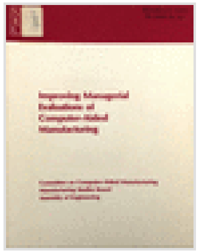

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IMPROVING MANAGERIAL EVALUATIONS OF COMPUTER-AIDED MANUFACTURING

A Report to the
Air Force Systems Command
U.S. Air Force

by the
Committee on Computer-Aided Manufacturing
Manufacturing Studies Board
Assembly of Engineering
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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1. OBJECTIVES AND WORK DONE

Computer-aided manufacturing (CAM) offers major potentials for providing urgently needed advances in the productivity and competitiveness of a wide array of industries. Despite the pioneering development of this powerful new technology in this country, domestic adoption rates have fallen far short of exploiting resulting opportunities and even threaten to lag behind the use of these new capabilities by foreign competitors.

The speed with which technological innovations diffuse among prospective users depends on a variety of factors. Two of the most important of these seem to be: the criteria used by management to choose among alternative proposals for the allocation of available resources; and the means relied on to develop such proposals. In industries that have had experience with successive technological innovations, proposal-development and evaluation processes have come to be highly systematized. Because most such arrangements have emerged from efforts to deal with the continuing flow of incremental improvements, however, they are not likely to be effectively applicable to the relatively uncommon challenges of major advances in technology. Our field research suggests that this limited applicability of standardized approaches had led to a serious underestimation of the prospective benefits of computer-aided manufacturing, and, hence, to unduly slow rates of adoption.

This exploratory project was designed, therefore, to develop an approach to managerial evaluations of computer-aided design/computer-aided manufacturing (CAD/CAM) systems that would be more effective in capturing their distinctive capabilities and requirements than the capital budgeting procedures commonly used for appraising proposed acquisitions of new equipment. It is hoped that the availability of such a more directly relevant evalution model, together with the more thorough understanding of CAD/CAM potentials likely to be engendered in the course of applying this analytical framework, will help to accelerate recognition of additional rewarding applications of this powerful new technology.

As a first step, a preliminary model was based on the analyst's past studies of the effects of major technological innovations[1] and also of the limitations of common capital budgeting methods.[2] This model was

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[1] The most recent publications that present such findings are Gold [6] and Gold *et. al.* [11].

[2] For example, see Gold [4] and Gold and Boylan [10].

subjected to successive modifications on the basis of a series of detailed plant-level studies supplemented by discussions with a number of other users of CAD/CAM systems. Although the seven cases covered by the field research exceeded the original target of four or five, they obviously represent only a meager sampling of existing installations.

It should be noted that, in accordance with the project plan, these initial cases were concentrated within the automobile, farm machinery, and electrical equipment industries for two reasons. First, it was recognized that such applications would tend to be less comprehensive, and hence easier to model, than the more complex systems already widespread in the aerospace industry. Second, it was assumed that the CAD/CAM results could be evaluated more effectively in economic terms in such essentially standardized manufacturing operations than in defense industries subject to more frequent modifications in product designs, production methods, and quality standards, and also subject to a variety of non-market criteria of performance. Any extensions to the model which may prove necessary to encompass more comprehensive CAD/CAM systems would accordingly have to be developed through subsequent studies.

In accordance with its basic objective, Chapter 2 of this report will review needed revisions of the managerial approaches used to develop and evaluate proposals for CAD/CAM applications. Chapter 3 will suggest an improved approach to modeling CAM evaluations. Chapter 4 will then summarize some of the issues and problems likely to be encountered in implementing such an approach both before and after application decisions have been made. And Chapter 5 will present some concluding observations concerning requirements for increasing the diffusion of CAD/CAM applications.

2. REVISING MANAGERIAL EVALUATIONS OF CAM SYSTEMS

This chapter has two objectives. First, it will seek to identify some of the elements of prevailing practices for developing and evaluating CAM proposals that are likely to result in underestimating their prospective benefits and, thus, in discouraging more rapid diffusion of this technology. Second, it will suggest ways to alter these processes so as to provide managements with more effective appraisals of CAM potentials and requirements.

SOME COMMON ELEMENTS IN EVALUATIONS OF MAJOR EQUIPMENT ACQUISITIONS

Decisions about the adoption of CAM systems are still widely based on applications of relatively standard capital budgeting methods. These have evolved through long experience in appraising proposals for acquiring capital equipment. For this very reason, however, such methods are rooted in unrecognized assumptions and restrictive perspectives which are unsuited to the evaluation of CAM systems and tend to encourage erroneous evaluations of their potential benefits.

Most efforts to appraise proposals for equipment acquisitions in industry tend to share certain common assumptions about the general characteristics of such additions. One of these is that the equipment under consideration would be directly applicable to, and would exert all or most of its effects within, particular narrow sub-sectors of production. A second is that the capabilities of the equipment and of its embodied technology are known and will not change after installation except for eventual decline. A third is that its contributions to the effectiveness of operations and to cost improvements can be estimated within reasonably close margins. And a fourth is that the prospective advantages and limitations of such an acquisition can best be understood and evaluated by the managerial and technical specialists familiar with that sub-sector.

Such assumptions have accordingly encouraged broad reliance on processes for generating and choosing among equipment acquisition proposals involving several common elements. Thus, most or all proposals to be considered by top management tend to be originated or approved by officials of the operating sub-sectors that would be affected. In addition, proposals are generally appraised independently of one another as top management seeks to allocate available capital resources among competing equipment as well as non-equipment proposals. Finally, their choices tend to be based on the relative attractiveness of the estimated economic returns among all proposals that exceed some minimum "hurdle rate."

Under the foregoing conditions, it is apparent that the nature and volume of the equipment acquisition proposals submitted to top management tend to be heavily influenced by the technical background and motivations as well as the innovativeness of the sub-sectoral managerial and technical staffs. Their incentives obviously center on potential financial and status rewards. But the directions in which improvements are likely to be sought often tend to avoid innovations that may threaten to undermine rather than to reinforce the technological authority and organizational security of the specialists guiding the search and evaluating resulting possibilities.

The preceding assumptions, expectations, and procedures undoubtedly remain relevant for evaluating many kinds of equipment acquisition proposals. Nevertheless, each element of the above approach tends to prevent the effective development and appraisal of CAM potentials.

NEEDED REVISIONS IN THE APPROACH TO CAM SYSTEMS

Appraising Prospective Effects

The major reason why the preceding approach tends to underestimate the potential benefits of the computerization of manufacturing is that this represents an essentially general process of progressive advances in technological capabilities and productive efficiency rather than simply an array of independent equipment acquisitions whose effects are restricted to the narrow operations in which they are embedded. Computerization may, of course, be applied beneficially to particular operations. But its major potentials derive from providing a means of achieving progressively increasing conformance with optimal operation conditions. Such improvements are not limited to the given operation where an initial application is made. Rather it provides the basis for an increasingly effective integration of successive stages of production. Moreover, it also provides the means of achieving progressively closer coordination of materials flow and maintenance with production activities and, beyond that, to the increasing integration of manufacturing activities with managerial planning, control, and performance evaluation systems. This means that even initial applications of CAM segments within larger production operations cannot be evaluated effectively except within the context of such larger developmental potentials.

A second reason why the prevailing approach tends to underestimate the benefits of CAM applications is that the contributions of most CAM systems are likely to keep increasing for extended periods beyond initial installation, instead of yielding the unchanging or declining contributions offered by most specialized equipment units. Such growing contributions result in part from the increasing understanding and experience of technical specialists in the plant about how to harness the multiple potentials of their computerized systems. In even greater part, such increasing contributions result from the still rapidly advancing improvements in the computers, software, and related instrumentation which determine the potentials of this relatively new technology in all applications. Still another important source of increasing contributions over time is the flexibility of programmable CAM systems. This facilitates adjusting operations to accommodate the changes in product designs, shifts in product-mix, and modifications in operating methods which seem to be an unavoidable feature of most manufacturing and which are a major cause of the progressive under-utilization over time of specialized equipment, even when its original capabilities have remained unimpaired.

On the other hand, the prevailing approach to the evaluation of equipment acquisitions also fails to take adequate account of some other features of CAM systems which involve differentially larger burdens. For example, computerization requires substantial outlays for non-hardware components of the system, including the development and improvement of software, the updating of the data bases used, and the maintenance of equipment. In addition, the potentials for continuing improvements in the system's contributions can only be realized if sufficient resources are allocated to such development efforts.

Developing CAM Proposals

The need for altering prevailing procedures for developing proposals for new equipment acquisitions arises from the fact that computerization involves heavy reliance on a technology unlike that which has dominated most manufacturing establishments. As a result, it may be regarded by many managerial and technical specialists, especially those who are older and hold influential operating positions, as threatening the adequacy of their technological expertise and even the security of their organizational authority.

The former is caused, of course, by the need to evaluate new kinds of hardware, to consider modifications in existing operations using the capabilities of unfamiliar equipment, and to appraise performance which is partly controlled by devices with new kinds of characteristics and limitations. Moreover, the potential benefits of using computers to achieve closer integration of successive operations and different functions (e.g., design, manufacturing, testing, and maintenance) may also be regarded as a threat to the continued separation of existing organizational units and the associated authority of their respective managers. Hence, it may be prudent to revise the procedures for engendering equipment acquisition proposals.

