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The Corporation: Will It Be Managed by Machines?[1]

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I don't know whether the title assigned to me was meant seriously or humorously. I shall take it seriously. During the past five years, I have been too close to machines—the kinds of machines known as computers, that is—to treat the question lightly. Perhaps I have lost my sense of humor and perspective about them.

My work on this paper has been somewhat impeded, in recent days, by a fascinating spectacle just outside my office window. Men and machines have been constructing the foun-

[1] In preparing this paper, I have drawn heavily on two previous essays written in collaboration with Allen Newell: "Heuristic Problem Solving: the Next Advance in Operations Research," *Operations Research*, 6:1–10, January–February, 1958; and "What Have Computers to Do With Management?" in G. P. Shultz and T. L. Whisler (eds.), *Proceedings of the McKinsey Seminar*, 1959.

dations of a small building. After some preliminary skirmishing by men equipped with surveying instruments and sledges for driving pegs, most of the work has been done by various species of mechanical elephant and their mahouts. Two kinds of elephants dug out the earth (one with its forelegs, the other with its trunk) and loaded it in trucks (pack elephants, I suppose). Then, after an interlude during which another group of men carefully fitted some boards into place as forms, a new kind of elephant appeared, its belly full of concrete which it disgorged into the forms. It was assisted by two men with wheelbarrows—plain old-fashioned man-handled wheelbarrows—and two or three other men who fussily tamped the poured concrete with metal rods. Twice during this whole period a shovel appeared—on one occasion it was used by a man to remove dirt that had been dropped on a sidewalk; on another occasion it was used to clean a trough down which the concrete slid.

Here, before me, was a sample of automated, or semiautomated production. What did it show about the nature of present and future relations of man with machine in the production of goods and services? And what lessons that could be learned from the automation of manufacturing and construction could be transferred to the problems of managerial automation? I concluded that there were two good reasons for beginning my analysis with a careful look at factory and office automation. First, the business organization in 1985 will be a highly automated man-machine system, and the nature of management will surely be conditioned by the character of the system being managed. Second, perhaps there are greater similarities than appear at first blush among the several areas of potential automation—blue-collar, clerical, and managerial. Perhaps the automated executive of the future has a great deal in common with

the automated worker or clerk whom we can already observe in many situations today.

First, however, we must establish a framework and a point of view. Our task is to forecast the changes that will take place over the next generation in the job of the manager. It is fair to ask: Which manager? Not everyone nor every job will be affected in the same way; indeed, most persons who will be affected are not even managers at the present time. Moreover, we must distinguish the gross effects of a technological change, occurring at the point of impact of that change, from the net effects, the whole series of secondary ripples spreading from that point of initial impact.

Many of the initial effects are transitory—important enough to those directly involved at the time and place of change, but of no lasting significance to the society. Other effects are neither apparent nor anticipated when the initial change takes place but flow from it over a period of years through the succession of reactions it produces. Examples of both transient and indirect effects of change come to mind readily enough—e.g., the unemployment of blacksmiths and the appearance of suburbia, respectively, as effects of the automobile.

Since our task is to look ahead twenty-five years, I shall say little about the transient effects of the change in the job of the manager. I do not mean to discount the importance of these effects to the people they touch. In our time we are highly conscious of the transient effects, particularly the harmful ones, the displacements of skill and status. We say less of the benefit to those who acquire the new skills or of the exhilaration that many derive from erecting new structures.

Of course, the social management of change does not consist simply in balancing beneficial transient effects against harmful ones. The simplest moral reasoning leads to a general rule for the introduction of change: The general society which stands to benefit from the change should pay the major costs of introducing it and should compensate generously those who would otherwise be harmed by it. A discussion of the transient effects of change would have to center on ways of applying that rule. But that is not the problem we have to deal with here.

Our task is to forecast the long-run effects of change. First of all, we must predict what is likely to happen to the job of the individual manager, and to the activity of management in the individual organization. Changes in these patterns will have secondary effects on the occupational profile in the economy as a whole. Our task is to picture the society after it has made all these secondary adjustments and settled down to its new equilibrium.

Let me now indicate the general plan I shall follow in my analysis. In the first section, "Predicting Long-run Equilibrium," I shall identify the key factors—the causes and the conditions of change—that will mold the analysis. Then I shall show how a well-known tool of economic analysis—the doctrine of comparative advantage—permits us to draw valid inferences from these causes and conditions. In the second section, "The New Technology of Information Processing," I shall describe the technological innovations that have appeared and are about to appear in the areas of production and data processing, and I shall use this material to draw a picture of the business organization in 1985, with particular attention to the automation of blue-collar and clerical work. In the third section, "The Automation of Management," I shall consider more specifically the role of the manager in the future business organization. In the final section, "The Broader Significance of Automation," I shall try to identify some of the important implications of these developments for our society and for ourselves as members of it.

PREDICTING LONG-RUN EQUILIBRIUM

To predict long-run equilibrium, one must identify two major aspects of the total situation: (1) the variables that will change autonomously and inexorably—the "first causes," and (2) the constant, unchanging "givens" in the situation, to which the other variables must adjust themselves. These are the hammer and the anvil that beat out the shape of the future. The accuracy of our predictions will depend less upon forecasting exactly the course of change than upon assessing correctly which factors are the unmoved movers and which the equally unmoved invariants. My entire forecast rests on my identification of this hammer and this anvil.

The Causes of Change

The growth in human knowledge is the primary factor that will give the system its direction—in particular, that will fix the boundaries of the technologically feasible. The growth in real capital is the major secondary factor in change—within the realm of what is technologically feasible, it will determine what is economical.

The crucial area of expansion of knowledge is not hard to predict, for the basic innovations—or at least a large part of them—have already occurred and we are now rapidly exploiting them. The new knowledge consists in a fundamental understanding of the processes of thinking and learning or, to use a more neutral term, of complex information processing. We can now write programs for electronic computers that enable these devices to think and learn.[a] This knowledge is having, and will have, practical impacts in two directions: (1) because we can now simulate in considerable detail an important and increasing part of the processes of the human mind, we have available a technique of tremendous power for psychological research; (2) because we can now write complex information-processing programs for computers, we are acquiring the technical capacity to replace humans with computers in a rapidly widening range of "thinking" and "deciding" tasks.

