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ROBOTICS, PROGRAMMABLE AUTOMATION AND IMPROVING COMPETITIVENESS*

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* Prepared for the Robotics Workshop of the Congressional Office of Technology Assessment held in Washington, D. C. on July 31, 1981.

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ROBOTICS, PROGRAMMABLE AUTOMATION AND INCREASING COMPETITIVENESS*

Bela Gold**

More than 25 years of empirical research on the productivity, cost and other effects of major technological innovations in a wide array of industries in the U.S. and abroad have led me to draw two conclusions:

First: that the actual economic effects of even major technological advances have almost invariably fallen far short of their expected effects; and

Second: that such exaggerated expectations have been due to their overconcentration on only a limited sector of the complex of interactions which determine actual results.

Hence, sound analysis of the prospective effects of increasing applications of robotics in domestic industries on their cost effectiveness and international competitiveness requires avoidance of such over-simplifications.

Accordingly, Part I of this paper will present some foundations for policy analysis, including: the place of robotics within current and prospective advances in manufacturing technology; the effects of increasing robot utilization on productivity and costs; and the resulting effects on international competitiveness. Part II will then consider the problems and policy implications of seeking: to accelerate the development of robotics and related advances in manufacturing technology; to accelerate the diffusion of such advances within domestic manufacturing industries; and to mitigate any potentially burdensome social and economic effects of such developments.

I POLICY ANALYSIS FOUNDATIONS

A. Robotics and Programmable Automation in Manufacturing

1. Programmable Automation

Gains in the physical efficiency of manufacturing operations may be derived

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from a variety of developments. The most important among these include: advances in technology; increases in the scale of production; improvements in the output and quality capabilities of equipment; adjustments in labor contributions; and continuing increments in the effectiveness of production planning and control. Because the effectiveness of such operations depends on integrating all these factors, changes in any one are likely to interact with others. Hence, evaluation of the effects of any innovation requires consideration of all resulting readjustments in the system.

After basic advances in technology, the most important and continuous source of gains in the physical efficiency of production operations in the past has probably been increases in the specialization of facilities and equipment. The degree of specialization which was found most rewarding was determined by the variety and volume of output which needed to be processed by the given equipment. Thus, increases in the standardization of products and in the quantity required encouraged the introduction of progressively more narrowly specialized production systems. Eventually, the manufacture of completely uniform products in very large quantities led to the construction of interlocking arrays of highly specialized machines capable of producing enormous quantities with very great physical efficiency. Such "dedicated systems", however, permit only minor adjustments in product designs or processing methods. As a result, they are not applicable to the overwhelming proportion of manufacturing activities which involve the production of wider arrays of products in smaller quantities. In addition, the heavy investment required by such dedicated systems, combined with their very limited flexibility, also encourages their users to resist changes in products and improvements in production methods in an effort to use their existing equipment as long as possible.

Of course, engineering design permits a wide range in the extent to which specialization is built into production machinery. Thus, "general purpose" equipment may be designed to accommodate a wide array of tools and processing functions in return for limiting its rate of output as well as other capabilities in respect to any particular task. Such equipment's output is also heavily dependent on the concomitant specialized contributions of operators and other service personnel. And intermediate degrees of equipment specialization have offered progressively larger trade-offs of decreases in the range of functions capable of being performed,as well as decreases in reliance on the specialized contributions of operators and other external inputs,in return for increases in the level of output, quality and effectiveness of designated production tasks.

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AS a result of intensifying market pressures, there have been sharply increased efforts in recent years to improve the cost competitiveness of manufacturing operations devoted to a limited variety of products required in volumes ranging from relatively small to moderate. Such needs are dominant in most small and intermediate manufacturing plants as well as even in large plants manufacturing capital goods. By far the most important advance in such capabilities has come from the development of computerization and related communication and instrumentation capabilities. These permit the utilization of replaceable programmed instructions in combination with programmable controls to enable given equipment to turn out varying amounts of a succession of different parts with little or no operator requirements.

In order to help clarify the broad potentials of the resulting revolution in manufacturing technology which will be unfolding with accelerating rapidity over the next decade, it may be useful to illustrate the interconnected changes being generated as a result. Increasingly, the process will begin with computer-aided design (CAD), with engineers developing new designs on the screen of a terminal by specifying certain points on the screen and tapping instructions concerning the desired shapes and dimensions of the configurations to be drawn around them. The key point to understand is that in the course of projecting the design shown on the screen the computer is storing a detailed mathematical model of all of its features. It then becomes possible to use this information, or data base, for an expanding array of purposes. For example, the resulting definition of the dimensions and configurations of the designed part may be used in computer programs to generate such manufacturing requirements as:

1. a schedule of the sequence of machines to be used in producing the part;
2. specific operating instructions for each machine as well as identification of the tools required to perform such operations;
3. dimensional criteria for testing conformance of the finished part with design requirements;
4. production schedules specifying individual machine assignments to accord with estimated machining time required for each part and with previously scheduled machine loadings as well as delivery dates;
5. estimates of the unit cost of each operation, including the wages of the operator;
6. estimates of total unit costs of producing specified products may be used to determine bids for contracts; and

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7. combining the design data with materials specifications and planned output, along with expected scrap rates and waste, to generate procurement requirements.

As indicated in Figure 1, various other kinds of performance evaluation and control information may also be generated.

By tracing only one direction of such information flows, however, even the preceding impressive array of applications understates the potential benefits of such systems. In fact, all such flows move in both directions. Engineers can use them to explore the relative costs of alternative designs: Manufacturing specialists can evaluate alternative processing sequences and machining instructions. Inventory adjustments can be adapted to accord with production and distribution variations. Production requirements and manpower availabilities can be adapted to one another.