DESIGNING MORE EFFECTIVE ANALYTICAL FRAMEWORKS

It may be useful to begin by recalling that most of the capital budgeting methods used in evaluating equipment acquisition proposals are subject to serious vulnerabilities even when applied to acquisitions not involving significant modifications in basic technologies. Among the determinants of such evaluations which may entail wide margins of error are the required estimates of long-term changes in product and factor prices, in output levels and product-mix, and even in actual final investment requirements--to say nothing of the discount rates applied to deferred net revenues.[3]

And the vulnerability of such *ex ante* estimates of the profitability of proposed acquisitions grows progressively with the extent of the plant personnel's unfamiliarity with the technologies embodied in the new facilities. This is due to the fact that the actual performance of new kinds of equipment varies widely with the effectiveness of technical and managerial adaptations to the potentials and limitations of the innovation, not only in the operation directly affected but also in the antecedent and subsequent operations with which coordination must be reestablished.[4] These latter difficulties in estimating the returns from innovations apply with extra force to CAM systems, inasmuch as the technologies involved are quite different from the kinds of expertise available in most manufacturing plants, instead of merely requiring available technical personnel to supplement their past experience with some additional specialized seminars and workshops.

The primary concern of this report, however, is to suggest means of dealing more effectively with the additional special challenges to the evaluation of capital allocation posed by CAM systems. Accordingly, these will be considered under three headings: the need to re-orient management perceptions of CAM; the resulting need to alter past procedures for generating capital allocation proposals affecting this technology; and, in the next section, the need to extend the analytical frameworks commonly used to evaluate equipment acquisition proposals and also to consider the changed patterns of adjustment likely to be encountered in respect to the variables encompassed by capital budgeting models.

Management Perceptions of CAM

The single most important requirement for successful exploration of CAM potentials seems to be the recognition within senior levels of management of the strategic importance of this essentially new dimension of manufacturing technology and also of the critical requirements for harnessing its powerful potentials. The former involves realization that CAM systems will be a rapidly increasing determinant of relative competitive strength, not unlike the role during recent decades of in-

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[3] For a more detailed discussion, see Gold [4].

[4] Such problems are considered more fully in Gold *et. al.* [11, Chapter 14].

creasing research and development--another general form of technological progress.

Among the critical requirements for effectively exploiting CAM potentials, the following seem to rank highest:

- commitment of increasing resources to long-term programs for developing improved and wider applications of this still emerging technology;

- acceptance of the need to evaluate individual CAM proposals within the context of expected continuing programs involving further applications which draw in part on the resources allocated to earlier projects;

- awareness that such efforts call not only for new kinds of technical expertise, but also for growing understanding by management of the implications of resulting improvements in operational potentials for the modification of planning and control systems; and

- willingness to consider possible changes in organizational structure--including the closer integration of design, manufacturing, distribution, and procurement with one another and with management planning, control, and performance evaluation systems.

It is obvious that such far-reaching reorientations of management perspectives are unlikely to be effected rapidly. But the inertia of long-established habits of thought may be expected to diminish rapidly under the combined pressures of resource stringencies, limited markets, and intensified competition. At any rate, until managements become convinced that CAM systems offer major opportunities, which are likely to be transformed into serious threats if neglected, little cumulative progress is likely to be achieved. Even successful stand-alone applications--so long as they are regarded as no different from past introductions of equipment with only locally restricted impacts--are unlikely to engender the momentum resulting from a clear recognition of broader potentials.

One of the major factors stimulating the rapid advances of computerization in Japanese industry was early recognition by many top managements of the tremendous potentials for strengthening productive efficiency as well as managerial planning and control. This led to an essentially "top-down" approach involving widespread recognition of senior management's commitment to progressively broader applications within an overall framework that provided a continuous mapping of the missing blocks in the system along with a holistic rather than a localized view of the relative desirability of alternative next applications.

Such a "top-down" approach is almost the opposite of the essentially "bottom-up" approach found in many American companies. The latter tends to be more sporadic in coverage as a response to the changing pattern of pressures and initiatives generated by different operating units. Moreover, in the absence of a comprehensive plan for increasing computerization, the "bottom-up" approach tends to lose momentum as each project's completion tends to be followed by new choices among various competing technological and non-technological proposals for allocating available capital. Even more serious, the bottom-up approach tends to face repeated difficulties in persuading each new sector of applications to accept its absorption into an integrated computerized system, instead of being assured of the ready cooperation engendered by awareness of top management's support for continuing extensions.

Sources of CAM Proposals

More thorough exploration and development of CAM proposals would seem to require several deviations from arrangements that rely on having equipment acquisition recommendations generated by the managerial and technical specialists in narrow sub-sectors of operations. This would seem necessary in part because most, and often all, sub-sectors lack sufficient expertise in appraising CAM potentials convincingly; and in part because personnel lacking confidence in their understanding of such CAM technology are likely to shy away from recommending it. Indeed, as was noted earlier, such personnel may often be biased against the introduction of innovations that threaten to undermine their technological security or to involve a need to share decision-making authority. But patiently awaiting the eventual burgeoning of interest in CAM by a random array of engineers and managers, which may not manifest itself at influential levels for several more years, may risk serious competitive advantages.

Accordingly, consideration might usefully be given to providing and stimulating the use of additional channels for generating CAM proposals. One of these might well be a manufacturing engineering group with demonstrated expertise in CAM applications whose responsibilities include the exploration of successive sectors of operations to identify attractive CAM potentials. This would support the formulation not only of standalone proposals for particular sub-sectors, but also of potential sequences of applications that are mutually reinforcing. Encouragement should also be given to the development of CAM proposals by other specialized line and staff groups (including engineering design, quality control, process planning, and materials management) whose activities interact with others and thus may suggest additional means of improving the effectiveness of joint operations.

Because of the broad potentials and implications of CAM, it may even be desirable for management to sponsor comprehensive efforts to alert all levels of managerial and technical staffs to the prospective benefits of utilizing it more fully. Resulting interest might then be reinforced by providing whatever training and development programs are likely to achieve the widespread familiarity necessary to multiply the potential sources of CAM application proposals and also to ensure the managerial responsiveness needed to encourage such innovative suggestions.

3. AN IMPROVED APPROACH TO MODELING CAM EVALUATIONS

The basic coverage of CAM evaluations should obviously conform to the framework of the firm's customary capital budgeting model. This is necessary not only to facilitate comparisons with competing proposals, but also to ensure that CAM evaluations do not slight any of the estimated effects required of other proposals. Hence, CAM evaluations, too, must cover expected costs and revenues as well as net investment requirements over the expected effective working life of the proposed innovation.

In order to increase the applicability of such appraisals of CAM proposals, however, conventional approaches must be extended so as to:

- penetrate more deeply into the bases for the estimates of inputs, outputs, and costs that are fed into the capital budgeting model;
- include estimates of probably carryover effects on successively broader sectors of operations; and
- encompass estimated effects over an array of successively longer periods.

STRENGTHENING THE FOUNDATIONS OF CAPITAL BUDGETING ESTIMATES

Capital budgeting models are used by managements to help make rational choices among competing requests for resources. But the quantitative estimates that enter into the final calculations are not only subject to wide margins of error, as was noted earlier, but involve judgments that are often arguable and even unacknowledged. For example, few capital budgeting exercises undertake to evaluate not only the effects of adopting a proposal, but also the effects of rejecting it; and few include estimates of the effects of alternative decisions by competitors.[5] Moreover, few estimates are based on careful analyses of the relative evaluations--most of them tending to err on the side of overestimating returns.[6] Nevertheless, the following discussion will be restricted to highlighting the areas in which the estimates relating to CAM systems are likely to deviate significantly from those commonly made for major equipment proposals.

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[5] For fuller discussion, see Gold and Boylan [10].
[6] For fuller discussion, see Gold _et_. _al_. [11, Chapters 14 and 16].

Capital budgeting models are designed to yield estimates of the rate of profits on investment to be expected from an acquisition. Resulting outcomes are based on estimates of the time patterns of revenues, costs, and investment requirements over the prospective effective working life of the acquisition. Each of these inputs is determined in turn from a substructure of estimates. Thus, revenue estimates must obviously be based on estimates of output and price levels; cost estimates on estimates of the unit input requirements of each factor of production and of their respective prices at the assumed output levels; and net investment estimates on estimates of the acquisition cost of the facilities and equipment, of their expected working life, and of the pattern of depreciation charges to be applied. And these estimates rest in turn on a deeper structure of estimates, as is illustrated in Table 1. In addition, the "net present value" forms of capital budgeting models also require selection of a discount rate to be applied in evaluating deferred returns.

The cost, investment, and revenue estimates used in capital budgeting evaluations are not only subject to wide margins of error, as was noted earlier, but involve judgments that are often arguable and even unacknowledged. Estimated costs, for example, have generally been derived from a substructure of engineering estimates of expected changes in the volume of various input requirements. It has then been assumed that unit costs would parallel expected changes in their respective input requirements per unit of output. Of course, the more modest the technological advances involved, the less vulnerable these and related estimates of prospective effects are likely to be. Hence, confidence in their reliability has tended to be bolstered in firms whose dominant experience has been a succession of limited technological improvements. But it is precisely within this substructure of changes that underlie the final cost and investment estimates entering into capital budgeting models where major technological advances tend to have distinctive impacts--and thus require reconsideration of traditional bases for estimating such effects.

Investment Outlays and Overhead Charges

In respect to the outlays made up to the point of achieving effective operations, the important differences tend to center on two categories. First, CAM systems have apparently taken longer to "debug" and have frequently required larger costs to modify and even to replace some of the original hardware. Although significant improvements seem to be emerging in this area as a result of improvements in equipment design, computer reliability, and instrument diagnostics, widespread awareness of the problems encountered in the past continues to encourage excessive estimates. Second, CAM systems have required very much greater inputs of engineering, programming, planning, and maintenance personnel than anticipated. If such supporting outlays had been correctly estimated, and if they had been fully charged against initial applications, the diffusion of CAM systems might well have been even slower than has been the case. Thus, the basis chosen for allocating these costs may significantly alter new adoption decisions.