Closely allied to the development of complex information-processing techniques for general-purpose computers is the rapid advance in the technique of automating all sorts of production and clerical tasks. Putting these two lines of development together, I am led to the following general predictions: Within the very near future—much less than twenty-five years—we shall have the *technical* capability of substituting machines for any and all human functions in organizations. Within the same period, we shall have acquired an extensive and empirically tested theory of human cognitive processes and their interaction with human emotions, attitudes, and values.

To predict that we will have these technical capabilities says nothing of how we shall use them. Before we can forecast that, we must discuss the important invariants in the social system.

The Invariants

The changes that our new technical capability will bring about will be governed, particularly in the production sphere, by two major fixed factors in the society. Both of these have to do with the use of human resources for production.

1. Apart from transient effects of automation, the human re-

[a] For documentation of this claim, see under "The Nearly Automatic Factory and Office," pp. 26 ff.

sources of the society will be substantially fully employed. *Full employment* does not necessarily mean a forty-hour week, for the allocation of productive capacity between additional goods and services and additional leisure may continue to change as it has in the past. *Full employment* means that the opportunity to work will be available to virtually all adults in the society and that, through wages or other allocative devices, the product of the economy will be distributed widely among families.

2. The distribution of intelligence and ability in the society will be much as it is now, although a substantially larger percentage of adults (perhaps half or more) will have completed college educations.

These assumptions—of capability of automation, accompanied by full employment and constancy in the quality of the human resources—provide us with a basis for characterizing the change. We cannot talk about the technological unemployment it may create, for we have assumed that such unemployment is a transient phenomenon—that there will be none in the long run. But the pattern of occupations, the profile showing the relative distribution of employed persons among occupations, may be greatly changed. It is the change in this profile that will measure the organizational impact of the technological change.

The change in the occupational profile depends on a well-known economic principle, the doctrine of comparative advantage. It may seem paradoxical to think that we can increase the productivity of mechanized techniques in all processes without displacing men somewhere. Won't a point be reached where men are less productive than machines in *all* processes, hence economically unemployable?[a]

[a] The difficulty that laymen find with this point underlies the consistent failure of economists to win wide general support for the free trade argument. The central idea—that comparative advantage, not absolute advantage, counts—is exactly the same in the two cases.

The paradox is dissolved by supplying a missing term. Whether man or machines will be employed in a particular process depends not simply on their relative productivity in physical terms but on their cost as well. And cost depends on price. Hence—so goes the traditional argument of economics —as technology changes and machines become more productive, the prices of labor and capital will so adjust themselves as to clear the market of both. As much of each will be employed as offers itself at the market price, and the market price will be proportional to the marginal productivity of that factor. By the operation of the market place, manpower will flow to those processes in which its productivity is comparatively high relative to the productivity of machines; it will leave those processes in which its productivity is comparatively low. The comparison is not with the productivities of the past, but among the productivities in different processes with the currently available technology.

I apologize for dwelling at length on a point that is clearly enough stated in the *Wealth of Nations*. My excuse is that contemporary discussion of technological change and automation still very often falls into error through not applying the doctrine of comparative advantage correctly and consistently.

We conclude that human employment will become smaller relative to the total labor force in those kinds of occupations and activities in which automatic devices have the greatest comparative advantage over humans; human employment will become relatively greater in those occupations and activities in which automatic devices have the least comparative advantage.[4]

[4] I am oversimplifying, for there is another term in this equation. With a general rise in productivity and with shifts in relative prices due to uneven technological progress in different spheres, the demands for some kinds of goods and services will rise more rapidly than the demands for others. Hence, other things being equal, the total demand will rise in those occupations (of men and machines) that are largely concerned with producing the former, more rapidly than in occupations concerned largely with producing the latter. I have shown elsewhere how all these mechanisms can be handled formally in analyzing technological change. See "Productivity and the Urban-Rural Population Balance," in *Models of Man*, John Wiley & Sons, Inc.: New York, 1957, chap. 12; and "Effects of Technological Change in a Linear Model," in T. Koopmans (ed.), *Activity Analysis of Production and Allocation*, John Wiley & Sons, Inc.: New York, 1951, chap. 15; see also pp. 28–29 below.

Thus, if computers are a thousand times faster than bookkeepers in doing arithmetic, but only one hundred times faster than stenographers in taking dictation, we shall expect the number of bookkeepers per thousand employees to decrease but the number of stenographers to increase. Similarly, if computers are a hundred times faster than executives in making investment decisions, but only ten times faster in handling employee grievances (the quality of the decisions being held constant), then computers will be employed in making investment decisions, while executives will be employed in handling grievances.

THE NEW TECHNOLOGY OF INFORMATION PROCESSING

The automation of manufacturing processes is a natural continuation and extension of the Industrial Revolution. We have seen a steady increase in the amount of machinery employed per worker. In the earlier phases of mechanization, the primary function of machinery was to replace human energy with mechanical energy. To some extent in all phases, and to a growing extent in recent developments, another goal has been to substitute mechanical for human sensing and controlling activities. Those who distinguish the newer "automation" from the older "mechanization" stress our growing ability to replace with machines simple human perceiving, choosing, and manipulating processes.

The Nearly Automatic Factory and Office

The genuinely automatic factory—the workerless factory that can produce output and perhaps also, within limits, maintain and repair itself—will be technically feasible long before our twenty-five years have elapsed. From very unsystematic observation of changes going on in factories today, one might surmise that the typical factory of 1985 will not, however, be fully automatic. More likely the typical factory will have reached, say, the level of automaticity that has been attained in 1960 by the most modern oil refineries or power generating stations.

The same kinds of technical developments that lead toward the automatic factory are bringing about an even more rapid revolution—and perhaps eventually a more complete one—in large-scale clerical operations. The very abstract nature of symbol manipulation facilitates the design of equipment to do it, and the further automation of clerical work is impeded by fewer technical barriers than the further automation of factory production. We can conjecture that by 1985 the departments of a company concerned with major clerical functions—accounting, processing of customers' orders, inventory and production control, purchasing, and the like—will have reached an even higher level of automation than most factories.