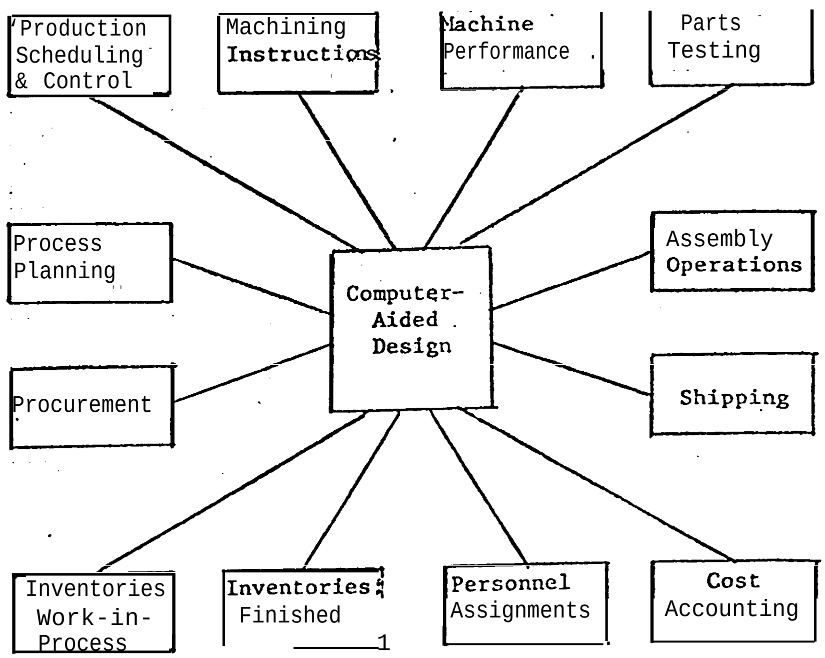

Figure 1: Potential Applications of Design Data Bases

Programs have already been developed to apply each of the possibilities cited above. But few plants are actually utilizing many of them on a continuing rather than an experimental basis. Despite the clarity of the logic involved, the development of a functioning system requires confronting very large masses of details and many alternative possibilities at most stages of defining sequential decisions. There can be little doubt, however, that the future will see increasing realization of such potentials with profound effects on the requirements for remaining competitive.[1]

2. On the Role of Robotics Within Programmable Automation

Most robots are used in manufacturing as mechanical replacements **for** formerly manual operations. Major categories of such assignments include "pick and place", "manipulate" and "process". Essentially, the first involves transferring individual parts from one location to another, the second usually involves bringing parts together, as in assembly, and the third involves carrying out actual operations, such as welding or painting or testing. The complexity of these efforts may be enhanced if the robot is required to select among several objects through identifying key characteristics, or if it has to sense proximity to its target location, or if it has to adapt its manipulative or processing efforts to variable conditions. Efforts to extend the range of applications **of** robots have accordingly involved shifting increasingly from mechanically guided and controlled models to those which are programmable, equipped with feedback controls, capable of some degree of "learning" and possessed of a wider array and more sensitive manipulative potentials. Thus, in the perspective of labor-replacement objectives, developmental programs have sought to supplement the greater strength, speed, fatigue resistance and imperviousness to boredom of robots with increasing such capabilities as visual discrimination, precision of location and movement, and sensitivity to touch, pressure and torque.

Robots have commonly taken the form of separate pieces of equipment which are readily movable from one location to another. This obviously yields advantages of mobility comparable to the relocation of operators to adjust to changes in production needs. But the performance of what have come to be considered as "robot-like" functions need not be restricted to such separate mobile units. Indeed, the development of flexible manufacturing systems (FMS), or programmable automation systems, may well involve new combinations of "built-in" robot-like functions. In the case of machining centers, for example, instead of using a separate robot to select needed tools from a rack and then

(1) For further discussion, see B. Gold, An Improved Model for Managerial Evaluation and Utilization of Computer-Aided Manufacturing: A Report to the National Research Council Committee on Computer-Aided Manufacturing, Washington, D. C., March 1981.

attach and remove them in proper sequence, this capability is built into the equipment. Various kinds of machines also have built-in capabilities for grasping, loading, unloading and passing parts along. And still others include devices for testing the conformance of finished parts with dimensional requirements.

The point being emphasized is that continuing development of programmable automation systems may well involve changes in the physical forms as well as in the functional capabilities of robot-like contributions to production. Physically separate units may be increasingly supplemented by replaceable attached units to service the changing requirements of particular machines, as well as by built-in robot-like capabilities in cases where the need for such services is expected to be continuous and to remain within a range which can be met effectively -- thus, many labor-replacing robots may themselves be replaced. Indeed, the very development of improved capabilities in robots may stimulate the redesign of later equipment to incorporate some of these additional functions. Hence, while it may remain feasible to assess the prospective effects of many individual robot applications, an increasing number of cases may require a broader evaluative context in order to ensure consideration of their interactions with other inputs as well as of other factors affecting performance in tightly integrated production operations.

B. ROBOTICS, MANUFACTURING PRODUCTIVITY AND COSTS

1. On the Concept and Measurement of Productivity

Despite widespread concern about lagging productivity in many U.S. industries, analyses of the problem and proposed improvement policies are still seriously handicapped in several ways. The most serious of these involves continuing reliance on inadequate concepts and misleading measures of productivity, such as "output per man-hour" or "value added per man-hour" or the supposedly sophisticated "total factor productivity" -- all of which can be shown to be of dubious value, when not actually misleading, for managerial purposes.

For example, "output per man-hour" has nothing to do with the effectiveness of production as a whole, or even with the effectiveness of labor contributions to output. By comparing the combined product of all inputs with the sheer volume of paid hours by one input, it patently ignores changes in the volume **and contributions of all other inputs.** "Value added per man-hour" repeats this error of attributing changes in output to only one of the inputs, but also encourages interpreting mere increases in wage rates, because they enter into value added, as evidences of increased "labor productivity". The grandly labelled "total factor productivity", on the other hand, is so overly aggregative as to make interpretations of resulting changes both difficult and highly vulnerable. Specifically, how is one to interpret changes in its ratio of "product value at fixed product prices" to "total costs at fixed factor prices"? Do they represent changes in deflated profit margins, or changes in the ratio of product price to factor price indexes, or changes in product-mix, or changes in a variety of other relevant factors including some aspects of productivity?

In addition to such erroneous concepts and measures, prevailing discussions of productivity problems and remedial policies are also undermined by highly vulnerable deductions about the causes of apparent changes in productivity levels and by dubious claims about the effects of productivity adjustments on costs and profitability. As a matter of fact, findings that output per man-hour, or value added per man-hour, or total factor productivity had increased or decreased by 5 per cent last year would reveal nothing to management about: what had caused this change; or how rewarding or burdensome it was; or what might be done to improve future performance.