Table 1. Components of Basic Forecasts Entering into Capital Budget Models

Bases for Investment Estimates	Bases for Revenue Estimates	Bases for Cost Estimates
Engineering designs and estimated physical requirements Prospective changes in factor prices during construction	Estimated time pattern of plant output: a. Estimates of industry's output, product-mix and geographical composition b. Estimates of firm's market share by product and region c. Estimates of plant's share of firm's output by product and region	Time Pattern of unit variable costs: a. Changes in unit input requirements of materials, energy and labor b. Changes in prices of such inputs c. Shifts in input factor proportions.
Possible delays in construction Problems of achieving effective functioning of facilities. Required readjustments in associated facilities and operations	Estimated time pattern of prices for this plant's products: a. Estimates of production and distribution costs b. Estimates of changes in supply-demand relationships c. Estimates of changes in general price levels d. Estimates of shifts in competitive pressures among companies and products	Time pattern of average unit fixed costs: a. Depreciation patterns b. Changes in salary employment and payment levels c. Changes in cost of working capital d. Estimates of capacity utilization rates. Time pattern of marketing and distribution costs
	Estimated economic working life of plant: a. Prospects of partial displacement by substitute products b. Risk of partial displacement by technological advances in processes or facilities c. Estimates of important shifts in markets or sources of needed inputs.	Estimates of changes in tax rates and incentives

It is obvious that new kinds of expertise are necessary if CAM systems are to be operated effectively, and also that such inputs are likely to be especially costly when plant staffs are just learning about specific CAM requirements and how to meet them. But it is also clear that after such resources have been strengthened by on-the-job experience, they would be required only part-time by the initial application once it has begun to function effectively, thus freeing such specialists to support additional applications. One might contend, therefore, that learning how to plan, introduce, operate, and improve CAM systems may appropriately be regarded as a continuing part of strengthening a firm's competitiveness. In that perspective, the resources involved might be considered a strategic investment for which costs should be allocated as part of a general overhead, paralleling research and development or engineering staff functions, instead of being charged fully against the initial, or even the first few, applications.

Net investment would tend to decline, of course, for both general equipment and CAM installations according to whatever depreciation formulae are applied. But our preliminary field studies suggest that CAM system evaluations should consider the possibility that they may require more frequent and larger investment injections in order to take advantage of continuing advances in the technology and associated hardware.

Capacity and Output Adjustments

Most machine acquisitions tend to have clearly established production capabilities. These tend to approximate a maximum once effective functioning has been achieved and to decline gradually after some years. Moreover, capacity utilization rates likewide tend to decline as a result of changes in product design, precision requirements, and product-mix to which the given machines cannot be fully adapted.

CAM systems, however, may exhibit quite different adjustment patterns over time. As was noted earlier, continuing improvements in computers, programming, instrumentation, and maintenance frequently make possible progressive increases in the productive capacity of given systems. Moreover, the greater adaptability of such systems to changes in product characteristics and product-mix tends to ensure fuller utilization of capacity than can be maintained for specialized machinery. As a result, CAM system evaluations should consider the likelihood that they may offer substantially greater capacity and average output per dollar of net fixed investment than alternative machine acquisitions, especially in manufacturing industries producing relatively limited batches of a wide variety of products.

Direct Operating Costs

In estimating the effects of major technological innovations on operating costs, it is important to recognize that these may alter the qualitative as well as the quantitative dimensions of one or more inputs. Because such qualitative changes may affect the prices of the inputs involved, it may no longer be appropriate to assume that changes in each category of unit costs will parallel changes in their unit input volumes.[7] Moreover, major technological advances may also engender substantial changes in the productive roles of various inputs as well as in the allocation of tasks among successive operations. Such adaptations might not only alter the flexibility of total unit costs with fluctuations in output levels, but they might also involve the possibility that cost reductions in some operations might be at least partially attributable to the shifting of some tasks and associated costs to other operations.

The potentially distinctive effects of CAM applications on unit wage costs concern changes in both direct and indirect labor inputs. Major decreases in the direct labor man-hours per unit of output may be accentuated in their effects on such unit wage costs by the fact that associated decreases in required skills may yield lower wage rates as well. Such benefits are likely to be only partially offset by increases in the volume and skills of the higher-priced but much smaller indirect labor force engaged primarily in maintenance and in the setting up of machines for new or renewed production runs. It should also be noted that the magnitude of increases in such indirect labor costs per unit of output have tended to decrease in recent years as a result of the increasing reliability of system components and the introduction of devices to speed the identification and replacement of malfunctioning elements. In addition, cumulative experience with a CAM application tends to reduce its maintenance requirements, thus freeing more staff time for other applications.

The potentially distinctive effects of CAM applications on unit material costs center on possible changes in input requirements and in the scrap rates resulting from processing. The latter would be expected to decline, of course, as a result of the increased consistency with which computer-controlled operations would satisfy defined product requirements. Material input requirements would tend to be held within closer tolerances in respect to dimensional or other properties for any production run and this might incur somewhat higher material input prices. But the greater flexibility of CAM systems would facilitate adapting such requirements if necessitated by changes in the supply, quality, or price of available materials. Together, these capabilities are likely to yield at least modest savings in unit material costs as compared with alternative systems using similar material inputs.

Cost Flexibility and Cost Trends

Evaluations of the prospective cost effects of CAM systems and of other

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[7] For an extended discussion, see Gold [1, pp. 183-199].

major technological innovations often tend to underestimate emerging deviations from traditional conceptions of the relative flexibility of wage costs and capital charges with fluctuations in output levels. Thus, although capital charges are commonly regarded as "fixed costs," various practices have been used to increase their flexibility. Instead of allocating fixed amounts of such charges per operating period, alternatives in use include allocating them at a fixed rate per machine-hour or per unit of output, or allocating them at rates per period that vary with average capacity utilization levels during each month or quarter. Similarly, while wage costs are still widely regarded as "variable costs," their flexibility has been substantially reduced in many industries by trade union resistance to reductions in employment levels and wage rates during periods of decreased output, as well as by the introduction of increasing cost penalties for layoffs through unemployment insurance. As a result, the tendency of CAM and other major technological innovations to increase the ratio of capital to labor inputs need not reduce cost flexibility as much as traditional expectations would suggest (Gold [1, p. 141]).

Recent economic trends also suggest consideration of the possibility that capital inputs are becoming progressively more economical than labor inputs relative to their respective contributions to output. In part, this reflects the fact that continuing technological progress tends to enhance the processing and fabrication contributions of capital equipment and facilities for 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 are not prevented from rising after workmen have been hired--indeed, the cost of using capital goods may decline progressively under some forms of depreciation. And 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 sickness, holidays, and pensions as well as lay-offs (Gold [9, p. 31]).

Revenue and Net Returns

In order to provide an estimate of the expected return on investment, which is the key focus of capital budgeting, the preceding array of estimates must be supplemented by an estimate of expected revenues. One obvious means of providing it would be to combine estimates of price and of output adjustments over the expected effective working life of the acquisition. But estimates of long-term output patterns are subject to very wide margins of error, especially when made for single plants rather than entire industries; and forecasts of individual product prices tend to be so vulnerable, even over periods of a few years, that virtually no confidence can be placed in such estimates covering 5-10 years (Gold [4]).

Hence, the more common (though often unspecified) approach seems to assume an average profit margin above unit costs and to multiply the resulting total by expected output patterns to yield total revenues for comparison with total costs. But resulting estimates are often too optimistic for several reasons. First, they tend to overestimate the average rate of capacity utilization by underestimating the decline of competitiveness of most productive machinery over time as a result of limitations on adapting to changes in product-mix and as a result of lacking the technological improvements embodied in later acquisitions by competitors. In turn, such expectations encourage overestimates of the profit margins that can be maintained in the face of increasingly powerful pressures on market shares.[8]

As has already been noted, however, the greater flexibility of programmable CAM systems in adapting to changes in product-mix, as compared to dedicated machine systems, and their greater ability to absorb technological improvements in a variety of system components both tend to bolster the continuing competitiveness of CAM systems. Moreover, CAM systems may be expected to provide a higher level of consistency in product quality and to be more readily adaptable to improvements in quality standards. Such capabilities may reasonably be expected to yield higher average utilization rates and profit margins than would be expected on the basis of past experience with the incremental improvements offered by most new machinery. Of course, even these benefits might be insufficient to offset the advantages of later installations of even more advanced CAM systems by competitors.

Some Additional Potential Benefits

In order to fully appraise the distinctive potentials of CAM systems, consideration should also be given to a variety of other benefits which may be derived from many such applications. For example, such systems help to minimize the downtime of production equipment due to the ineffective coordination of material flows through sequential stages of production. The greater reliability of such flows may also permit the reduction of work-in-process inventories. And this together with the closer physical integration of the machines assigned to successive production operations may yield significant savings in floor space. In addition, the ready availability of programmed instructions for producing each of a variety of parts also reduces the time lost in shifting from one to another, thereby making short production runs more profitable than conventional ways of manufacturing. Still another important advantage is the probability of reducing the total cycle time between preparing a bid or receiving an order and delivering the products contracted for--an improved capability which may be very attractive to some classes of customers. Finally, continuing longer-term benefits result from the train-

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[8] For example, see Skeddle [13, p. 561] and also a variety of empirical findings in Gold [6, Chapter 13].

ing and experience gained from initial CAM applications by engineers, maintenance staff, programmers, and operators. The original investment in such personnel may then facilitate the development and introduction of additional CAM applications in other sectors of the firm.