Both the factory and the office, then, are rapidly becoming complex man-machine systems with a very large amount of production equipment, in the case of the factory, and computing equipment, in the case of the office, per employee. The

clerical department and the factory will come more and more to resemble each other. The one will present the picture of a small group of employees operating (I am tempted to use the more accurate phrase *collaborating with*) a large computing system; the other, the picture of a similar small group of employees operating a large production system. The interrelation of man with machine will become quite as important a design problem for such systems as the interrelation of man with man.

Now we must not commit the error I warned against in discussing the doctrine of comparative advantage. When we foresee fewer employees in factory and office, we mean fewer per unit of output and fewer per unit of capital equipment. It does not follow that there will be fewer in total. To predict the occupational profile that will result, we must look more closely at the prospective rates of automation in different occupations.

Before we turn to this task, however, it is worth reporting a couple of the lessons that are currently being learned in factory and clerical automation:

1. Automation does not mean "dehumanizing" work. On the contrary, in most actual instances of recent automation jobs were made, on the whole, more pleasant and interesting, as judged by the employees themselves, than they had been before. In particular, automation may move more and more in the direction of eliminating the machine-paced assembly line task and the repetitive clerical task. It appears generally to reduce the "work-pushing," "man-driving," and "expediting" aspects of first-line supervision.

2. Contemporary automation does not generally change to an important extent the profile of skill levels among the employees. It perhaps calls, on the average, for some upgrading

of skills in the labor force, but conflicting trends are observable at different stages in automation.[5]

The Occupational Profile

To predict the occupational distribution of the employed population in 1985, we would have to go down the list of occupations and assess, for each, the potentialities of automation. Even if we could do this, our inferences would not be quite direct. For we also have to take into account (1) income elasticity of demand—the fact that as productivity rises, the demands for some goods and services will rise more rapidly than the demands for others; (2) price elasticity of demand—the fact that the most rapidly automated activities will also show the greatest price reductions, so that the net reduction in employment in these activities will be substantially less than the gross reduction at a constant level of production.

As a fanciful example, let us consider the number of persons engaged in the practice of psychiatry. It is reasonable to assume that the demand for psychiatric services, at constant prices, will increase more than proportionately with an increase in income. Hence, the income effect of the general increase in a society's productivity will be to increase the proportion of psychiatrists in the employed population. Now, let us suppose that a specific technological development permits the automation of psychiatry itself, so that one psychiatrist can do the

[5] I think I have fairly summarized the conclusions reached by those few observers who have looked in detail at actual cases of recent automation. Two excellent references are James R. Bright, *Automation and Management*, Harvard University Graduate School of Business Administration: Boston, 1958; and S. Lilley, *Automation and Social Progress*, International Publishers Co., Inc.: New York, 1957.

work formerly done by ten.[6] It is not at all clear whether a 90 per cent reduction in price of psychiatric services would increase the demand for those services by a factor of more or less than ten. But if the demand increased by a factor of more than ten, the proportion of persons employed in psychiatry would actually increase.

Thus prediction of the occupational profile depends on estimates of the income and price elasticity of demand for particular goods and services as well as estimates of relative rates of increase in productivity. This is not the only difficulty the forecaster faces. He must also be extremely cautious in his assumptions as to what is, and what is not, likely to be automated. In particular, automation is not the only way to reduce the cost of a process—a more effective way is to eliminate it. An expert in automation would tell you that the garbage collector's job is an extremely difficult one to automate (at any reasonable cost) in a straightforward way. It has, of course, simply been eliminated in many communities by grinding the garbage and transporting it in liquid through the sewerage system. Such Columbus-egg solutions of the production problem are not at all rare, and will be an important part of automation.[7]

Another Approach to Prediction

With all these reservations and qualifications is any prediction possible? I think it is, but I think it requires us to go back to

[6] This example will seem entirely fanciful only to persons not aware of some of the research now going on into the possible automation of psychiatric processes.

[7] I advise the reader, before he makes up his mind as to what is feasible and infeasible, likely and unlikely, to try out his imagination on a sample of occupations, e.g., dentist, waitress, bond salesman, chemist, carpenter, college teacher.

some fundamentals. The ordinary classification of occupations is basically an "end-use" classification—it indicates what social function is performed by each occupation. To understand automation, we must begin our classification of human activities at the other end—what basic capacities does the human organism bring to tasks, capacities that are used in different proportions for different tasks?

Viewed as a resource in production, a man is a pair of eyes and ears, a brain, a pair of hands, a pair of legs, and some muscles for applying force. Automation proceeds in two ways: (1) by providing mechanized means for performing some of the functions formerly performed by a man and (2) by eliminating some of these functions. Moreover, the mechanized means that replace the man can be of a general-purpose character (like the man) or highly specialized.

The steam engine and the electric motor are relatively general-purpose substitutes for muscles. A butter-wrapping machine is a special-purpose substitute for a pair of hands which eliminates some eye-brain activities the human butter wrapper would require. A feedback system for controlling the temperature of a chemical process is a special-purpose substitute for eyes, brain, and hands. A digital computer employed in preparing a payroll is a relatively general-purpose substitute for eyes, brain, and hands. A modern multitool milling machine is a special-purpose device that eliminates many of the positioning (eye-brain-hand) processes that were formerly required in a sequence of machining operations.

The earlier history of mechanization was characterized by: (1) rapid substitution of mechanical energy for muscles; (2) partial and spotty introduction of special-purpose devices that

performed simple, repetitive eye-brain-hand sequences; (3) elimination, by mechanizing transport and by coordinating sequences of operations on a special-purpose basis, of many human eye-brain-hand sequences that had previously been required.

Thus, man's comparative advantage in energy production has been greatly reduced in most situations—to the point where he is no longer a significant source of power in our economy. He has been supplanted also in performing many relatively simple and repetitive eye-brain-hand sequences. He has retained his greatest comparative advantage in: (1) the use of his brain as a flexible general-purpose problem-solving device, (2) the flexible use of his sensory organs and hands, and (3) the use of his legs, on rough terrain as well as smooth, to make this general-purpose sensing-thinking-manipulating system available wherever it is needed.

