life in incessant work. Work will assuredly become an inner necessity, rather than an external compulsion in the lives of more and more people as it has already been doing--but the perspective that by the end of the century mankind will have more leisure time than now, is surely something of which we should be glad. More time will be available to the family, to hobbies, to cultural and societal activities, to sports, education, travel and voluntary work on behalf of others. Evidently, much good organizing and administrative activity will have to be put into equitably spreading the blessings of leisure (and not the burden of unemployment). Education and social mores in many countries will have to undergo a radical change to prepare people for this kind of life: i.e., to live beautifully and usefully when they are not at work. And urbanistics, transports, communications will all have to be geared to these new requirements. Certainly no healthy society will wish to adopt the contrary stratagem of dividing its members into "workers" and "non-workers".

Computerization has also been charged with rendering jobs monotonous and reducing the worker to the status of a cogwheel in the whole integrated machinery of industry. Certain aspects of present-day computer practice, particularly primitive I/O arrangements involving much menial work, have substantiated these views. The future of computerization, however, is expected to be quite different. By the end of the century the input of many of the data bases in integrated manufacturing systems will be from within the system itself (e.g., CAD inputting the full product documentation), and the truly exogenic inputs will be read into the computer from the original documents or from speech, without the need for human key-operation. The new, intensively computerized industry will, in fact, require a redefinition of the job contents and job structures to make them correspond to the new realities.

> By introducing computer-based machine tools and manufacturing procedures they can offer participative management to the worker, while freeing him from unpleasant, harmful, potentially dangerous or exhausting conditions. (Merchant, 1975a)

Naturally, such positive conclusions may only be drawn on the premise of a rational social base. As James Albus of the U.S. National Bureau of Standards (1975) has put it:

> As long as we have a system in which a minority of the people own or control virtually all of the wealth-creating capital stock and the rest of the population must rely on selling their labor for income, we will have a situation where automatic manufacturing and robot technology will inevitably threaten the security and personal dignity of most people. Only if we can devise a means by which everyone can share in the control of modern technology as well as in the wealth which it creates, will the fantastic capacities of the coming generation of superautomation be released to assist mankind in solving the urgent problems of his society.

Settlement

The biggest cities of our times have evolved around industry and the related services of transport, trade, and finance. Many of these huge settlements have, indeed, grown up around one single factory, which needed tens of thousands of workers to man its machinery. Evidently, with the shift away from industrial jobs to those in the services sector, there will be a radical change in the motives for settlement patterns, and these will be reflected in the settlements themselves. Strangely, there are nevertheless many works about the future which completely ignore any possible development over the next 25 years through which industry could reshape the settlements of the future (Bronwell, 1970; Chinoy, 1973; Doxiadis and Papaioannou, 1974). These authors must implicitly assume that industrial technology then, will be essentially the same as it is now. Such a view is in direct contradiction with all experience, so it will be better to join those authors (Alpert, 1969; Kamrany, 1973; Norman, 1975; OECD, 1970; Wingo, 1963), whose assumption is that the intensive computerization of industry will in fact influence almost every aspect of our lives.

It appears that in fact industrial activity might well undergo a kind of polarization. The really big mass production plants (particularly in the continuous process industries) will form one pole, the extremely flexible, locally-based small-scale manufacturing facilities will form the other. In the case of the first, the major change to be brought about by intensive computerization will be that since the labor force required to run them can be reduced to a few tens of people for, say, a multi-million ton steel works, the plants can mostly be located in areas remote from centers of human habitation and the crews to man them can be transported in, from a distant city (if they wish). This obviously makes for better environmental protection and secondarily obviates the load on communal services (transport, electricity, etc.) which any large plant would otherwise impose.

At the other end of the scale, the highly concentrated, completely closed facilities for the flexible production of one-off or small batch quantities of a very great variety of goods, with their own carefully controlled anti-pollution measures, can well be sited in the midst of otherwise residential areas. Here they will be near their labor force, their markets and their fellows.

It is for the Urban Systems specialists to analyze the further settlement implications of these two factors, which will in due course reverse the hitherto concentrative effect of industry on the settlements of the advanced nations.

Environment and Resources

The main effects of intensive computerization on improving industrial compliance with the requirements of environmental policies and on economies with scarce human and natural resources, will be due to two factors.

Firstly, intensive automation will lead to a growth in productivity exceeding that which would have been achievable by present-day methods. In some views (Albus, 1975) the resulting growth in GNP could be so great as to make even the most exotic solutions to problems of the environment and of natural resources economically feasible.

> We could afford to collect solar energy or dig for geothermal power anywhere on earth. We could afford to power all industry, homes and transportation with hydrogen fuel. We could process all sewage and farm drainage to the purity of rainwater. (Albus, 1975)

Second, the plants themselves can and will assuredly have all the necessary predictive and corrective apparatus for environmental control, which it was not possible to provide in the previous period (Kamrany, 1973; Kasper, 1972; Merchant, 1975b; Quinn, 1971).