Thus, a comprehensive assessment of CAM systems effects may yield potential results quite different from those which past experience has led managers to expect from acquisitions of gradually improved generations of customary types of equipment. Such differences may relate not only to the magnitude and relative proportions of various categories of cost savings and product quality, but also to the patterning of such benefits over extended periods.

EXPANDING THE ORIGINAL COVERAGE OF CAPITAL BUDGETING ESTIMATES

Expanding Functional Coverage

All of the preceding discussion has been restricted in accordance with the traditional emphasis of capital budgeting models on expected results within the specific sector of operations into which the new equipment is to be inserted. But CAM systems also have two additional characteristics which may be used to develop wider-ranging advances in production operations. One of these is the amenability of programmable controls to interlocking connections with other such controls, thus facilitating the closer integration of material and product flows through a succession of operations. The second is the inherent capability of such systems to generate a broad array of data which can be used for a variety of planning, control, and performance evaluation systems.

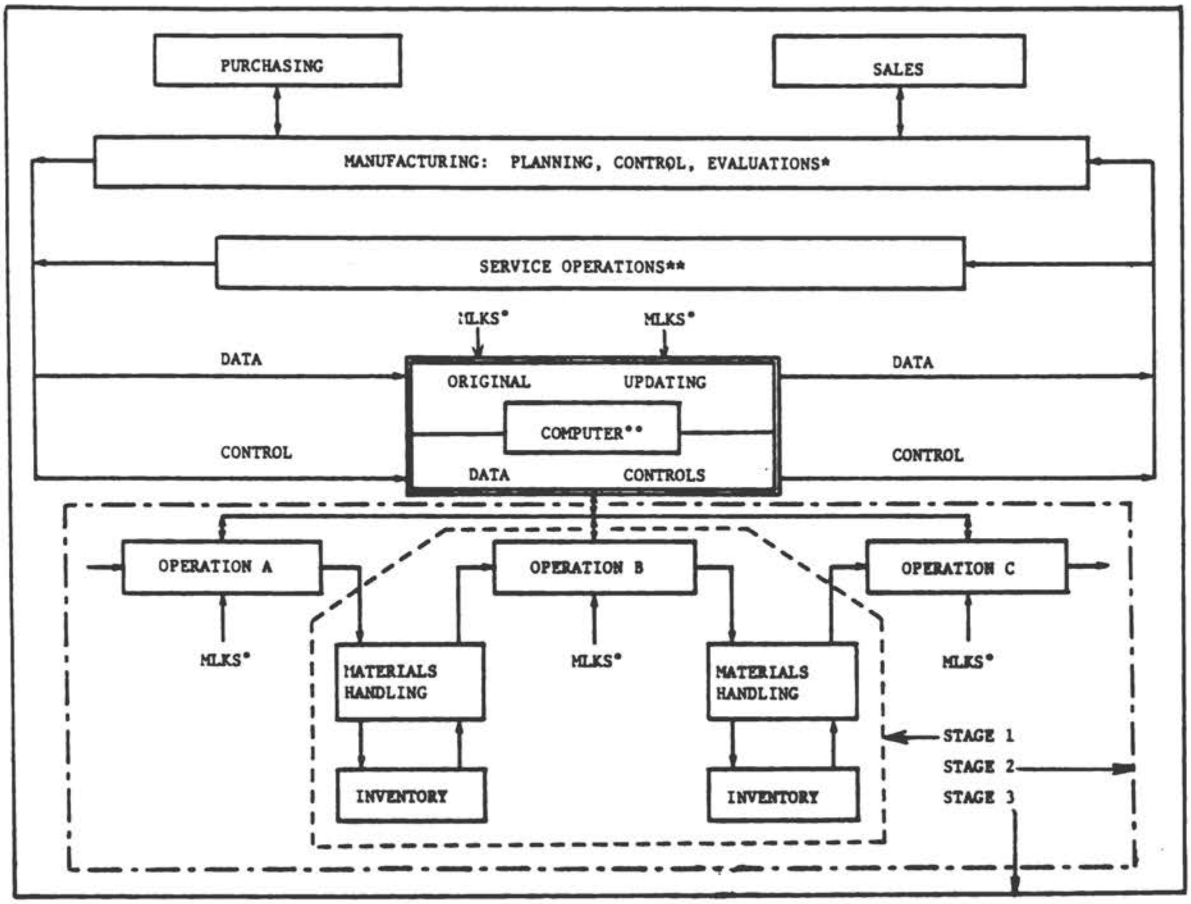
In order to encompass these additional important potentials of CAM systems, it is suggested that capital budgeting evaluations of such proposals be developed through the following three stages--all focused solely on expected effects during the first three years after installation, including the period of "de-bugging," as shown in Figure 1:

1. first, estimate expected effects within the particular sector of operations directly affected, including all of the considerations reviewed in the preceding section above;

2. then extend the coverage of the first stage to include the prospective effects of the acquisition on the performance and costs of the preceding and subsequent operations in the production process--as well as on the performance and costs of such associated service functions as materials handling, inventory management, and maintenance, and

3. finally, extend the coverage of the second stage further to include the prospective effects of the acquisition on production planning and control, on quality improvement, on personnel,

Figure 1. Successive Stages of Coverage in Economic Evaluations of Applications of Computer-Aided Manufacturing



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Manufacturing Support	Service Operations	Basic Inputs	Computer Support
Engineering & Design	Inventories	M-Materials	Data Management
Production Methods	Materials Handling	L-Labor	Programming
Planning & Control	Maintenance	K-Capiital	Applications
Production	Heat and Power	S-Salaried	Development
Maintenance	General Supplies		Maintenance
Inventories			
Quality			
Personnel			
Cost Accounting			

on cost accounting, and on other management planning, control, and performance evaluation functions.

The purpose in suggesting such a sequential development of estimates within the first three years is to encourage a systematic review of the progressively broader repercussions of CAM applications. These may not actually be realized in many cases, either because organizational arrangements encourage the concentration of development and utilization efforts within the original sub-sector, or because no one is responsible for developing such potential carryover contributions. But requiring such potentials to be considered as part of the evaluation of each CAM proposal may help to alert management not only to these larger potential benefits, but also to the need for considering organizational arrangements designed to ensure their realization.

Expanding the Time Period Covered

In order to encompass the distinction potentials of CAM systems, it is also necessary to discourage reliance on the kinds of routine projections of estimated revenues, costs, output, and investment beyond the first three years that are commonly made for equipment acquisition proposals. Instead, it is critically important that probably longer-run adjustment patterns be examined afresh on the basis of the special characteristics of CAM systems.

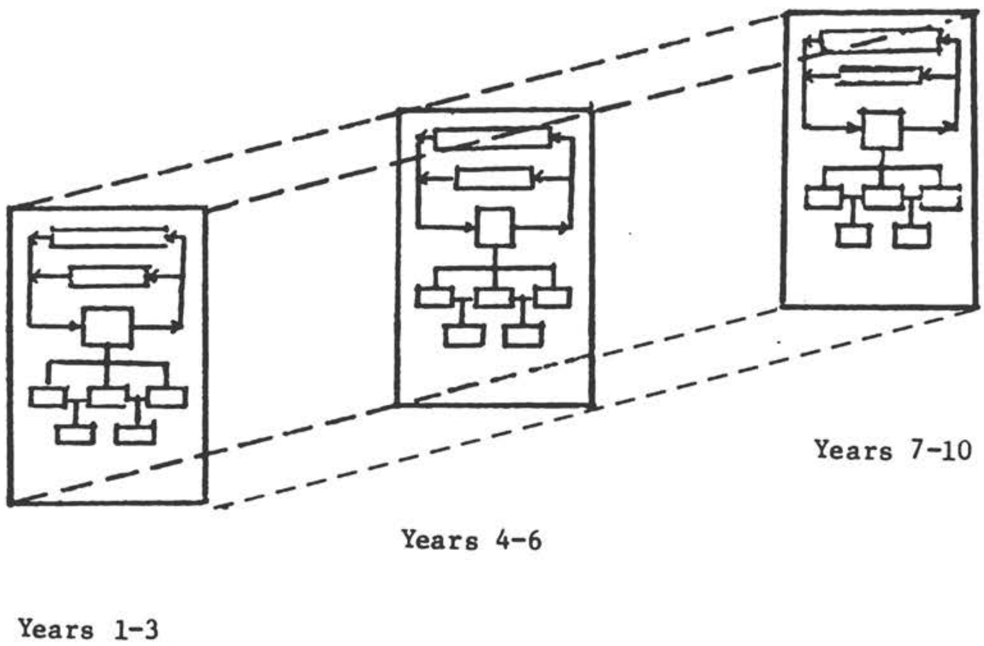
These include the likelihood that benefits will continue to increase (instead of remaining unchanged or declining gradually) well beyond the initial three years of use. And consideration must also be given to the likelihood that repeated additional investments may be necessary to ensure the continuing development and utilization of CAM potentials in place of the common pattern of progressively declining net investment over time as a result of depreciation charges.

Accordingly, effective evaluation of the prospective effects of CAM system applications would seem to require supplementing the initial estimates covering the following three years. And in the case of proposals that envision the progressive installation of extensive and complex systems, effects over even longer time horizons might well warrant exploration (Figure 2).

On Maximizing "Net Present Value"

Attention should also be given to the question of whether the widely prevailing evaluation of investment alternatives in terms of the relative net present values of their future returns is really in practical accord with corporate objectives. This issue is particularly important in respect to major technological innovations and other capital projects involving extended time horizons.