This picture of man's functions in a man-machine system was vividly illustrated by the construction work going on outside my window. Most of the energy for earth-digging was being supplied by the mechanical elephants, but each depended on its mahout for eyes and (if you don't object to my fancy) for eye-trunk coordination. The fact that the elephant was operating in rough, natural terrain made automation of the mahout a difficult, although by no means insoluble, technical problem. It would almost certainly not now be economical. But other men—the men with wheelbarrows particularly—were performing even more "manual" and "primitive" tasks. Again, the delivery of the concrete to the forms could have been much more fully automated but at a high cost. The men provided a flexible, if not very powerful, means for delivering small quantities of concrete to a number of different points over uneven terrain.

"Flexibility" and general-purpose applicability is the key to most spheres where the human has a comparative advantage over the machine. This raises two questions:

1. What are the prospects for matching human flexibility in automatic devices?

2. What are the prospects for matching humans in particular activities by reducing the need for flexibility?

The second question is a familiar one throughout the history of mechanization; the first alternative is more novel.

Flexibility in Automata

We must consider separately the sensory organs, the manipulatory organs, the locomotive organs, and the central nervous system. Duplicating the problem-solving and information-handling capabilities of the brain is not far off; it would be surprising if it were not accomplished within the next decade. But these capabilities are so much involved in management activity that we shall have to discuss them at length in a later section.

We are much further from replacing the eyes, the hands, and the legs. From an economic as well as a technological standpoint, I would hazard the guess that automation of a flexible central nervous system will be feasible long before automation of a comparably flexible sensory, manipulative, or locomotive system. I shall state later my reasons for thinking this.

If these conjectures are correct, we may expect (other things being equal) automation of thinking and symbol-manipulating functions to proceed more rapidly than the automation of the more complex eye-brain-hand sequences. But before we grasp this conclusion too firmly, we need to remove one assumption.

Environmental Control a Substitute for Flexibility

If we want an organism or mechanism to behave effectively in a complex and changing environment, we can design into it adaptive mechanisms that allow it to respond flexibly to the demands the environment places on it. Alternatively, we can try to simplify and stabilize the environment. We can adapt organism to environment or environment to organism.

Both processes have been significant in biological evolution. The development of the multicellular organism may be interpreted as simplifying and stabilizing the environment of the internal cells by insulating them from the complex and variable external environment in which the entire organism exists. This is the significance of homeostasis in evolution—that in a very real sense it adapts the environment to the organism (or the elementary parts of the organism) and hence avoids the necessity of complicating the individual parts of the organism.

Homeostatic control of the environment (the environment, that is, of the individual worker or the individual machine) has played a tremendous role in the history of mechanization and in the history of occupational specialization as well. Let me cite some examples that show how all-pervasive this principle is:

1. The smooth road provides a constant environment for the vehicle—eliminating the advantages of flexible legs.

2. The first step in every major manufacturing sequence (steel, textiles, wood products) reduces a highly variable natural substance (metallic ore, fiber, trees) to a far more homogeneous and constant material (pig iron, thread, boards, or pulp). All subsequent manufacturing processes are thus insulated from the variability of the natural material. The applica-

tion of the principle of interchangeable parts performs precisely the same function for subsequent manufacturing steps.

3. By means of transfer machines, work in process in modern automated lines is presented to successive machine tools in proper position to be grasped and worked, eliminating the sensory and manipulative functions of workers who formerly loaded such tools by hand.

We see that mechanization has more often proceeded by eliminating the need for human flexibility—replacing rough terrain with a smooth environment—than by imitating it. Now homeostatic control of the environment tends to be a cumulative process. When we have mechanized one part of a manufacturing sequence, the regularity and predictiveness secured from this mechanization generally facilitates the mechanization of the next stage.

Let us apply this idea to the newly mechanized data-processing area. One of the functions that machines perform badly at present, humans rather well, is reading printed text. Because of the variability of such text, it would seem that the human eye is likely to retain for some time a distinct comparative advantage in handling it. But the wider the use of machines in data processing, the more pains we will take to prepare the source data in a form that can be read easily by a machine. Thus, if scientific journals are to be read mostly by machines, and only small segments of their scanning presented to the human researchers, we shall not bother to translate manuscripts into linotype molds, molds into slugs, and slugs into patterns of ink on paper. We shall, in time, use the typewriter to prepare computer input—punched tape or cards, for example, and simply bypass the printed volume.

Now these considerations do not alter our earlier conclusion

that humans are likely to retain their comparative advantage in activities that require sensory, manipulative, and motor flexibility (and, to a much lesser extent, problem-solving flexibility). They show, however, that we must be careful not to assume that the particular activities that now call for this flexibility will continue to do so. The stabilization of the environments for productive activity will reduce or eliminate the need for flexible response at many points in the productive process, continuing a trend that is as old as multicellular life. In particular, in the light of what has been said of the feasibility of automating problem solving, we should not make the simple assumption that the higher-status occupations, and those requiring most education, are going to be the least automated. There are perhaps as good prospects technically and economically for automating completely the job of a physician, a corporate vice-president, or a college teacher, as for automating the job of the man who operates a piece of earth-moving equipment.

Man as Man's Environment

In most work situations, an important part of man's environment is man. This is, moreover, an exceedingly "rough" part of his environment. Interacting with his fellow man calls on his greatest flexibility both in sensory activity and response. He must read the nuances of expressions, postures, intonations; he must take into account in numerous ways the individuality of the person opposite him.

What do we mean by *automating* those activities in organizations that consist in responding to other men? I hardly know how to frame the question, much less to answer it. It is often asserted—even by people who are quite sophisticated on the general subject of automation—that personal services cannot be automated, that a machine cannot acquire a bedside manner or produce the positive effect that is produced by a courteous sales clerk.

Let me, at least for purposes of argument, accept that proposition. (It leaves me uneasy, for I am aware of how many people in our own culture have affective relations with such mechanisms as automobiles, rolling mills—and computers.) Accepting it does not settle the question of how much of man's environment in the highly automatized factory or office will be man. For much of the interpersonal activity called for in organizations results from the fact that the basic blue-collar and clerical work is done by humans, who need supervision and direction. Another large chunk of interpersonal activity is the buying and selling activity—the work of the salesman and the buyer.