A full, separate chapter should be (but is not) devoted to the very novel and special Japanese proposal (Yamaga, 1974) for a "renewal plant". Analagous also is the work aimed at establishing "industrial colonies" of plants, some of whose refuse and by-products are the raw materials of others, resulting in a group with no overall output of pollutants. While neither of these two ideas is based necessarily on computerization, the latter could obviously be a very large help in achieving them.

Research and Development

Analyzing the hardware/software development costs in computerized automation systems, Bjørke (1975) has found that while in the late 1950's the software cost was only 25% of the total cost of a computer system, it is now about 70% and will rise by about 1985 to reach 90% (due to increasing hardware costs and increasing labor charges). The indirect costs of software, the effects of software delays and errors on operational readiness, are even greater.

The amount of software going into an integrated production system represents a very large research and development investment. The large number of subsystems have each to be viable in themselves, but also to fit into a large whole. Modules must be transportable, as they will be expected during their lifetime to run on probably several successive generations of hardware. Despite very strong traditional prejudices to the contrary, the realization has in the last five years become so universal that no single company or organization--and probably no single nation--can tackle this problem single-handed with a realistic hope of getting profitable results before the earlier stages have already become obsolete.

Research and development in the area of computer-based, integrated automation systems is, therefore, undergoing a revolutionary development. After years of discussion and legal argument (reflecting very real divergences of interest), the giant firms of the world are now cooperating on joint research on

-- analysis techniques to analyze large, complex systems,
-- planning the development of such systems,
-- sharing out the development of individual (jointly specified) subsystems,
-- the synthesis of subsystems into large entities.

Unfortunately, reflecting present-day political and military "realities," there are at present <u>two</u> such multi-national joint projects: that conducted by the US-based Computer-Aided Manufacturing-International (CAM-I), and a highly analagous similar effort within the CMEA. In CAM-I a detailed plan has been drawn up for the preparation and gradual synthesis of the main systems modules by the mid-1980's (1975). In the CMEA organizations, where more of the modules appear to be available, though in a less compatible form, the target dates are a little closer.

A very broadly based international cooperation in industrial systems analysis, construction and synthesis is rapidly developing. It now requires advanced theoretical and practical tools and a level of coordination commensurate in quality with the complexity of the task.

Investment, Trade, and Money

A recent British Government publication (Leicester, 1972) has summed up its relevant present-day forecasting assumptions on industrial capital as follows:

> We are aware that technological change may possibly accelerate and that future increases in the capital-intensity of production techniques--associated with such forms as increased mechanization, full automation and cybernation--are likely to come about. We also believe that the scale of production will increase...accelerating paths for output...will

> enhance the standardization of product, will assist the rate of technical innovation and generally contribute to the obtaining of mass economies available from dynamic growth.

On this basis, the author proceeds to make numerical forecasts until 2001 AD.

The situation is probably very much more complex than this, and the literature surveyed (Hass and Stone, 1972; Horacek, 1975; Janossy, 1969; Krasovsky, 1970; Leicester, 1972-Mayer, 1974; Simai, 1971; Ussijewitsch, 1971) does not create the impression that the capital investment problem on the transition period to intensive computerization, or that arising once this new form of industry is with us, has received an economic analysis based on close interaction with the scientific and technological.

The more foward-looking general investment policy analyses do, of course, place great emphasis on the special treatment necessary for the new, science-based industries. Krasovsky (1970), for instance, postulates four major areas of industrial investment:

-- projects in fundamental science,
-- new branches of industry based on science,
-- expansion and reconstruction of productive capacities,
-- replacement and modernization of existing equipment.

It remains, however, to be determined by what criteria investments should be apportioned between these areas. The differences in approach to this distribution problem are well reflected in such phenomena as "Silicon Valley" in the United States and Akademgorod (Novosibirsk) in the U.S.S.R.

The "capital-intensiveness" of the more critical, generally computer-based technologies is also something that requires more profound interdisciplinary study. Table 1 is a comparison of specific inputs for a given technologist. The figures show that these are not phenomena that can be glibly categorized as simply "economies of scale" or "increasingly capital-intensive processes". They are an interaction of several such factors to produce something qualitatively different and new, which has yet to be elucidated and generalized.

Another little explored problem, so far, is how the vastly enhanced ability of intensively computerized industry to produce a greatly increased variety of goods at the time and close to the place where they are required, will effect the present methods of distribution. It has even been suggested by D. Ross (SofTech 1976), that a systems approach to distribution in an age characterized by the plentitude and easy availability of a very much larger range of commodities might produce results that could ultimately be even more important than the technological progress itself.

The concept and role of money will certainly have to change, with a far closer relation to the complex contribution of the value-producer to society. (And once this readjustment of money-reflected values to societal ones is complete, the place of money itself will gradually recede from the everyday, citizen-level sphere to the accounting and planning spheres.) If no such readjustment is made, the contradictions between the artificial status of money with respect to the realities of production will exacerbate to an even worse degree than we are witnessing at present.

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