In order to serve the practical requirements of management, a productivity measurement and analysis system must encompass all of the inputs whose interacting contributions determine the level of output and the effectiveness of production operations. For this purpose, one approach which has been applied in a wide array of industries utilizes the concept of a "network of productivity relationships". As shown in Figure 2, it encompasses the six components which management can manipulate in seeking to improve production efficiency: three representing the input requirements per unit of output of materials, labor and capital goods; (2) and three more representing the proportions in which these are combined with one another. The latter obviously need to be included because management could, for example, substitute more highly processed inputs in place

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(2) Fixed investment is related to capacity rather than to output, however, because that is what capital goods provide. Actual output may then vary with demand, entailing varying levels of idleness of such equipment. In measuring the proportions in which the major inputs are combined with one another, however, labor and materials inputs are compared not with total fixed investment but with actively-utilized fixed investment, i.e., with fixed investment adjusted for the ratio of output to capacity.

of using some of its own labor or equipment, *or* it could substitute more equipment to replace labor. The inter-connectedness of these six elements emphasizes that **a** change may be initiated in any one, but that its effects must then be traced around the entire network to ensure that all adaptive adjustments have been made which are necessary to reintegrate the system. This also means that an observed change in one of the links need not have been engendered in that link, hut rather have resulted as an adjustment to a change induced elsewhere in this system.

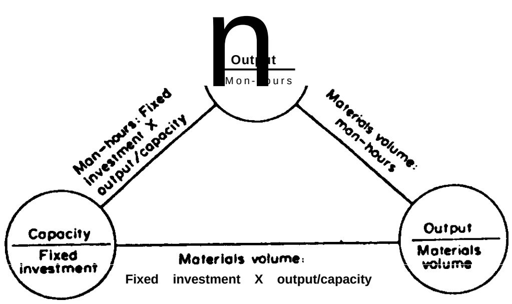

Fig. 2 The network of productivity relationships among direct input factors [9].

For example, mechanizing some manual operations would first affect the ratio of actively-utilized fixed investment to man-hours. This would tend to reduce man-hours per unit of output, while the attendant increase in fixed investment might alter its ratio to capacity. And if the innovation reduced scrap rates, it would also decrease the materials input volume per unit of output.

Because management's primary motivation in altering productivity relationships is usually to improve its cost competitiveness, it is necessary to evaluate past or prospective changes in the productivity network by tracing resulting effects on the cost structure. This involves, first, tracing the interaction of changes in each unit input requirement with its factor price to calculate resulting changes in its unit cost. For example, a 10 per cent increase in output per man-hour would yield only a 5 per cent reduction in unit wage cost, if it were accompanied by a 5 per cent increase in hourly wage rates. In turn, the effects of resulting changes in various unit costs on total unit costs depend, of course, on their respective proportions of total costs, as shown in Fig. 3.

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Thus , the preceding example of a five per cent reduction in unit wage costs would tend to reduce total unit costs by only one per cent if wages accounted for only 20% of total unit costs. And total unit costs need not have declined at all if the assumed ten per cent increase in output per man-hour had been engendered by increased investment in machinery,or by purchasing more highly processed and hence more expensive material inputs.

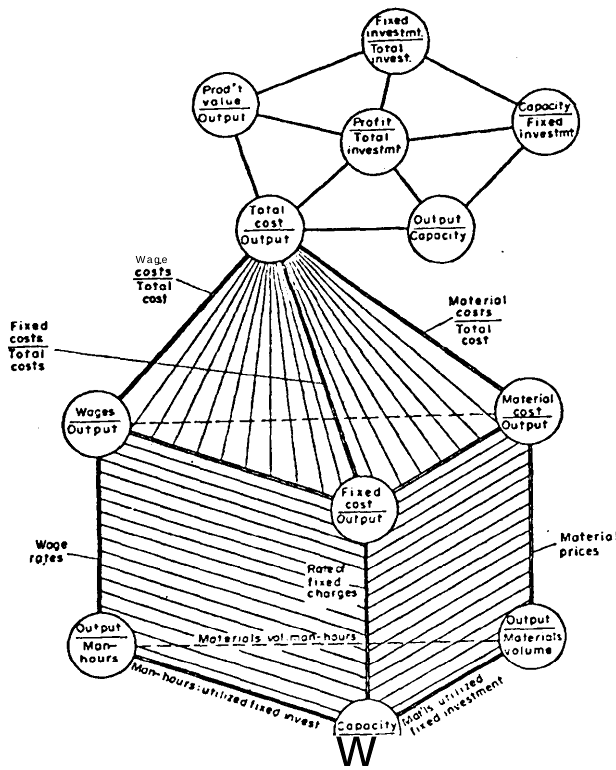

FIG. 3 Productivity network, cost structure and managerial control ratios.

Management tends to be even more concerned about the effects of prospective innovations on profitability than on costs. Hence, account must be taken of the fact that such effects involve not only the direct impact of changes 'on total unit costs, but also the indirect effects of any changes in product quality or product-mix on product prices and capacity utilization rates. In addition, profitability would also be affected by any changes in the proportion of total investment allocated to fixed investment and in the productivity of fixed investment. But this discussion will not pursue such further ramifications. It may be of interest to add, however, that the above analytical framework can be disaggregate from plant level results to results within individual product lines or individual cost centers, and it can also be decomposed to trace the effects of changes among various components of material, labor or capital goods inputs.(3)

2. Exploring Productivity and Cost Effects of Robotics and Programmable Automation

The preceding framework may now be used to trace the prospective effects of increased applications of robots and of broader systems of programmable automation.

Within the network of productivity relationships, the immediate impacts of introducing additional robots would tend to center around increases in fixed investment and reductions in labor requirements per unit of output. In cases where the utilization of machine capacity had been restricted by the sustainable speed of labor efforts, output capabilities might be increased. And in some processing operations, robots might reduce the reject rate or even raise the average quality of output. Of course, part of the reduction in direct man-hour requirements would tend to be offset by the need for providing additional skilled maintenance and set-up personnel as well as programming capabilities when required.

These indirect manpower requirements emphasize the need to consider the prospective effects of individual robot applications separately from the effects of robotization programs, especially when more complex programmable robots are involved. Simple mechanical robots which are introduced as direct replacements for labor without altering other component of the production process offer no special evaluation problems. But the requirements of more complex programmable robots for various types of skilled servicing technicians and even engineers involves the assumption of substantial specialized and relatively fixed minimum manpower commitments. Hence, the effectiveness with which these are utilized depends on the number and variety of robots to be employed. Indeed, such manpower requirements might offset most or all of the expected benefits of reductions in operator man-hours if the number of robots acquired were too small to utilize

(3) For more detailed discussion of this analytical approach and for some empirical findings resulting from its applications, see B. Gold, Productivity, Technology and Capital: Economic Analysis, Managerial Strategies and Government Policies (Lexington, MA: D.C. Heath-- Lexing on Press, 1979).

such additional expertise. Because of such threshold requirements, the evaluation of proposals for the acquisition of more complex robots should cover the planned program to be carried out over several years rather than charging the whole of such basic service manpower requirements against the first robots acquired.