As far as supervisory work is concerned, we might suppose that it would decrease in the same proportion as the total number of employees; hence that automation would not affect the occupational profile in this respect at least. This may be true in first approximation, but it needs qualification. The amounts and types of supervision required by a work force depend on many things, including the extent to which the work pace is determined by the men or by machines and the extent to which the work is prescheduled. Supervision of a machine-paced operation is a very different matter from supervision of an operation where the foreman is required to see that the workers maintain a "normal" pace—with or without incentive schemes. Similarly, a highly scheduled shop leaves room for much less "expediting" activity than one where scheduling is less formal and complete.

As a generalization, I would predict that "work-pushing" and "expediting" will make up a much smaller part of the

supervisory job at lower and middle levels in highly automated operations than they generally do at present. Whether these activities will be replaced, in the total occupational profile, by other managerial activities we shall have to consider a little later.

What about the salesman? I have little basis for conjecture on this point. If we think that buying decisions are not going to be made much more objectively than they have in the past, then we might conclude the automation of the salesman's role will proceed less rapidly than the automation of many other jobs. If so, selling will account for a larger fraction of total employment.

Summary: Blue-collar and Clerical Automation

We can now summarize what we have said about the prospects of the automatic factory and office and about the general characteristics of the organization that the executive of 1985 will manage. Clearly, it will be an organization with a much higher ratio of machines to men than is characteristic of organizations today. The men in the system can be expected to play three kinds of roles:

a. There will be a few vestigial "workmen"—probably a smaller part of the total labor force than today—who will be part of in-line production, primarily doing tasks requiring relatively flexible eye-brain-hand coordination (a few wheelbarrow pushers and a few mahouts).

b. There will be a substantial number of men whose task is to keep the system operating by preventive and remedial maintenance. Machines will play an increasing role, of course, in maintenance functions, but machine powers will not likely develop as rapidly relatively to those of men in this area as in in-line activities. Moreover, the total amount of maintenance work—to be shared by men and machines—will increase. For the middle run, at least, I would expect this group to make up an increasing fraction of the total work force.

c. There will be a substantial number of men at professional levels, responsible for the design of product, for the design of the productive process, and for general management. We have still not faced the question of how far automation will go in these areas, and hence we cannot say very firmly whether such occupations will be a larger or smaller part of the whole. Anticipating our later analysis, I will conjecture that they will constitute about the same part as they do now of total factory and office employment.

A second important characteristic of future production and data-processing organizations is that some of the kinds of interpersonal relations—in supervising and expediting—that at present are very stressful for most persons engaged in them, will be substantially reduced in importance.

Finally, in the entire occupied population, a larger fraction of members than at present will be engaged in occupations where "personal service" involving face-to-face human interaction is an important part of the job. I am confident in stating this conclusion; far less confident in conjecturing what these occupations will be, for the reasons already set forth.

In some respects—especially in terms of what "work" means to those engaged in it—this picture of the automated world of the future does not look drastically different from the world of the present. Under the general assumptions we made—rapid automation, but under full employment and with a stable skill profile—it will be a "happier" or more relaxed place than it is now; perhaps more of us will be salesmen. As far as man's productive life is concerned, these do not appear to be earth-

shaking changes. Moreover, our conclusions do not depend very sensitively on the exact degree of automation we predict: A little more or a little less would not change the occupational picture much.

THE AUTOMATION OF MANAGEMENT

I have several times sidestepped the question of how far and how fast we could expect management activities to be automated. I have said something about supervision, but little about the large miscellany of management activities involving decision making, problem solving, and just plain "thinking."

In what follows I shall use the terms *decision making* and *problem solving* in a broad sense to refer interchangeably to this whole range of activities. Decision making in this sense involves much more than the final choice among possible courses of action. It involves, first of all, detecting the occasions for decision—the problems that have to be dealt with—and directing the organization's attention to them. It involves, secondly, developing possible problem solutions—courses of action—among which the final choice can be made. Discovering and defining problems, elaborating courses of action, and making final choices are all stages in the decision-making process. When the term *decision making* is used, we generally think of the third stage, but the first two account for many more man-hours of effort in organizations than the third. Much more management effort is allocated to attention-directing functions and to the investigation, fact gathering, design, and problem solving involved in developing courses of action than to the process of selection. Decision making, defined in this broad way, constitutes the bulk of managerial activity.

The problems that managers at various levels in organizations face can be classified according to how well structured, how routine, how cut and dried they are when they arise. On the one end of the continuum are highly programed decisions: routine procurement of office supplies or pricing standard products; on the other end of the continuum are unprogramed decisions: basic, once-for-all decisions to make a new product line, or strategies for labor negotiations on a new contract, or major styling decisions. Between these two extremes lie decisions with every possible mixture of programed and nonprogramed, well-structured and ill-structured, routine and nonroutine elements.

There is undoubtedly a rough, but far from perfect, correlation between a manager's organizational level and the extent to which his decisions are programed. We would expect the decisions that the president and vice-president face to be less programed, on the average, than those faced by the factory department head or the factory manager.

We are now in the early stages of a technological revolution of the decision-making process. That revolution has two aspects, one considerably further advanced than the other. The first aspect, concerned largely with decisions close to the programed end of the continuum, is the province of the new field called *operations research* or *management science*. The second aspect, concerned with unprogramed as well as programed decisions, is the province of a set of techniques that are coming to be known as *heuristic programing*.

Operations Research

I will not recount the history of operations research. It is largely the product of efforts that began on a large scale during World War II. Nor will I essay a careful definition, for operations research is as much a social movement—a migration of

natural scientists, econometricians, and mathematicians into the area of business decision making—as it is a definable body of knowledge.

Operations research attempts to apply mathematics and the capabilities of modern electronic computers to business decision making. By now it is clear that the attempt is going to be highly successful. Important areas of business and engineering decision making have yielded to these techniques, and the area of possible and actual application continues to grow.

Let me be more concrete and show how operations research is affecting management and how it will affect it. I shall ignore business data processing—the automation of clerical activities —and look exclusively at management activities. I can describe the situation by examples, for we are interested in the technical and economic potential of these techniques, not the present extent of their use.