Figure 2. Sequential Capital Budgeting Evaluations



If estimated future returns are discounted at 15-20 percent annually, delays of even 3-4 years before major new facilities can be constructed, made to function effectively, and brought to high levels of utilization tend to result in net present values that invite rejection in comparison with readily available low-risk short-term investments in money markets. But such seemingly rational evaluation techniques suffer from a myopic point of view. In seeking to choose the most attractive among current proposals on the basis of net present values, they fail to consider the long-term effects of successive rejections of all sources of major advances in technological capabilities. Progressively increasing competitive disadvantages in respect to productive efficiency and costs, or in respect to the service capabilities of products, is likely not only to undermine future profitability but even to endanger survival--as has been demonstrated in an increasing array of domestic manufacturing industries.

Hence, in firms confronting decisions involving major technological innovations requiring substantial investments and extended period before offering attractive benefits, it may prove helpful to explore reliance instead on what might be called a "continuing horizons" approach. This involves the development of a portfolio of major projects with overlapping time paths of net returns--calculated in terms of discounted net worth at successive 3-5 year intervals--that promise to safeguard long and intermediate as well as short-term profitability within an integrated perspective covering the practical alternatives facing management (Gold [3, p. 22]).

In considering the development and utilization of substantial CAM systems, for example, few realistic proposals are likely to offer discounted net present values competitive with the low-risk high-interest rates which have been available for several years in short-term money markets. Hence, it is understandable that decisions based on net present value appraisals would tend to reject CAM proposals repeatedly. But this would also tend to undermine the future market position of manufacturing firms capable of substantially improving their cost competitiveness through this new technology--just as the lagging adoption of major new technologies has already undermined the long run competitiveness of a variety of domestic manufacturing industries vis-a-vis Japanese and other foreign producers. In respect to major new technologies, repeated delays in initiating development and application are likely to result not only in such decreasing competitiveness, however, but in incurring increasingly lengthy periods of continuing competitive inferiority during the gestation periods necessary for belated catch-up efforts to succeed.

4. SOME PROBLEMS OF IMPLEMENTATION

CLARIFYING ACQUISITION OBJECTIVES AND PROSPECTIVE BENEFITS

In order to evaluate the prospective benefits of CAM systems, and of other major technological innovations, effectively, it is necessary to begin by clarifying the objectives to be achieved. Of course, all capital investment proposals in private industry are expected to yield attractive financial benefits, except those needed to conform to legal requirements. Such benefits are usually expected to take the form of rates of return on investment exceeding, or equal to, the firm's current average profitability and are expected to be achieved through reducing production costs, or increasing product quality and prices, relative to current levels. Encompassing the realities of a changing economy, however, require a more comprehensive analytical framework.

The Dynamic Setting of Objectives

The basic point of departure must not be the current levels of production costs, product prices, and market share, but prospective <u>trends</u> in each of these over the planning horizon represented by the probable working life of the proposals being considered. If such trends foreshadow declining rates of profitability from the continuation of existing operations, innovations may be considered justifiable if they promise only to limit, or even merely to slow the rate of, prospective reductions in profitability. In analyzing these trends, attention should first be directed beyond the firm to consider potential efforts by competitors to improve their market positions as well as to consider emerging adjustment patterns to input factor and in product markets. Resulting conclusions should then be coupled with the outcome of analyses of intra-firm trends in product capabilities, productive efficiency, and other determinants of future performance. These findings, together with an assessment of the resources available to the firm, constitute what has been called the "pre-decision environment" (Gold [3, pp. 142-144]).

Such estimates of needs and potentials, in turn, help to define the criteria to be used in determining the prospective benefits of CAM systems or other major technological innovations. To do so requires translating hoped-for profit adjustments into supporting improvements in costs, prices, and output. And these latter gains must then be translated into the alternative changes in various unit input requirements and associated factor prices as well as in product qualities that would yield the targeted results. Each of these successive stages of analysis is essential. For example, undertaking major innovations may yield disappointing results if current performance has been limited primarily by marketing inadequacies rather than by technological capabilities. Nor would there be much point in considering innovations which promise significant reductions in the unit of cost of producing current products if market demand has shifted to higher quality or otherwise altered products.

A Suggested Analytical Framework

An analytical framework that provides systematic coverage of the interactions that connect changes in the profitability of total investment and its direct determinants (which have been termed "the managerial control ratios") with changes in the underlying "structure of costs" and, below that, with the "network of productivity relationships" is provided in Figure 3.

This emphasizes that changes in output per man-hour constitute but one of the six interacting components of the network of productivity relationships and that a change in any one of these may engender adjustments in some or all of the others before the system has been effectively reintegrated. Hence, evaluation of a major technological innovation would involve first evaluating its effects on this network. The effects of these changes on various unit costs would obviously depend on accompanying changes in factor prices. For example, associated changes in materials specifications often alter their prices, and wage rates tend to be responsive to shifts in the composition of skill requirements and to increases in output per man-hour. In order to determine resulting changes in total unit costs, the relative changes in each unit cost would have to be weighted by its proportion of total costs. And finally, prospective changes in total units costs would have to be integrated with the prospective effects of any innovation-induced changes in product quality on output levels and prices to estimate resulting changes in the determinants of profitability.[9]

In addition to ensuring that evaluations of prospective technological innovations cover the entire Profit-Cost-Productivity Analysis System, it is necessary that the "pre-decision environment" determinations of the specific physical input and physical output adjustments needed to improve competitive position be matched against the prospective physical contributions of the innovations being considered. And expected cost effects must similarly be compared with estimated cost adjustment needs. This raises the very important question of how such prospective effects are to be estimated.

A firm lacking the specialized technological skills directly relevant to the prospective innovations tends to rely too much on the estimates offered by the vendors. Even if such estimates were not biased

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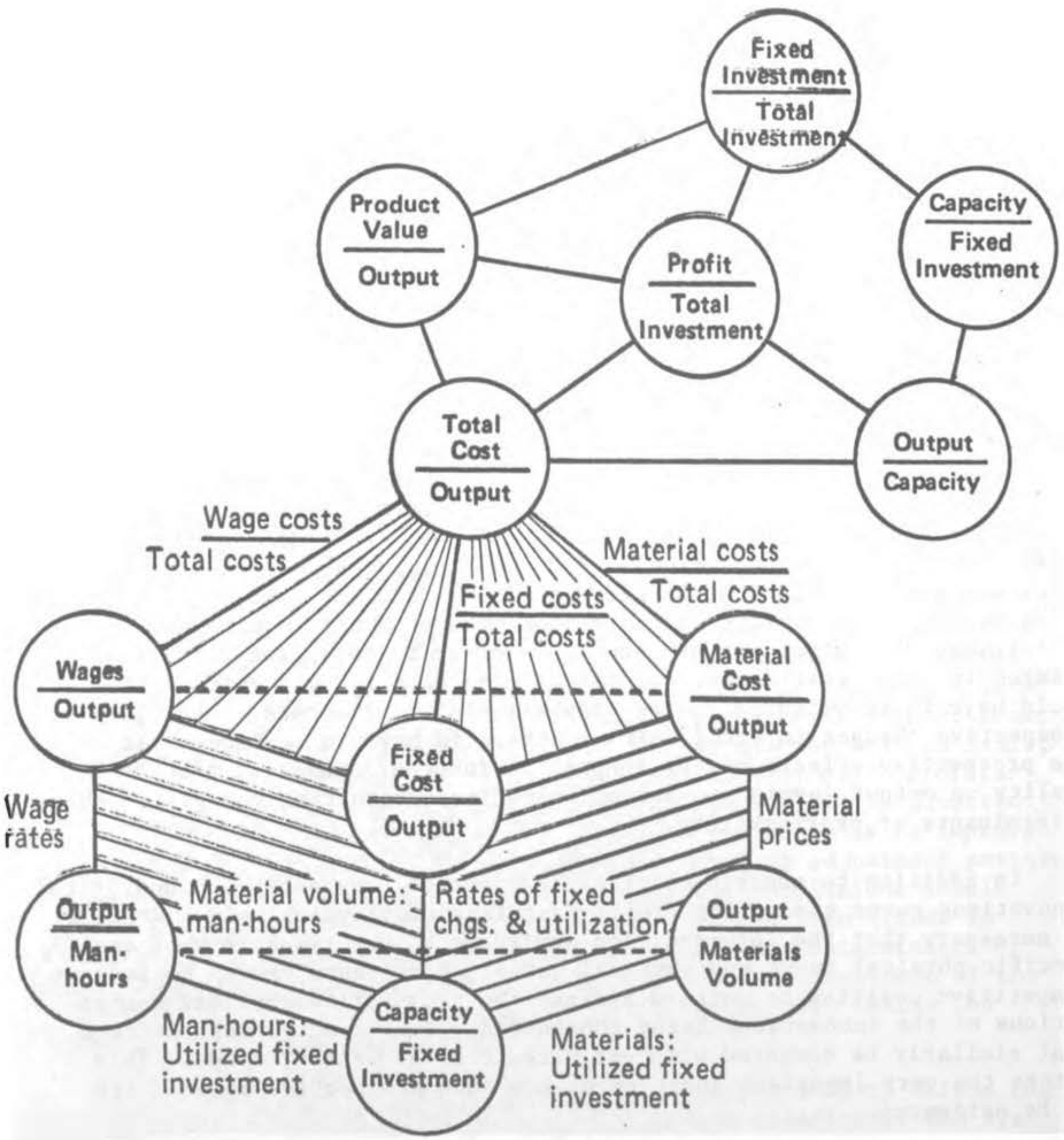
[9] For a more detailed discussion, see Gold [6, Chapter 3].