As was indicated earlier, the effects of increasing the use of robots on unit manpower costs depends on resulting changes in the volume of direct and indirect manpower per unit of output and in their respective rates of payment. In the case of relative simple robots which replace labor and involve quite minimal demands on existing maintenance and set-up personnel, the result tends to be a sharp reduction in the unit wage cost of the particular operation which was affected. In the case of adoptions of more complex robots, such reductions in direct unit wage costs would tend to be at least partly offset by increases in the number of needed maintenance and other specialists as well as by their higher average earnings. The net effects on total unit manpower costs would depend then on the output levels over which these larger indirect costs were distributed. Thus, because of the decreased flexibility in employment levels for such service personnel, attendant changes in output levels may have a significant effect on total unit manpower costs as well as on total unit capital charges. But the introduction of robots is not likely to affect output levels except, as was noted earlier, where operator limitations of effort, fatigue or carefulness have resulted either in under-utilization of the related equipment capacity, or in higher reject rates (thus involving higher unit material costs as well) -- or where robots are subject to significant periods of unexpected downtime for repairs or readjustments.

Expected changes, in the total unit costs of the operation directly affected can then be readily calculated by weighting the estimated percentage change in unit materials, labor and capital costs by their respective proportions of total costs, as shown in Fig. 3. In the case of more complex robots, however, as exemplified by processing and assembly robots, a broader evaluation framework may be necessary if the effective functioning of such robots requires modifications in prior operations in order to provide more precise or higher quality parts to enter such processes. A broader evaluation framework may also be necessary if such robotized operations significantly affect the productivity and costs of subsequent stages of operations, or the quality of the final product in ways affecting prospective demand or prices.

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In short, the increasing diffusion of robots is likely to make only a modest, though still significant, contribution to improving the cost effectiveness of most manufacturing firms. One of the basic factors limiting such potential benefits is that direct wage costs seldom account for more than 15-25 per cent of total costs and any savings through reducing direct man-hour requirements tend to be partly offset by increases in capital charges and in indirect wage and salary costs, and further offsets would be generated if wage rates are increased to help gain acceptance of such innovations. An additional limitation on such potential benefits ‘arises from the fact that only a narrow array of tasks can be performed more economically by robots than by labor or by machines which include the robotizable capabilities. Indeed, even some of the manual functions which can be economically transferred to robots now may in time be transferred into redesigned machines, as was noted earlier.

From the standpoint of longer term planning perspectives, consideration should also be given to a plant’s cost proportions and to the prospective effects of increasing the ratio of “fixed” to “variable” costs. Cost proportions differ very widely, of course, among industries as well as among plants within industries. The long term average proportion of total costs accounted for by actual wages in U.S. manufacturing has been well under 20 per cent, ranging between less than 10 per cent in ore smelting, petroleum refining and other industries which represent the first stage of processing natural resources to more than 40 per cent in industries involving the fabrication of complex machinery.(4) Thus, the prospective effects of robotization on total unit costs through reductions in unit wage costs would tend to be far greater at the latter extreme. Attention must be given not only to the magnitude of cost proportions, however, but also to the extent to which a given category of unit costs could be reduced through robots or other innovations. Thus, any resulting increases in output per man-hour which are largely or wholly offset by attendant increases in hourly wage rates would yield little or no cost advantage, however large the wage cost ratio -- especially if account is

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(4) For a comparison of cost proportions in 20 manufacturing industries, see B. Gold, Explorations in Managerial Economics: Productivity, Costs, Technology and Growth (London: Macmillan, 1971; New York: Basic Books, 1971), p. 137. Japanese translation - Tokyo: Chikura Shobo, 1977. Differences in cost proportions among plants in the same industry are attributable primarily to differences in their “make vs. buy” ratios, in the modernity of their technologies and facilities, in their scale of operations and in their product-mix. For further discussion, see B. Gold, “changing Perspectives on Size, Scale and Returns: An Interpretive Survey”, Journal of Economic Literature March 1981, especially pp. 21 et.seq.

also taken of the associated increase in capital charges. On the other hand, sight must not be lost in such evaluations of the powerful leverage of reductions in total unit costs on profit margins, for even a 5 per cent reduction in total unit costs could increase profit margins by 33-50 per cent. Hence, the relative magnitudes of wage cost proportions warrants careful consideration in choosing targets among different sectors of operation for robotics applications whose benefits are expected to center on wage savings.

Longer term planning for advancing manufacturing technology has also been affected in many industries by the traditional concern about the burdens of increasing the ratio of total capital charges, which are considered "fixed", to labor costs which are considered "variable"-- meaning that the former are unaffected by reductions in output, while the latter decline with them. But" it is obvious that labor costs have become less "variable" because of trade union resistances to reductions in employment and wage rates, and because of increasing cost penalties for lay-offs through "social benefit" requirements. Increasing attention has also been given in recent years to adjusting depreciation rates in response to changing levels of capacity utilization, thus enhancing the variability of total capital charges.

The possibility should also be considered that capital inputs are becoming progressively more economical than labor inputs as compared with their respective contributions to output. In part, this reflects the fact that continuing technological progress tends to enhance the production contributions of facilities and equipment far more than those of labor. Moreover, although capital goods prices and wage rates both rise during inflationary periods, the prices to be paid for the former stop rising as soon as they are purchased, while wage rates continue to rise even after workmen are hired,and might rise even more if "higher labor productivity" can be claimed as a result of the additional equipment. Indeed, the costs of using such capital goods may even decline steadily under some forms of depreciation. In addition, most increases in capital facilities involve some, and often substantial, replacements of labor inputs, thus helping to offset part of the capital costs. Still another factor tending to increase the relative economy of capital inputs is the seemingly irreversible trend towards increasing payments to labor for non-working time, including:lay-offs; sickness; holidays; vacations; and pensions. Altogether, these considerations suggest that, in addition to altering past characterizations of capital and labor costs as "fixed" or "variable" in response to output fluctuations, attention should be given to

characterizing the long term tendencies of capital and labor costs -- with indications that the latter may warrant classification as "rising" relative to the former.