1. Managers make a whole series of decisions to control inventory and production: purchasing decisions, setting the production rate and product mix, ordering stock for warehouses, shipping decisions, and the like. Several alternative mathematical techniques are now available for making such decisions; these techniques have been more or less extensively tested in practical situations, and they are being used in day-to-day decision making in a number of companies. The evidence seems to me convincing that decisions of these kinds can now be made, in most situations, with the aid of operations research techniques and with the virtual elimination of managerial "judgment," far better than such decisions have been made in the past. Moreover, in most tests that have been made, even at this early stage in the development and application of such techniques, they have shown that they can justify themselves eco-

nomically. There is little or no excuse for purchasing agents, production control managers, factory managers, or warehouse managers intervening in such decisions any more. (I hasten to add that, as with any new technique, a company that wishes to make use of it must be willing to incur some development and training expense.)

2. The injection of the mathematical techniques just mentioned into the clerical processes involved in procurement, factory production control, and filling customers' orders can permit the virtually complete automation of this flow in many situations, with the removal of both clerical and low-level management participation from the day-to-day activity. Customers' orders can be received and filled, the customer invoiced, orders placed on the factory, and raw-material stocks replenished—all untouched by human hands and unthought of by human decision makers.

3. Mathematical techniques for detailed scheduling of factory production, while less far advanced than the techniques just described, will almost certainly have reached within five or ten years the point where scheduling can also be completely automated, both in its clerical and in its decision-making aspects.

4. In the early years of the computer, one of its main applications was to relieve engineering organizations of the bulk of routine calculations in design. The computer initially was a clerical aid to analysis. Within the past three or four years, we have discovered how the computer can also take over the design-synthesis job in many relatively simple situations. (Though these situations are "simple," they were complex enough to require the services of college-trained engineers.) To put it simply, computers can now take customers' orders

for many types of electric motors, generators, and transformers, synthesize devices that meet the design specifications, and send the manufacturing specifications to the factory floor—again untouched by human hands. Where these techniques are now used, it is reported that they yield improved designs at about the same cost as the human design process they replace.

5. Computers, programed to carry out linear programing calculations, are now widely used to determine product mix for oil refineries and to determine formulas for commercial feed mixes. The Iowa farmer who tunes in to the morning radio reports of hog prices now learns from the commercial that XYZ feed gives him the best nutrition at the lowest cost because it is blended by electronic computers using modern mathematical techniques.

6. A large commercial airline has used computers to simulate major parts of its flight and terminal operation and has used the simulation to decide how many reserve aircraft it needed—an investment decision of great magnitude.

The plain fact is that a great many middle-management decisions that have always been supposed to call for the experienced human judgment of managers and professional engineers can now be made at least as well by computers as by managers. Moreover, a large part of the total middle-management job consists of decisions of the same general character as those that have already yielded to automation. The decisions are repetitive and require little of the kinds of flexibility that constitute man's principal comparative advantage over machines. We can predict with some confidence, I think, that persons making such decisions will constitute a much smaller fraction of the total occupied group within a few years than they do now.

Heuristic Programing [8]

The mathematical and computing techniques for making programed decisions replace man but they do not generally simulate him. That is to say, a computer scheduling a refinery does not make the same calculations as would be made by an experienced refinery scheduler—even if it comes out with a very similar solution.[9]

This fact has led to some misconceptions about the nature of computers and about their potentialities. "Computers are just very speedy morons for carrying out arithmetic calculations," it is often said. "They only do what you program them to do." These statements belong to that class of half-truths that are important just because their implications are so misleading. I shall have to pause long enough to make some categorical statements about computers. I do not have space here to develop them at length.

1. Computers are very general devices capable of manipulating all kinds of symbols—words as readily as numbers. The fact that computers generally do arithmetic is an historical accident. If a particular decision-making situation is not quantitative we cannot handle it with traditional mathematical techniques. This constitutes no essential barrier to computerization. Much successful research has been carried out in the past five

[8] The ideas in this section grew out of work in a joint Carnegie Tech-RAND Corporation research project, and I am deeply indebted to Allen Newell, J. C. Shaw, and other colleagues in that project for this common product.

[9] On the other hand, the computer programs for synthesizing motor, tranformer, and generator design do mimic rather closely the processes previously used by engineers. These programs stand on the border line between the operations research techniques discussed in the previous section and the heuristic techniques discussed in this section.

years on the use of computers for processing nonnumerical information.

2. Computers behave like morons only because we are just beginning to learn how to communicate with them in something better than moronic language. There now exist so-called compiling techniques (e.g., FORTRAN) that instruct computers in general language very similar to the ordinary language of mathematics. With these compilers, we now can program a computer to evaluate a formula by writing down little more than the formula itself and the instruction: Do. Compiling techniques of almost comparable power have been developed for nonnumerical computing. They have not reached the point where they permit the programer to communicate with the computer in idiomatic English, but only in a kind of simple pidgin English.

3. Computers do only what you program them to do, but (*a*) you can program them to behave adaptively and (*b*) you can program them to improve their own programs on the basis of their experiences—that is, to learn. Hence, the more accurate statement is: Computers do only what you program them to do in exactly the same sense that humans do only what their genes and their cumulative experiences program them to do. This assertion leaves little room for free will in either computer or human, but it leaves a great deal of room in both for flexible, adaptive, complex, intelligent behavior.

4. It has now been demonstrated, by doing it, that computers can be programed to solve relatively ill-structured problems by using methods very similar to those used by humans in the same problem-solving situations: that is, by highly selective trial-and-error search using all sorts of rules of thumb to guide the selection; by abstracting from the given problem and solv-

ing first the abstracted problem; by using analogy; by reasoning in terms of means and ends, goals and subgoals; by adjusting aspirations to the attainable. There is no longer reason to regard phenomena like "judgment" and "insight" as either unanalyzable or unanalyzed, for, in some forms at least, these phenomena have been simulated—computers have exercised judgment and exhibited insight. The range of capabilities of computer programs of this sort is still extremely narrow, but the significant point is that some such programs have been written, tested, and even compared in their behavior with the behavior of human laboratory subjects performing the same tasks.