Figure 3. Productivity Network, Cost Structure and Managerial Control Ratios



towards over-optimism because of the desire to make a sale, they would still be vulnerable because of inevitable shortcomings in the awareness by the vendor's specialists of the array of organizational, personnel, and operating problems that are peculiar to every plant. Nor can the vendor's orientation program for plant personnel be expected to provide the level of expertise needed to provide plant management with reasonably authoritative bases for evaluating substantial capital allocations. Accordingly, the acquisition or development of at least a small core of relevant specialists would seem to be a highly desirable, and probably essential, prerequisite to sizeable investments in major technological innovations. Moreover, additional valuable perspectives on a variety of often unanticipated problems may be obtained from visits to, and discussions with, earlier adopters of the innovations being considered.

The acquisition of such qualified specialists and of insights into the experiences of other users of the innovation would then help to generate carefully designed proposals for an integrated program of successive CAM systems, which would probably cut across a number of different sectors of operation. This would reflect perspectives broader than would be likely to guide proposals generated separately within each sector. It would also encourage more rapid and more authoritative exploration of CAM potentials. And it would facilitate realization of the extra benefits of CAM applications resulting from the mutual reinforcements provided by the addition of properly sequenced building blocks.

ABSORBING CAM SYSTEMS

Computer-aided manufacturing systems cover a wide range in terms of the complexity of the operations performed and, even more important, in terms of the array of other production activities and managerial functions on which they may impinge. This means that the resulting problems of effectively integrating such innovations into the structure and flow of plant operations may encompass a comparably broad spectrum.

Simple Stand-Alone Units

At one extreme, such innovations may involve the application of programmable controls to single machines, so that they may be readily adjusted to performing similar operations on parts of varying dimensions and of moderately altered configurations. In such cases, the characteristics of preceding and of subsequent operations are likely be unchanged--especially if the faster operation of the new equipment is used merely to replace a larger number of manually operated machines, as in the case of programmable tube benders. Hence, the problems of absorption tend to be restricted to altering labor input requirements and tasks, to providing for the preparation of programs for each part design, and to organizing and staffing new maintenance practices covering the computer and instrumentation as well as the production equipment.

Accordingly, such installations tend to accord reasonably well with the expectations and past experience of personnel who have been involved in integrating a variety of individual machine acquisitions into existing production operations. Provision must be made, of course, for supplying the specialized programming and maintenance which may be required along with related engineering assistance during the planning, selection, and de-bugging of each such acquisition. Because of the limited expertise required for any single application, however, and because of its minor part-time demands for servicing after effective functioning has been achieved, such needs are likely to be met by merely providing the required additional training to existing staff members and by modifying their past assignments to include these new tasks. The associated needs to reallocate any displaced labor and to revise the cost accounting standards affected also accord with familiar arrangements for dealing with such adjustments to absorb new units of equipment.

The very conformance of such simple CAM applications to past experience with other kinds of machine acquisitions tends to minimize awareness of the further potentials of CAM systems and thereby tends to delay effective preparation for exploring and developing them. Engineers whose major capabilities are focused on other problems, and whose time continues to be dominated by such responsibilities, are unlikely to undertake serious inquiries into these new possibilities and would probably not be adequately qualified to produce persuasive findings. Hence, such encapsulated individual applications of programmable controls are less likely to represent an entering wedge for the development of progressively expanding CAM systems than to blind management and technical staff to the major differences between the basic potentials of CAM technology and the continued acquisition of equipment units offering only incremental improvements in the application of established technologies.

Flexible Manufacturing Lines

There is considerable experience with dedicated transfer lines in industries manufacturing huge volumes of standardized products. These consist of an integrated sequence of automatic machines, each of which has been tooled to perform a particular set of operations on parts that are moved by automatic conveyors through the successive stages. Such systems require very heavy investments in highly specialized equipment designed and tooled to produce extremely large quantities of essentially unchanging products. Because of the high proportion of capital charges in such operations, economical production requires high levels of capacity utilization over extended periods.

But a very large proportion of manufacturing activity involves production of smaller quantities of individual products or parts. The extent to which the economies of automated machine operations can be realized in such operations depends on the flexibility of the equipment in shifting from one sequence of tasks to another without long delays and large costs for modifying machine capabilities. Development of programmable controls has opened new horizons in this respect and thereby stimulated intensified efforts to use them, not only to increase the cost effectiveness of operations involving smaller outputs of a more variable product-mix, but also to try to broaden the flexibility of relatively highly dedicated systems.

Effective development and utilization of flexible manufacturing systems (FMS), however, requires substantial deviations from past approaches to the introduction of dedicated systems and even of batch production systems. Perhaps the most important of these is that the plant that is to use the system can no longer delegate the entire task of design, construction, and testing to the machine builder, requiring the plant's staff to learn only to operate and maintain the system. On the contrary, the plant must develop sufficient expertise in its own staff to provide detailed guidance on design, instrumentation, and controls as well as to specify criteria for performance testing, reliability, and ease of maintenance. Only on the basis of such comprehensive internal capability can management be assured both of the continuing adjustability of the system to changes in part designs, in quality specifications, and even in product-mix, and also of safeguards against extended downtime while inexperienced personnel grope to deal with unexpected problems. Moreover, such involvement in the successive stages of developing an FMS might well reach beyond engineers to include some prospective foremen, maintenance personnel, and even operating labor, not only to help ensure comprehensive familiarity with the new system but also to facilitate its adaptation to specific operating conditions in the plant.

This latter point introduces a second set of important deviations from past experience with acquisitions of new equipment. In part, these derive from the fact that an FMS usually provides a substantial production capacity, thus posing special problems during the period of its introduction. For example, it is usually difficult or impossible to test the completed system effectively prior to its installation in the plant because of its size and because of the need to integrate its inputs and outputs and servicing needs with the plant's physical arrangements and resources. This means that provision must somehow be made either to retain the production capabilities that the innovation is intended to replace until the latter functions reliably enough to take on the full replacement burden, or to provide for external sources of supply during the "breaking-in" period of the new equipment. In addition, the tendency for FMS capacity to rise over time is likely to introduce additional adjustment problems. If the FMS capacity is intended merely to replace eventually the capacity of the preceding production process, there may well be a significant early period of utilization when it falls short of that target. On the other hand, if this target is met soon after application, it is quite likely that its capacity will continue to rise as a result of progressive improvements in its production capabilities as well as in its utilization--thus necessitating either under-utilization of these additions to capacity or readjustments in the preceding and subsequent stage of production.

It should be emphasized in this connection, however, that effecting such improvements in capacity and other production capabilities requires continuing applications of technical expertise, and may also necessitate some additional investments to take advantage of newly available improvements in equipment or instrumentation. Moreover, all such modifications not only require the updating of programs, but may also necessitate readjustments in production practices. This often engenders differences between the production engineers and supervisors who are constantly seeking to maintain smooth operations and the process development and control engineers who are constantly seeking means of improving the operation's capabilities by altering existing equipment or practices, with consequent dislocations of existing arrangements. Such changes in the performance of CAM systems also requires more frequent revisions of production control, inventory management, and cost accounting standards than is commonly provided on the basis of past experience with more stable operation.

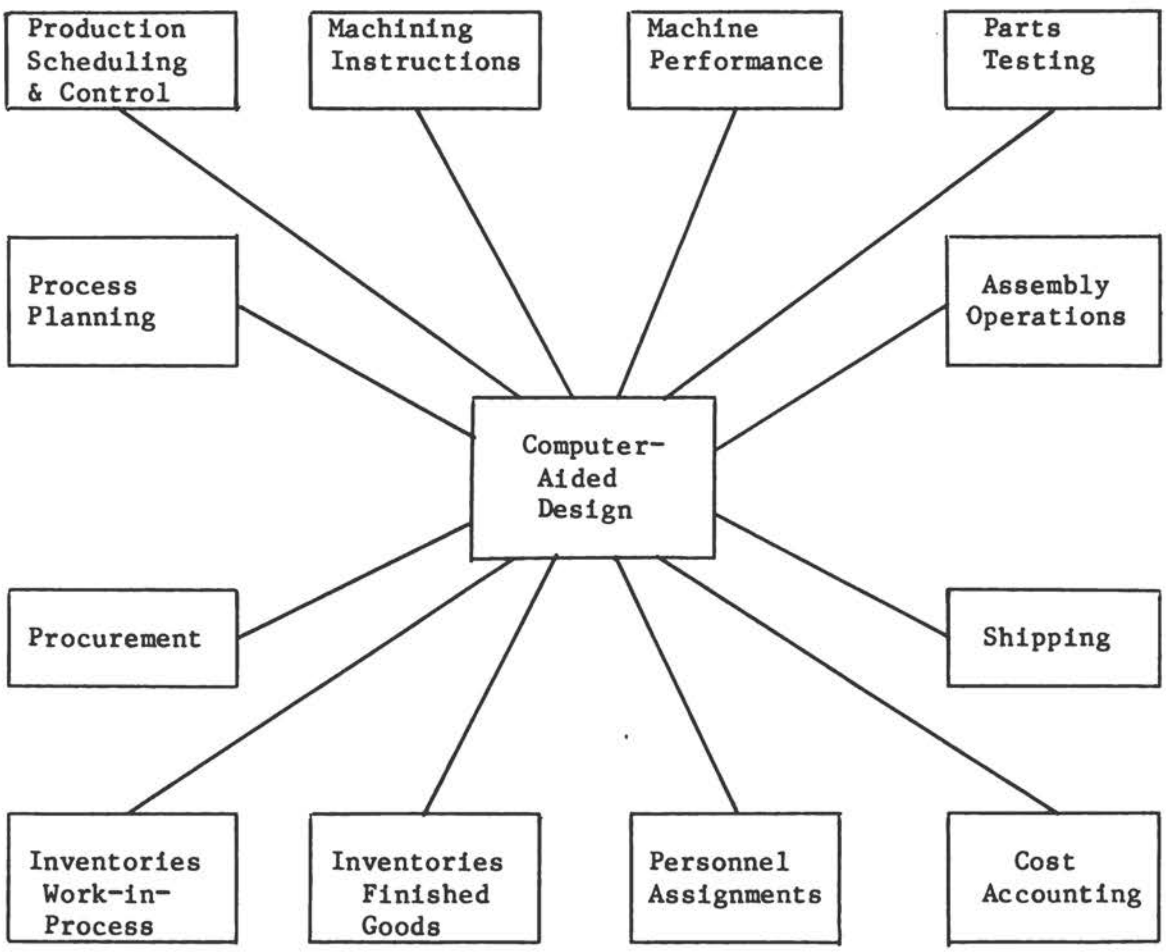
Broader CAM Systems

A third category of CAM systems may be defined as covering all applications reaching far beyond particular sub-sectors of manufacturing operations. Illustrations might range from integrating casting or forging with machining, to integrating several parts machining lines with subassembly operations. Potentially more important would be CAM systems that use computer-aided design (CAD) as the basis for providing a core data base which could then be integrated with one or more of the other major manufacturing and control functions, as illustrated in Figure 4.