Evaluating the prospective effects of advances in computer-aided manufacturing, or programmable automation also requires more complex considerations as well as still broader coverage and even longer time perspectives. Briefly summarized, they are likely to affect all unit input requirements as well as the factor proportions encompassed by the "network of productivity relationships", they tend to alter longer term trends in capacity levels as well as in capacity utilization, and their effects are likely to reach beyond production operations to modify managerial planning and control systems as well as the organizational structure of firms.[5]

C. ROBOTICS, MANUFACTURING TECHNOLOGY AND INTERNATIONAL COMPETITIVENESS

1. Some Basic Perspectives *on* the Determinants of International Competitiveness

The growing national concern with the declining international competitiveness of a significant array of major U.S. industries has generated a stream of proposals for remedial action. Unfortunately, most of these are based on untested assumptions about the general causes of such lagging competitiveness instead of on penetrating analyses of the specific industries affected.

It is important to recognize that foreign competitive pressures no longer concentrate only on older industries with mature technologies. On the contrary, such pressures are intensifying over a wide spectrum of "high technology" industries as well. Examples of the latter include: semi-conductors, computers, telecommunications, sophisticated robotics, aircraft and flexible manufacturing systems. Hence, following the panic-induced proposals to abandon our older industries, which are also major sources of employment and income, would merely intensify problems of domestic welfare and military security. It is important, of course, to foster the development of newly emerging industries because, although they are likely to make only modest contributions to employment, income

(5) For a brief summary of some of these effects, see B. Gold, "Revising Managa~~~~al Evaluations of Computer-Aided Manufacturing Systems", proceedings of fact West Conference, Vol 1 (Deaborn, Society of Manufacturing Engineers, Nov. 1980). For a more detailed report, see B. Gold, An Improved Model for Managerial Evaluation and Utilization of Computer-Aided Manufacturing: A Report to the National Research Council Committee on Computer-Aided Manufacturing Washington, D. C., March 1981.

and foreign trade during their first 5-10 years of development, some of them may become powerful sectors of our economy in the future. But encouragement and support for such embryonic industries must be supplemented by intensified efforts to re-establish the competitiveness of older major industries through advancing beyond their current technological frontiers,if the national welfare is to be safeguarded in the short-run and intermediate-run as well. (6)

A related view whose vulnerability is inadequately recognized holds that the international competitiveness of our basic manufacturing industries is bound to decline relative to less developed countries because of our higher wage rates. Of course, substantial wage rate differentials do exist and these are likely to encourage continuing shifts in the location of some light manufacturing industries. But such wage rate disadvantages are largely offset in many basic industries by higher output per man-hour and higher product quality. In addition, the tendency for wage rates to rise more rapidly in industrializing countries tends to further reduce resulting differences in unit wage costs. It is also worth recalling here that wages tend to account for less than 20 per cent in U.S. manufacturing as a whole, thus limiting the effects of lower wage rates in wide sectors of industry. Most important of all for the longer run is the fact that labor inputs are being replaced increasingly in determining the productive efficiency of most manufacturing industries by capital inputs, which embody the technological contributions of advances in processing, mechanization, computerization, programmable controls and robotics. Hence, advanced industrial nations are likely to retain their competitive advantages in many basic manufacturing industries for many years to come. Such advantages will be reinforced by the greater availability of investment funds and the greater availability of the advanced engineers and highly skilled labor needed to maintain, supervise and improve such sophisticated operations -- especially those producing higher quality and more complex products.

At any rate, more sharply focussed diagnoses are obviously essential to the development of effective remedial efforts, not only for the industries which have already been hard hit by foreign competitors, but also to help the additional array of domestic industries likely to face such increasing pressures during the next five years. In this connection, it may be worth noting some of the findings emerging from a study of the factors affecting the international competitiveness

(6) For further discussion, see B. Gold, "U.S. Technological Policy Needs: Some Basic Misconceptions," in H.H. Miller (cd.), Technology, International Economics and Public Policy (Washington, D. C. : American Association for the Advancement of Science, 1981).

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of a sample of domestic industry being conducted with the support of the National cience Foundation.(7) Contrary to widespread assumptions and beliefs, the major causes of the decreasing international competitiveness of various domestic industries differ widely among industries. Hence, generalized solutions are likely to result in only mild palliative at best. Also, although decreasing competitiveness in production efficiency is a major factor in a number of industries; such shortcomings are powerfully reinforced, and sometimes even over-shadowed by:

a. Product designs which are less efficient, less attractive, less trouble-free or less sensitive to changes in consumer preferences;
b. Higher unit wage costs resulting from wage rate increases which have out-run gains in output per man-hour;
c. Higher unit costs of raw materials, energy, capital goods, or investment funds; and
d. Less aggressive marketing and less responsiveness to customer delivery and servicing needs.

Third, even disadvantages in respective to production efficiency are due to a variety of causes. Less advanced technological processes, older facilities and more limited utilization of computer-aided manufacturing and robotics have certainly been important handicaps. But it would be a mistake to under-estimate the influence on strengthening the competitiveness of various foreign producers of such factors as: more aggressive managerial demands for productivity improvement; larger technical staffs under greater pressure and more effectively motivated to increase technological capabilities; and reliance on longer production runs of a more limited product-mix to help keep capacity utilization rates high.

Fourth, another important contributor to the production efficiency of some foreign producers has been their labor's greater productive efforts, greater willingness to accept and maximize utilization of technological advances and improvements, and greater mobility among tasks. But blaming a large share of the decreasing competitiveness of domestic industries on general declines in the capabilities and motivations of labor tends to be contradicted to some extent by the high quality of output and the apparent cost effectiveness of some foreign-owned plants in the United States. This does not mean that all trade unions have supported the introduction of technological advances, have co–operated in efforts to raise productivity levels to those achieved by foreign competitors, and have limited

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(7) The author is Chief Investigator, The report is scheduled for late 1981.

demands for increases in wage rates to match increases in their contributions to production capabilities. But it does mean that some foreign managements -- and some domestic managements as well -- have found it possible to work with domestic labor in ways which yield high quality products, high productivity and competitive costs. Here again, therefore, the need is to dig beneath superficial generalizations to come more closely to grips with the factors which are most influential in various sectors of industry, and under different conditions.

2. Potential Contributions of Robotics and Programmable Automation to Improving International Competitiveness

The potential contributions of robotics and programmable automation to improving the competitiveness of domestic manufacturing industries must be examined within the context of the preceding complex of influential factors.

Increasing the utilization of progressively improved robots would obviously tend to have a positive effect on technological competitiveness. But the resulting gain is likely to be of only modest proportions in most plants and industries unless such advances are integrated with simultaneous advances in other determinants of technological competitiveness. Roboticizing manual operations in old plants using old machinery to make old products has obviously limited potentials. Nor are major advances likely to result from improving any other single component of the interwoven fabric of changes underlying significant progress in technological competitiveness. Robotics can undoubtedly make substantial contributions to such progress, but only as part of a comprehensive program to improve technological competitiveness.