Computer programs that handle nonnumerical tasks, use humanoid problem-solving techniques (instead of the systematic algorithmic techniques of classical mathematics), and sometimes include learning processes, are called *heuristic programs.* They incorporate, in their processes, one or more aspects of what has been called "the art of plausible reasoning," an art that guides us through the numerous, diverse, ill-structured decisions of everyday life.

The engineering design programs I mentioned earlier are really heuristic programs, for they involve inductive reasoning. Heuristic programs have now been written for such tasks as playing checkers, playing chess, finding proofs for geometry theorems and for theorems in elementary symbolic logic, solving trigonometric and algebraic identities, balancing a factory assembly line, composing music (the ILLIAC Suite), and memorizing nonsense syllables. One program, the General Problem Solver, while not as general as its name may suggest, is entirely free from reference to any particular subject matter

and is, in fact, a quite flexible scheme for reasoning in terms of goals and subgoals about any subject.[10]

Let me make my point perfectly clear. Heuristic programs do not merely substitute machine brute force for human cunning. Increasingly, they imitate—and in some cases improve upon—human cunning. I can illustrate this by describing briefly the three existing computer programs for playing chess.[11] One of these, the Los Alamos program, depends heavily on machine speed. The program examines, at each move, almost one million alternative possibilities, evaluating them on the basis of simple, crude criteria and selecting the one that appears best. Clearly it is doing something quite different from the human chess player—the human neither could nor would select moves in this way. The second program, Bernstein's program, is much more selective. It examines about 2,500 alternatives, chosen on the basis of rules of thumb a chess player would use and evaluates them in a slightly more complicated way than does the Los Alamos program. The third program, the RAND-Carnegie program, is still more selective. It seldom examines as many as fifty alternatives but selects those to be examined and evaluates them in a rather involved way. All three programs, at present, play about the same level of chess—a very low level, it should be said. But they achieve this result in quite different ways. The Los Alamos program, though it embodies certain heuristic ideas, calls for

[10] See A. Newell, J. C. Shaw, and H. A. Simon, "Report on a General Problem-solving Program," reprinted in *Computers and Automation,* 8:10–17, July, 1959.

[11] See A. Newell, J. C. Shaw, and H. A. Simon, "Chess-playing Programs and the Problem of Complexity," *IBM Research and Development Journal,* 2:320–335, October, 1958.

machine speed rather than machine intelligence. The RAND-Carnegie program begins to approach, in the rules of thumb it embodies, the processes a human uses in choosing a chess move. Bernstein's program lies midway between the other two. Thus, in talking about our increasing capacity to write heuristic programs that simulate human problem solving, I am speaking of programs that lie toward the RAND-Carnegie end of this continuum rather than the Los Alamos end. I am speaking of programs that reason, think, and learn.

The microcosm of chess may still appear to you far more structured and programed than the macrocosm of the everyday world. Perhaps it is, although the point could be argued. However that may be, the microcosm of chess is sufficiently complex, sufficiently rich in alternatives, sufficiently irregular in structure that it poses to the problem-solving organism or mechanism the same ***kinds*** of difficulties and requirements that are posed—perhaps in higher degree—by ill-structured problems in general. Hence, the fact that chess programs, theorem-proving programs, music-composing programs, and a factory-scheduling program now exist indicates that the conceptual mountains have been crossed that barred us from understanding how the human mind grapples with everyday affairs. It is my conviction that no major new ideas will have to be discovered to enable us to extend these early results to the whole of human thinking, problem solving, decision-making activity. We have every reason to believe that within a very short time—I am even willing to say ten years or less—we will be able technically to produce computers that can grapple with and solve at least the range of problems that humans are able to grapple with and solve—those that are ill-structured as well as those that are well-structured.

If the technical prediction is correct, what about the economics of the matter? Again, we must apply the doctrine of comparative advantage. To what extent, in 1985, will managers and other humans be occupied in thinking about and solving ill-structured problems, as distinct from doing other things? On this point the image in my crystal ball is very dim. I will nevertheless hazard some guesses. My first guess is that man will retain a greater comparative advantage in handling ill-structured problems than in handling well-structured problems. My second guess is that he will retain a greater advantage in tasks involving sensory-manipulative coordination—"physical flexibility"—than in ill-structured problem-solving tasks—"mental flexibility." If this is true, a larger part of the working population will be mahouts and wheelbarrow pushers and a smaller part will be scientists and executives—particularly of the staff variety. The amount of shift in this direction will be somewhat diminished by the fact that as income and general productivity rise, the demand for work involving ill-structured problem solving will probably increase more than the demand for work involving flexible manipulation of the physical environment. The demand for psychiatric work will increase more rapidly than the demand for surgical work—but the rate of automation of the former will be much greater than the rate of automation of the latter.

A Summary: The Automation of Management

Our analysis rests on the assumption that managers are largely concerned with supervising, with solving well-structured problems, and with solving ill-structured problems. We have predicted that the automation of the second of these activities—solving well-structured problems—will proceed extremely rapidly; the automation of the third—solving ill-structured problems, moderately rapidly; and the automation of supervision more slowly. However, we have also concluded that, as less and less work becomes man paced and more and more of it machine paced, the nature of supervision will undergo change. There is no obvious way to assess quantitatively all these cross currents and conflicting trends. We might even conclude that management and other professional activities, taken collectively, may constitute about the same part of the total spectrum of occupations a generation hence as they do now. But there is reason to believe that the kinds of activities that now characterize middle management will be more completely automated than the others and hence will come to have a smaller part in the whole management picture.

Some Other Dimensions of Change in Management

There are other dimensions for differentiating management and professional tasks, of course, besides the one we have been using. It is possible that if we described the situation in terms of these other dimensions, the change would appear larger. Let me explore this possibility just a little bit further.

First, I think we can predict that in future years the manager's time perspective will be lengthened. As automated subsystems take over the minute-by-minute and day-by-day operation of the factory and office, the humans in the system will become increasingly occupied with preventive maintenance, with system breakdowns and malfunctions, and—perhaps most important of all—with the design and modification of systems. The automatic factory will pretty much—and subject to all of the qualifications I have introduced—run itself; the company executives will be much more concerned

with tomorrow's automatic factory. Executives will have less excuse than they now have to let the emergencies of today steal the time that was allocated to planning for the future. I don't think planning is going to be a machineless function—it also will be carried out by man-machine systems, but with perhaps a larger man component and a smaller machine component than day-to-day operations.