In the course of projecting the design shown on the screen of the terminal, the computer is storing a mathematical model specifying its dimensions and configurations. Combining this information with specifications of the kinds of materials to be used and the volume of such parts to be produced along with expected waste and scrap rates can be used to determine procurement instructions. The definition of the dimensions and configurations of the part may be used to establish the sequence of machines to be used, the specific operating instructions for each, the tools required to perform such operations, the estimated time required to machine each piece, and the estimated unit cost of each operation including the wages of the operator. As indicated in Figure 4, various other kinds of performance evaluation and control information may also be generated.

But the preceding understates the potential benefits of such systems by tracing only one direction of information flows. In fact, all such flows may 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. Production controllers can adjust specific machine assignments to accord with delivery commitments and individual machine loadings. The

Figure 4. Potential Applications of Design Data Bases



estimated costs of producing specified products may be used to determine bids for contracts. And many other guides to policy decisions and to choices among operating practices can obviously be developed.

Programs have already been developed to apply each of the possibilities cited above. But few plants are actually using 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. As a result, serious questions have been raised about the factors affecting the transferability of some of these programs from one application to another. What is of primary interest here, however, is that such applications are growing in number, are encompassing an increasing array of managerial functions, and are promising substantial advances in the effectiveness of resource utilization and, hence, in competitiveness. At the same time, experience to date seems to suggest that such advances in the computerization of manufacturing systems cannot be harnessed by simply buying systems developed by others and plugging them into one's own operations. This does not mean that all applications have to be developed de novo. But it does mean that a plant must have an internal staff of specialists capable of defining its needs with precision, of evaluating the potentials and limitations of the alternative systems available from outside, and of effectively adapting such systems to its own needs, or, if necessary, of developing its own.

Some Organizational Repercussions

As was indicated above, the introduction of single stand-alone units using programmable controls need not involve any organizational rearrangements. The introduction of flexible manufacturing lines was seen to require a core of expertise in CAM applications, a programming staff, and some specialized maintenance personnel. An initial application or two might be serviced through attaching such individuals to existing organizational units temporarily. It is apparent, however, that increasingly effective utilization of such resources to improve the performance of the original applications, and to explore additional possible applications, would benefit from providing special organizational arrangements committed to these purposes instead of relying on individuals to pursue such possibilities only in the interstices between other assignments.

Thus, there seems to be no workable alternative to the progressive introduction of a number of organizational innovations if serious efforts are to be made to harness the potentials of broader CAM systems. As indicated above, an initial requirement would seem to be the establishment of a new unit concerned with improving manufacturing technology with special emphasis on CAM systems. Its tasks would include: keeping up with new developments on the relevant hardware, software, and application frontiers; formulating plans to maximize the mutual reinforcement of sequential CAM applications; developing specific application programs for each new sector of application, including close operation with the hardware and software suppliers as well as responsibility for guiding the project through installation and de-bugging; and providing educational programs to increase the interest and knowledge of other technical and managerial personnel in CAM principles and potentials.

A second organizational requirement seems to be the development of relevant degrees of specialized CAM knowledge within each sector of manufacturing that is using or is expected to use CAM applications. Because such line operations cannot be supervised on a continuing basis by the manufacturing technology staff, and because operations and progressive improvements are likely to be less than optimal if not driven by internal operating responsibilities, increasing CAM capabilities are likely to be needed among the engineers, maintenance personnel, operating labor, and supervisors within each major manufacturing division.[10]

A third organizational requirement seems to be the introduction of a new level of managerial responsibility to ensure effective coordination between the groups that interact at critical nodes in the system. For example, one of the most important of these involves the integration of manufacturing operations with the data base core generated by computer-aided design. In the two cases in the present study covering such interactions, achievements have so far fallen short of expectations. One of the most important reasons seems to be that the transfer point is at the outer periphery of both the CAD and the CAM organizations, with no unified responsibility for ensuring the continuous mutual adaptations which are necessary at this interface. Unified responsibility may similarly be necessary to develop increasing coordination at some or all of the other nodes depicted in Figure 4.

Finally, there may well be an eventual need to provide some means of ensuring that progress in developing and utilizing the potentials of CAM systems is reviewed periodically and promoted systematically by some member of top management with responsibilities reaching beyond manufac-

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[10] It may be of interest in this connection to mention observations of the process whereby computerization is applied to new sectors of operations in some Japanese steel mills. Instead of having the systems group alone study the operation and devise a CAM application for it, one or more of the operation's supervisors are sent off for intensive training in computers and systems analysis, while one or more specialists from the systems group are assigned to help manage the actual operations to be computerized for a comparable period of at least several weeks. When the two groups are brought together to jointly develop the CAM application, their cooperation is facilitated by each member's understanding of the interacting problems to be dealt with; and it is further motivated by the fact that the next supervisor might be chosen from <u>either</u> group (Gold [5]).

turing alone. Because it is regarded as a key determinant both of market competitiveness and of the effective use of all company resources, such responsibilities are already lodged with senior corporate officers in some Japanese companies.

A more generalized conceptual view of organizational adjustments to new technologies is offered by Joel Goldhar[11] and various organizational theorists. Goldhar suggests a three-stage sequence:

- the first involves using the new technology to perform existing functions in essentially unchanged ways but faster, better, and more cheaply;
- the second involves the acquisition of people with new specialized skills and reallocating responsibilities so as to increase the effectiveness with which the potentials of the new technology are used to produce the same products and services as in the past; and
- the third involves using the new technology to produce new kinds of products and services.

In the cases covered in this study, only the simple stand-alone unit seems to fit into this category. All of the remaining cases are in the second category, while also exemplifying a number of additional component elements in such organizational adaptations--including coverage of increasing stages of production and of an expanding array of functions.

EVALUTING CAM SYSTEM PERFORMANCE

There is considerable literature on estimating the probable effects of technological innovations before decisions are made to adopt or reject them. But there is an astonishing paucity of research and writing on evaluating the actual effects of such innovations after they have been installed. Inquiries suggest that the reason for such neglect is the widespread assumption that the purposes, methodologies, applications, and interpretations of such undertakings are so obvious as to offer no interesting problems. Our own field studies of such innovations, however, yield a sharply contrasting view. Specifically, the few post-installation evaluations that have turned up in our research on the effects of major technological advances have been shot through with difficult problems and highly vulnerable bases for many of the results reported, even within the firms attempting such appraisals.

The key issues seem to center on four questions:

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[11] For fuller discussion, see Goldhar [12].

- What should be the primary criteria in such evaluations?
- When should such evaluations be made?
- Who should make them?
- To whom should the results be reported and what use should be made of such findings?

Each of these will be discussed briefly below, along with some suggested correctives.

Criteria of Evaluation

Most efforts to evaluate CAD/CAM or other technological innovations tend to concentrate on financial criteria, especially on the level of outlays made and resulting operating costs relative to original expectations. But, as was noted earlier, such findings may be inadequate and even misleading unless accompanied by a comprehensive appraisal of all other associated changes in the production operations affected. Among these should be included: any changes in the qualities as well as quantities of inputs and outputs; any shifts in operating tasks to (or from) preceding or subsequent stages of production; any adjustments in below-quality output ratios; any changes in the mix of products processed and in the length of production runs; and any changes in the proportion of equipment down-time not attributable to decreased market demand. It is important to recognize that many of these critical determinants of performance are likely not to be adequately reflected by existing cost accounting measures unless these have been thoroughly revised.

Even such a comprehensive array of measures falls short of evaluation needs however. Understanding performance changes also requires analysis of the reasons for observed results. At the very least, this requires distinguishing among changes attibutable to: the operating characteristics of the hardware; the planning and management of input and output flows; engineering modifications in production methods and product requirements; and labor capabilities and efforts. Inadequate probing of the specific causes of deviations from performance targets seems to encourage ascribing observed deficiencies all too readily to unpredictable or external factors, thus hindering identification of internal shortcomings.

It should also be recognized that experiences and insights during the processes of introducing and learning to use major innovations commonly result in modifying initial expectations concerning the specific tasks that can be performed most effectively as well as practical achievement potentials. Hence, comparisons of results with original expectations may be less meaningful than comparisons with such later perceptions of needed and attainable contributions.