Such programs must encompass carefully co-ordinated plans seeking to improve the capabilities and attractiveness of products, to adopt advanced technologies, to embody them in modern equipment of a scale deemed close to optimal for the level of output and product-mix to be provided, to provide for progressively adjusting input factor proportions and equipment utilization practices so as to maximize production efficiency, and to ensure continuing efforts to improve performance. It would be impractical, of course, to attempt to advance on all of these fronts simultaneously. But it would also be frustrating and wasteful to attempt to make major advances along any of these channels without considering prospective interactions with, and possibly offsetting pressures from, these other components.

Moreover, recognition of the complexity of the elements involved in achieving significant advances in technological competitiveness must be combined with appropriate time perspectives both in setting improvement targets and in planning progress towards them. In setting targets, it is important to base them not on catching up with the current capabilities of competitors, but on careful evaluations of prospective improvements in their capabilities over the next 5 years, along with parallel evaluations of prospective changes in the availability and prices of all required inputs,as well as in the output levels, mix and prices of products likely to be experienced in the market place. And in planning progress, realistic assessments need to be made of the likely availability of capital, of the time needed to acquire needed facilities and equipment and for management, engineers and labor to learn to use them effectively, as well as of the constraints likely to affect the rate of adjustments in employment levels and organizational rearrangements.

II SOME BASIC POLICY ISSUES AND ALTERNATIVES

A. BASIC ISSUES

Although it has already been emphasized that the declining international competitiveness of an increasing array of domestic manufacturing industries is attributable to a variety of factors, there can be no doubt that lagging technological competitiveness and related production efficiency is one of the leading causes. Such lags are due to belated and inadequate adoption of successful technological advances available from abroad, to inadequate modernization of facilities and equipment, to inadequate improvements in production management and controls, and to continued shortcomings in gaining labor co-operation for maximizing the cost and quality competitiveness of products.

Within this array, programmable automation is especially important not only because it can contribute to each of the others, but, above all, because it represents an essentially general process of progressive advances in technological capabilities and productive efficiency. Instead of offering the particular localized benefits of any single improvement in process technology, or in the capability of a new machine, programmable automation may be regarded as a form of "contagious" technology which keeps pressing to surmount the boundaries of any given application and thereby to "infect" adjacent sectors of operations and controls. It may, of course, be applied beneficially to single operations, but its major potentials derive from providing the means of achieving increasingly optimal functioning of each production unit, increasingly effective integration of all components of production, and increasingly effective co-ordination and control of other non-production operations as well -- as was illustrated in Figure 1.

Robots have been and will, of course, continue to be introduced simply as direct replacements for individual workers performing manual tasks. But an increasing proportion of their applications in the future are likely to derive from the continuing development and spreading of programmable automation systems, which are likely to require comparably improving capabilities in their robot components.

Accordingly, the key issues involved in increasing the contribution of programmable automation and robotics to strengthening the international competitiveness of domestic manufacturing industries would seem to center around:

1. the adequacy of the rate of development of the technological capabilities of programmable automation systems and of robotics relative to the rate of progress abroad;
2. the adequacy of the rate of diffusion of programmable automation systems and of robotics relative to their capacity to improve productive efficiency and cost competitiveness, and also relative to such diffusion rates among foreign competitors;
3. the relative effects of slower and faster rates of development and diffusion of such systems and of robotics on the competitiveness of various domestic industries as well as on their employment levels and capital requirements; and
4. the identification of the nature, sources and relative importance of the influential determinants of changes in the rate of development and diffusion of programmable automation systems and robotics.

The formulation of effective approaches to encouraging fuller realization of the constructive potentials offered by programmable automation systems and robotics would seem to require prior careful exploration of these issues.

B. SOME POLICY NEEDS AND ALTERNATIVES

1. On the Adequacy of Development Rates

Until now, most of the development efforts concerned with programmable automation and robots have been focussed on performing existing tasks more effectively or more safely. Because of the already recognized needs of managements and the consequent easing of marketing problems, early robot applications were designed to replace workers in dangerous or uncomfortable working environments, then in tasks involving heavy physical demands, and only later and more gradually in highly repetitive tasks. Most such past applications required few advances in technology, primarily representing new forms of specialized machine designs.(8)

Although later applications have required somewhat more complex operating and control capabilities, developmental efforts have continued to be dominated by the objective of performing existing jobs faster or more accurately. And this approach is likely to continue among robot manufacturers because of the inevitably narrow set of functions to be performed by anyone of their products and the consequent need to satisfy the completely pre-defined parameters of the component tasks to be performed. Research frontiers would accordingly concern improving manipulative capabilities, increasing the precision of actions taken, enhancing the reliability and durability of operations, and broadening the functions of programmable controls through extending the range of human senses which can be duplicated and through improving provisions for adaptive adjustments and "learning".

It is difficult to find persuasive data concerning relative progress in the development of robot capabilities in different countries. Active efforts have patently been under way for some years in Western Europe, Japan and the United States as well as in Eastern Europe. And impressive products have been marketed by producers from each of these areas. American manufacturers have been especially complimentary about the reliability of Japanese robots and about certain capabilities of Swedish and Italian robots, while also praising a number of domestic products. But the readiness of current and prospective American users of robots to rattle off a long list of specific limitations which tend to narrow the range of immediately rewarding applications much more sharply than is suggested by general discussions indicates that increased research and development may open the way to a major expansion of practical robot applications in domestic industries. And resulting innovative advances might well engender the rapid growth of the domestic robot manufacturing industry in addition to accelerating increases in the productive efficiency of robot-using domestic industries.

This raises the question of whether any additional measures should be considered by the government to augment the limited but increasing efforts by private

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(8) For an excellent review of robotics applications by a pioneer in their development, see J.F. Engelberger, Robotics in Practice (New York: AMACOM, 1980).

industry and universities to improve the capabilities and cost effectiveness of domestically produced robots. Some foreign governments have supported such efforts through research and development grants to industry and to universities and also through encouraging prospective users, especially in defense industries. Similar efforts have been made in this country, although probably on more limited scale.