Does this mean that executives will need a high level of technical competence in the engineering of automated factories or data-processing systems? Probably not. Most automation calls for increased technical skills for maintenance in the early stages; but the farther automation proceeds, the less those who govern the automated system need to know about the details of its mechanism. The driver of a 1960 automobile needs to know less about what is under the hood than the driver of a 1910 automobile. The user of a 1960 computer needs to know less about computer design and operation than the user of a 1950 computer. The manager of a highly automated 1985 factory will need to know less about how things are actually produced, physically, in that factory than the manager of a 1960 factory.

Similarly, we can dismiss the notion that computer programers will become a powerful elite in the automated corporation. It is far more likely that the programing occupation will become extinct (through the further development of self-programing techniques) than that it will become all-powerful. More and more, computers will program themselves; and direction will be given to computers through the mediation of compiling systems that will be completely neutral so far as content of the decision rules is concerned. Moreover, the task of communicating with computers will become less and less technical as computers come—by means of compiling techniques—closer and closer to handling the irregularities of natural language.[12]

I suppose that managers will be called on, as automation proceeds, for more of what might be described as "systems thinking." They will need, to work effectively, to understand their organizations as large and complex dynamic systems involving various sorts of man-machine and machine-machine interactions. For this reason, persons trained in fields like servomechanism engineering or mathematical economics, accustomed to dynamic systems of these kinds, and possessing conceptual tools for understanding them, may have some advantage, at least initially, in operating in the new world. Since no coherent science of complex systems exists today, universities and engineering schools are understandably perplexed as to what kinds of training will prepare their present students for this world.

THE BROADER SIGNIFICANCE OF AUTOMATION

I have tried to present my reasons for making two predictions that appear, superficially, to be contradictory: that we will have the technical capability, by 1985, to manage corporations by machine; but that humans, in 1985, will probably be engaged in roughly the same array of occupations as they are now. I find both of these predictions reassuring.

Acquiring the technical capacity to automate production as fully as we wish, or as we find economical, means that our per capita capacity to produce will continue to increase far beyond the point where any lurking justification will remain for poverty or deprivation. We will have the means to rule out

[12] We can dismiss in the same way the fears that some have expressed that only mathematicians will be able to cope with a computerized world.

scarcity as mankind's first problem and to attend to other problems that are more serious.[13]

Since, in spite of this increased productivity, the occupations that humans will find in the corporation of 1985 will be familiar ones, we can dismiss two fears: first, the fear of technological unemployment, second, the "R.U.R. fear"—the fear that many people feel at the prospect of fraternizing with robots in an automated world. Fraternize we shall, but in the friendly, familiar way that we now fraternize with our automobiles and our power shovels.

Having dismissed, or dealt with, these two issues, we shall be better prepared to face the more fundamental problems of that automated world. These are not new problems, nor are they less important than the problems of scarcity and peace. But they are long-range rather than short-range problems, and hence seldom rise to the head of the agenda as long as there are more pressing issues still around. Three of them in particular, I think, are going to receive a great deal of attention as automation proceeds: developing a science of man, finding alternatives for work and production as basic goals for society, and reformulating man's view of his place in the universe.

A Science of Man

I have stressed the potentialities of the computer and of heuristic programing as substitutes for human work. The research now going on in this area is equally important for understanding how humans perform information-processing tasks—how they think. That research has already made major progress toward a psychology of cognitive processes, and

[13] In saying this, I am not unaware of the apparent insatiability of wants. We can, however, make moral distinctions between the neediness of an Indian peasant and the neediness of an American middle-class one-car family.

there are reasons to hope that the potential of the new tools is not limited to cognition but may extend to the affective aspects of behavior as well.

We can predict that in the world of 1985 we shall have psychological theories that are as successful as the theories we have in chemistry and biology today. We shall have a pretty good understanding of how the human mind works. If that prediction is correct, it has obvious and fundamental consequences for both pedagogy and psychiatry. We may expect very rapid advances in the effectiveness and efficiency of our techniques of teaching and our techniques for dealing with human maladjustment.

Social Goals

The continuing rise in productivity may produce profound changes, in addition to those already caused by the Industrial Revolution, in the role that work plays in man's life and among man's goals. It is hard to believe—although this may just exhibit the weakness of my imagination—that man's appetite for gadgets can continue to expand at the rate required to keep work and production in central roles in the society. Even Galbraith's proposal for diverting expenditures from gadgets to social services can only be a temporary expedient. We shall have to, finally, come to grips with the problem of leisure.

In today's society, the corporation satisfies important social and psychological needs in addition to the needs for goods and services. For those who do well in managerial careers, it satisfies needs for success and status. For some of these men and for others, it is one of the important outlets for creativity. In a society where scarcity of goods and services is of little importance, those institutions, including the corporation, whose

main function is to deal with scarcity, will occupy a less central position than they have in the past. Success in management will carry smaller rewards in prestige and status than it now does. Moreover, as the decision-making function becomes more highly automated, corporate decision making will perhaps provide fewer outlets for creative drives than it now does. Alternative outlets will have to be supplied.

Man in the Universe

It is only one step from the problem of goals to what psychiatrists now refer to as the "identity crisis," and what used to be called "cosmology." The developing capacity of computers to simulate man—and thus both to serve as his substitute and to provide a theory of human mental functions—will change man's conception of his own identity as a species.

The definition of man's uniqueness has always formed the kernel of his cosmological and ethical systems. With Copernicus and Galileo, he ceased to be the species located at the center of the universe, attended by sun and stars. With Darwin, he ceased to be the species created and specially endowed by God with soul and reason. With Freud, he ceased to be the species whose behavior was—potentially—governable by rational mind. As we begin to produce mechanisms that think and learn, he has ceased to be the species uniquely capable of complex, intelligent manipulation of his environment.

I am confident that man will, as he has in the past, find a new way of describing his place in the universe—a way that will satisfy his needs for dignity and for purpose. But it will be a way as different from the present one as was the Copernican from the Ptolemaic.