Timing of Evaluations

When should the results of major innovations be evaluated? Our studies suggest that most firms seem to rely on one appraisal within 6 to 12 months after the project's completion. Such early estimates often yield overly optimistic conclusions because generous allowances are made to offset actual shortcomings by assuming these to be attributable to temporary problems--such as excess maintenance, inadequate labor experience, or under-utilization due to incomplete integration into adjacent stages of production. Such one-shot appraisals may mislead managers by focusing on actual results achieved by the time when the appraisal is made instead of on trends in such performance measures. An analysis of such trends would be of far greater value by revealing whether performance was continuing to improve or not, and be encouraging attention to the sources of additional gains. This would help to uncover any dubious claims of only temporary shortcomings, while also helping to focus attention on identifying additional sources of improvement and developing plans for harnessing them.

For example, in the case of many innovations, and especially in the case of CAD/CAM applications, it is only after the innovation has achieved effective functioning and reasonably high levels of utilization, that efforts are made to maximize realization of its fullest potentials by undertaking adaptive adjustments in preceding and subsequent operations, in managerial planning and control processes, and even in product designs and operating methods. Accordingly, more effective appraisals would require evaluations every 6 months for at least 3 years (and even longer, if performance and potentials have not yet stabilized--as is likely to be true of complex CAD/CAM installations). These would serve not only to to appraise successive changes in results, but also to provide the analytical basis for possible revisions of future performance targets.

Responsibility for Evaluations

One of the critical problems faced in appraising major innovations is the pressure for biased evaluations. In the case of very large projects, the tendency to seek out and to emphasize favorable aspects of results seems to be attributable to concern that negative judgments would reflect on the high-level officials responsible for approving such commitments and be resented by them. Such biases are often built into the evaluation process because allocation of such responsibilities to the officials deemed to have the relevant expertise often involves reliance on those who participated in making the project proposals.

Thus, technical evaluations are usually left to the specialized engineers and the investment and cost evaluations to the respective specialists who are likely to have been involved in preparing the original estimates--partly because of the absence of qualified internal alternatives and partly to protect the confidentiality of findings. Moreover, those assigned to make such evaluations are often led to mute critical judgments lest these inhibit future cooperative relationships with the officials responsible for such projects.

In order to help minimize the influence of such biases on evaluations, it seems necessary to have them made under the direct supervision of the official responsible for increasing the contributions of manufacturing to the profitability of the plant through improving product quality and production efficiency while reducing average unit costs. Such evaluations would, of course, require contributions by engineering, production management, cost accounting, and finance. But it would also seem to require a blending of their respective specialized insights within the larger and longer term perspectives of managerial efforts to improve market competitiveness and profitability.

This suggested need for special organizational arrangements for evaluating major innovations is especially important in the case of CAD/CAM applications. One reason is that, as has been noted earlier, the ramifications of this new technology tend to be varied and far-reaching, thus requiring consideration of such multi-dimensional effects in attempting serious appraisals of results. An equally important reason is that such evaluative efforts can also serve as a valuable educational device, sensitizing to CAD/CAM potentials even those functional specialists who have not yet experienced major impacts from such developments.

Using Evaluation Results

Using evaluation results to provide an ex post appraisal of the ex ante expectations that led to the decision to adopt the innovation is an obvious and widespread application. But it is seldom regarded as very important, partly because past decisions are regarded as "spilled milk" and partly because each major innovational decision is regarded as unique, and hence unlikely to benefit from experiences with prior ostensibly unique decisions.

In the case of CAD/CAM applications, additional projects and extensions tend to represent a blending of unique elements with considerable common elements. Hence, substantial benefits may result from using ex post findings of past installations to uncover the loci and primary causes of significant deviations from expectations as a basis for identifying those likely to be influential in later applications as well. Moreover, careful analysis of trends in the performance of any CAD/CAM project may help to reveal both the sources of constraints on further achievements and the means by which past constraints were eased or overcome. Finally, findings from past applications concerning the periods over which successive improvements have been achieved may help to ensure continued efforts to keep increasing performance levels instead of accepting the early ceilings on maximum capabilities associated with experiences involving other types of equipment innovations.

Incidentally, attention should be directed to the seemingly universal avoidance of post-installation estimates of the incremental contributions of major innovations to profitability. Efforts are often made to estimate reductions in some input requirements and, somewhat less frequently, in total unit costs. But this implied recognition of the difficulties in attempting to determine resulting effects on profitability, even on the basis of actual *ex post* data, raises even more serious doubts about the practical usefulness of continuing widespread reliance on *ex ante* estimates of such profitability effects as the basis for decisions involving the adoption or rejection of major innovations.[12]

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[12] For further discussion of the problems of making and improving evaluations of technological innovations, see Gold *et al* [11, Chapter 14].

5. CONCLUSIONS: REQUIREMENTS FOR INCREASING THE DIFFUSION OF CAD/CAM APPLICATIONS

THE ROLE OF MANAGEMENT

The dominant obstacle to more effective evaluation of CAM potentials is the continuing failure of most industrial managements to realize that CAM offers potentials far beyond merely reducing requirements for machine operators. The widespread prevalence of that restricted image encourages its continued relegation to consideration by sub-sectoral production managers and engineers as well as its continued evaluation within the usual constraints of capital budgeting. Only a fuller appreciation by senior officials of the critical bearing of CAM on their competitiveness, even within the next 5 to 10 years, is likely to engender the top-level commitments necessary to motivate and support effective development and implementation efforts.

A related obstacle is the heavy emphasis by most American managements on maximizing short-term returns from investments. This has already tended to reduce commitments to long-term research projects as well as to construction and modernization projects requiring long periods for completion. Efforts to gain approval for CAM projects within such short horizons has lead some firms to concentrate on essentially small stand-alone projects, thus reinforcing the dwarfed conceptions of CAM potentials already held by managements--while leading others to overestimate short-term returns, thus prejudicing evaluations of subsequent proposals.[13]

Another significant obstacle is the relative decline in influence of technical specialists in many industrial firms. When the dominant roles in shaping company policies are played by specialists in finance, marketing, and government relationships, the progressive undermining of technological competitiveness may not be fully appreciated until it has become critical--and may not even then attract the capital needed to redress such long neglect if results cannot be assured within relatively short periods.[14]

Moreover, the absence of recognized CAM expertise among senior officials of most companies prevents allaying the uncertainties and even

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[13] For further discussion, see Gold [6, pp. 298-299].
[14] For further discussion, see Gold [9, pp. 503-504].

fears that have affected those executives who know something about the serious problems that have been encountered by some of the well-known pioneers in applying CAM. Lacking understanding of the improvements that have been made in all components of CAM in recent years, and being unaware of the extent to which such problems differ with the kinds of applications attempted as well as the adequacy of back-up resources, such executives can hardly be expected to be responsive or even neutral when CAM proposals are presented by vendors. And when such active or even latent negativism is reinforced by the veteran managerial and technical specialists within the firm--who not only lack CAM expertise but fear its possible impacts on their own careers--favorable decisions are even less likely.

THE ROLE OF VENDORS AND BROADER PROMOTIONAL EFFORTS

Diffusion has been severely inhibited by reports in the trade about the numerous and frequently serious difficulties that have been encountered by adopters of complex CAM systems and by the failure of some well-known pioneers to intensify such commitments. To overcome such influential deterrents, vendors will need to demonstrate increasing capability in designing systems to respond to user needs more effectively and to ensure the increasing reliability and effective working time of their hardware. In addition, vendors may create greater confidence in their services by being more candid in detailing the substantial supporting inputs of engineering, planning, programming, and maintenance personnel likely to be required to speed the effective harnessing of their hardware capabilities.

There has already been widespread discussion of CAD/CAM in engineering and management journals. But the conversion of resulting general awareness and interest into active consideration of applications also requires increasing authoritative evidences of the actual benefits achieved by a wide array, rather than a small and unrepresentative sample, of industrial users. Increasing diffusion also requires expanding the availability of engineers, software designers, and programmers capable of assessing and servicing the needs of prospective installations--through increasing the educational and training opportunities offered by engineering schools and community colleges as well as through specialized training programs.

Because of the far-reaching potentials of CAD/CAM technology for increasing the efficiency and competitiveness of American industries, serious consideration should be given to developing governmental incentives and support for accelerating business commitments to the costly and somewhat risky efforts to harness these powerful potentials. Such contributions might involve support for relevant educational an research programs as well as favorable depreciation and other tax treatment of the investments involved.

THE ROLE OF MARKET PRESSURES

The most consistent and most influential determinant of managerial interest in CAD/CAM potentials over the longer run is bound to be a variety of increasingly intensive market pressures. These include improvements in the product qualities and decreases in the relative prices offered by foreign as well as domestic competitors. And they also include increases in material and energy prices as well as in the wage rates that determine production costs. As a result, CAD/CAM applications are bound to increase. But the resulting rate may not be rapid enough to strengthen competitive position, or even to regain the market shares that many firms and entire domestic industries have lost in recent years.

CAD/CAM technology is still new enough so that few users have as yet adopted it on a wide scale and harnessed its broad range of benefits. Hence, accelerating its diffusion among domestic industries appears to offer one of the most promising opportunities available in recent years to achieve major advances in their international competitiveness.

THE ROLE OF LABOR

It may be of interest to note that CAD/CAM applications have not encountered the serious labor opposition that had been anticipated by managers. This may be due to the very limited impacts of existing installations, or it may be due to the heightened managerial sensitivity to the need to minimize any attendant hardships. Thus, larger scale applications that threaten immediate sharp employment reductions might well incite labor resistance, unless associated market pressures and internal adjustment capabilities are carefully reviewed with labor or its representatives as a means of seeking to minimize problems. At any rate, analysis suggests that the other factors that have been reviewed above have been far more influential than labor reactions in limiting the diffusion of CAD/CAM applications until now and may continue to be more influential for some time to come.

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