Turning to programmable automation, somewhat. similar early developmental patterns may be noted. Initial applications tended to concentrate on developing process controls for individual production units. But the fact that computer manufacturers had a broader range of application potentials in view than robot producers resulted in a rapidly expanding concern with co-ordinating progressively wider sets of individual process controls and then integrating these into increasingly encompassing performance-monitoring and control systems. Although international surveys have called attention to some foreign systems which seem to be much more advanced than any in the United States, most of these seem still to represent uncommon cases of pioneering or largely experimental applications. (9)

Developmental efforts are under way in a number of domestic firms, especially those involved in aerospace programs, to extend applications of programmable controls to a variety of production, planning and control functions. But most of these have not yet reached the stage of reliable broad commercial applicability and none at all have achieved effective integration over a wide array of such functions. Moreover, both developmental efforts and applications have been of distinctly meager proportions in firms basically devoted to non-defense production. Hence the question arises in this connection, as it did in respect to robotics, whether any additional measures should be considered to augment the increasing, but still limited, efforts of private industry and of universities to accelerate the development of increasingly comprehensive programmable automation system.

Finally, increasing attention might well be given to the possibility that the development of programmable automation systems may engender an alternative approach to the development of robotic functions and forms. Specifically, in place of the past approach of roboticizing existing manual tasks, the designing of programmable

(9) For example, see Dennis Wisnosky, Worldwide Computer-Aided Manufacturing Survey (Dayton, OH: Air Force Systems Command, December 1977) and also J. Hatvany, K. Rathmill and H. Yoshikawa, Computer-Aided Manufacturing: An International Comparison (Washington, D.C.: National Research Council Committee on Computer-Aided Manufacturing, Sept. 1981.)

automation system may result in generating altered definitions of the kinds of functions to be considered for robotization, and may even integrate some of these functions into other machine or equipment components of the system. It may be relevant to mantion in this connection that progress in programmable automation is often discussed within the context of efforts to develop "automatic factories".[(10)] Although such achievements still seem far off in respect to plants capable of producing limited quantities of a variety of products economically -- as differentiated from continuous process petroleum refineries and chemical plants -- they exemplify the reverse orientation which is likely to become increasingly important: designing the plant as a whole and then defining the functions and needed characteristics of the component parts, instead of developing robots and programmable controls for a succession of individual operations within existing plant characteristics.

What are the policy implications of such observations? There is ample basis within the basic values of the American" economic system for questioning the advisability of governmental support for efforts by private firms to develop appropriable commercial improvements in robot capabilities or in other technologies. But there are very cogent reasons indeed for recognizing the government's responsibility for supporting research and development programs seeking to extend and enrich the pre-commercial scientific and engineering foundations of increasingly effective industrial operations.

Most private firms seldom undertake technological development programs which are unlikely to reach commercial fruition in less than 5 to 8 years, including the time necessary to construct needed production facilities and to begin marketing their products. One of the most promising means of multiplying such private efforts would be to increase the array of technologies which have emerged from the often lengthy, costly and risky processes of intermediate development between basic research findings and a level of refinement deemed to be within striking distance of appropriable forms of commercialization. Moreover, such advances represent additions to national resources of knowledge which are likely to stimulate application efforts in many other sectors of the economy and social services, including office operations, construction, household services and health and rehabilitation activities.[(11)]

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(10) As an illustration of current efforts in this direction, see Proceedings of the Autofact West Conference (Dearborn, MI: Society of Manufacturing Engineers, Nov. 1980) Volumes I and II.

(11) For further discussion, see B. Cold, Productivity, Technology and Capital: Economic Analysis, Managerial Strategies and Government Policies (Lexington,MA: D. C. Heath - Lexington Books, 1979) pp. 302-303.

It should also be noted that one of the most important future sources of technological competitiveness in manufacturing industries -- the development of increasingly encompassing systems of programmable automation -- has not yet advanced sufficiently to minimize the possibility that intensified domestic efforts might not only match but might even surpass foreign progress. It should be recognized, however, that vendors of particular components are not likely to make substantial investments in developing broadly comprehensive systems of programmable controls. Indeed, they are more likely to resist any such developments which might generate requirements for components with characteristics different from their own offerings. Moreover, few manufacturers are likely to develop programmable automation systems which are applicable beyond their own unique operating and organizational arrangements. Hence, the practical questions would seem to be: what span of operating and functional coverage would be applicable widely enough to warrant the investment in developing it? and who might consider it worth making such a commitment? Efforts to develop such systems in aircraft manufacturing plants are being supported by government agencies. And some private firms have joined in developing some common components of such systems. But no comprehensive review of what needs to be done, or what the benefits of more effectively organized efforts might be, is available at this time. Here, then, is another area in which governmental support may yield valuable contributions to advancing the competitiveness of domestic manufacturing.

2. On the Adequacy of Diffusion Rates

The impact of technological advances on market competitiveness is determined not by the location or rate of their development, but by the rate of their diffusion and the extent of their utilization. Although some observers claim that Japanese industry has surpassed the United States in the utilization of programmable automation systems as well as of robots, such applications still account for only very limited sectors of their manufacturing industries and are even sparser in Western Europe, Accordingly, there is still a wide open opportunity for domestic manufacturing to overcome its current lags in this area and thereby achieve major improvements in its productive efficiency and cost competitiveness.

What factors have retarded the more rapid diffusion of these technologies? Perhaps the most important influence has been the basic unawareness of most industrial managements of the far-reaching potentials of this burgeoning revolution in manufacturing technology. Such inadequate appreciation of these potentials may be attributed in part to the limited knowledge of such capabilities of most of the senior engineering officials responsible for advising top management about important technological developments. Another influential factor has been the tendency of firms to continue relying on processes for developing innovational proposals, and on capital budgeting models for evaluating them, which worked reasonably well for incremental improvements in established technologies in the past, but which have serious shortcomings in generating and evaluating proposals for major advances in technology like programmable automation.[12]

Such restricted perspectives have also been supported by the concentration of most vendors of programmable control systems and of robots on selling bits and pieces to the lower level officials concerned with the sub-sectors likely to be directly affected by their application, thus reinforcing the traditional view that technical innovations can best be evaluated by specialists in the operations immediately involved, instead of emphasizing the broader potentials rooted in these emerging technologies. Widespread awareness of the shortcomings and resulting penalties of some early applications have also encouraged disinterest in these developments. It is important to recognize in addition that most universities have been quite backward in recognizing the new potentials of manufacturing technology and of providing the educational programs and research facilities needed to train urgently needed specialists and to provide urgently needed advances in related knowledge.

There would be no basis, of course, for efforts by government to urge all manufacturers to adopt these innovations, inasmuch as differences in their needs and resources ensure that no advances in technology are equally attractive for all firms even in the industries most directly affected. But it might well be desirable for government agencies to undertake active programs to help develop fuller understanding in industry of the potentials and accomplishments, as well as the current limitations, of programmable automation systems and robotics -- including periodic reports on progress in the development and utilization of such advances abroad. And such agencies might well consider exploring with a reasonable array of universities the possibilities and desirability of expanding educational as well as research programs in various sectors of manufacturing technology -- and helping to finance the acquisition of needed facilities as well as some scholarship aid.

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(12) For a detailed discussion of these processes and models, see B.Gold, An Improved Model for Managerial Evaluation and Utilization of Computer-Aided Manufacturing: A Report to the National Research Council Committee on Computer-Aided Manufacturing (Washington, D. C., March 1981).

3. Effects of Altering Development and Diffusion Rates

Appraising the adequacy of current rates of adopting and utilizing programmable automation and robotics obviously requires consideration of attendant enbefits and burdens. Past adoptions of both have been sufficiently limited and gradual to engender little observable effects on the employment and skill requirements of the work force, while increasing the need for servicing personnel. This experience has engendered some unconvincing assurances that the accelerated diffusion of such technologies will not entail significant displacements of labor at the same time that others have emphasized the urgency of utilizing these advances in order to overcome serious shortcomings in cost competitiveness through the attendant reductions made possible in labor requirements.

The basic fact is that unemployment in any firm is caused primarily by a decline in its competitiveness. If it fails to adopt the technological advances utilized by competitors, its employment will decline much more rapidly than if it adopts such advances, even if these involve some displacement of labor. Moreover, for many domestic industries such effects represent costs which have already been exacted and which threaten to become even greater if technological lags are not reduced. Regaining competitiveness in some domestic industries may now require reductions in man-hour requirements per unit of output of at least 20-30 per cent.[13] Moreover, such lags are continuing to grow as foreign competitors' efforts to surpass American performance keep intensifying -- as may be illustrated by Japanese developments in the steel, automobile, machine tool and semiconductor industries. In short, major improvements in the performance of domestic industries is imperative. Hence, rejecting attempts to accelerate the diffusion of programmable automation and robotics could only be justified by identifying and then promoting other means of achieving the needed large advances in the productive efficiency and cost competitiveness of major industries within the next five years.

It should also be recognized that implementing the major advances in technology involved in accelerating tha application of programmable automation represents a much more difficult and far–reaching challenge to management than is generally recognized. The key reason for this is the failure to recognize that basic technologies are built not only into the production machinery, but also into:

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(13) For a comparison of labor requirements in the Japanese and U.S. steel industries, see B. Gold, "Steel Technologies and Costs in the U.S. and Japan", Iron and Steel Engineer, April 1978. Japanese translation in Joho Shuho (Tokyo) July 1978.

a. **the** expertise of the technical personnel;
b. the structure and operation of the production system;
c. the economically feasible range of changes in product designs and product-mix;
d. and the very criteria used to evaluate the capabilities of new capital goods; as well as
e. the skills and organization of labor.

Each of these represents powerful and mutually reinforcing commitments to preserving existing operating and organizational arrangements, except for small, gradual and localized changes. Hence major advances are not likely to be achieved unless they are pushed aggressively by senior managers committed to achieve them and willing to invest the resources and to introduce the organizational means necessary to implement such programs.

4. Other Incentives and Deterrents

One of the most important stimuli to the increasing diffusion of robots has been the gradually growing awareness among managements, engineers and labor that these have proven themselves practical and economical in an expanding array of applications, and hence are becoming an increasingly unavoidable option among the alternatives to be considered whenever plans to improve productive efficiency are being developed. This fact alone has forced production managers and engineers to seek more information about robot capabilities, limitations and costs, thereby sensitizing them to the kinds of applications where they might prove most rewarding. And such inquiries from prospective customers obviously help to focus the development efforts of robot manufacturers on meeting newly emerging market opportunities.

On the other hand, one of the influential deterrents to more rapid adoptions of robots has been managerial concern about labor reactions. The introduction of robots to replace operators in dangerous or especially uncomfortable environments was readily accepted, of course, as, was their use in unduly exhausting jobs. The use of robots in" highly routinized ("boring") jobs has also been commonly accepted by labor provided that the replaced operators were given other assignments. But there seems to be widespread concern among managers that robot installations which threaten substantial employment reductions in existing plants may well engender serious labor problems, whose resolution would be likely to reduce expected cost-savings substantially. Major installations are accordingly likely to be restricted to new plants which can establish new manning levels in accordance with their new operating characteristics. Such managerial concerns need not, of course, prevent the increasing use of robots in older plants, but they would seem to encourage introducing robots only slowly and in scattered operations, thereby minimizing the rate of gains in productivity and cost savings while easing labor resistance. Only when an immediate threat to the survival of the plant is recognized by labor are such resistances likely not to inhibit major readjustments.

But it should be noted once again that large scale introductions of robots would seldom offer substantial economies anyhow, except as a means of implementing plans for broader programmable automation. And these can seldom be retrofitted into old plants, except through major modernization programs involving changes in production facilities and equipment as well as operating practices.

Consideration of large scale programs of programmable automation and roboticization, however, raises fundamental questions concerning the past balancing of prospective incentives and deterrents by managements, and the possible need to shift that balance to provide greater encouragement to undertaking the costly and risky commitments involved in developing and adopting major technological advances. Key elements would seem to include:

a. increasing the prospective profitability of longer term investments in advanced production facilities and in seeking to develop major technological improvements in processes as well as products;

b. increasing the availability of trained technical manpower to guide and manage such developments as well as the availability of a richer foundation of scientific and technological research and pre-commercial development as the basis for private commercialization efforts;

c. increasing labor recognition of the urgency of achieving major advances in cost competitiveness in order to ease threats to employment and also easing resulting burdens on labor resulting from co-operation in the utilization of technological innovations offering such advances.

Meeting such needs would seem to require substantial contributions from the government, from labor organizations and from universities as well as from industrial managements. And failure to meet such needs would probably exact penalties from each of these beneficiaries of an effective industrial economy. (14)

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(14) For more detailed discussion, see B. Gold, Productivity, ‘technology and Capital: Economic Analysis, Managerial Strategies and Government Policies (Lexington, MA: D. C. Heath - Lexington Books, 1979) Chapter 17. Also see B. Gold, An Improved Model for Managerial Evaluation and Utilization of Computer-Aided Manufacturing: A Report to the National Research Council Committee on Computer-Aided Manufacturing (Washington, D. C., March 1981).