ON THE POTENTIAL, REQUIREMENTS AND LIMITATIONS OF INFORMATION TECHNOLOGY IN MANUFACTURING*

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Recent and prospective advances in information technology have generated growing interest in its potential. To its enthusiastic promoters, information technology is a 'good thing' and hence more is obviously better. But increasing experience with information technology during the past twenty years emphasises that it covers a wide variety of capabilities, absorbs substantial resources and affects operations in other important ways. Hence, to ensure effective exploration and utilisation of information technology, management must assess its potential contributions, requirements and costs, as well as other significant effects.

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ON THE PROSPECTIVE BENEFITS OF INFORMATION TECHNOLOGY IN MANUFACTURING

As a result of emerging experience during recent years, three levels of information technology's capabilities are now discernible. The long recognised, and still dominant, 'primary level' of application focusses on information flows. Initially, it involves encompassing increasing amounts of information in data banks. Beyond that, it keeps enlarging capabilities for processing such information into specialised as well as repetitive analyses and reports with increasing speed. In addition, it seeks improved means of distributing results quickly to those most in need of them. These information processing functions have also dominated information technology applications in other fields, including finance, commerce, transportation and government.

There has also been growing awareness for several years now of a 'secondary level' of information technology applications in manufacturing. This involves the use of processed data flows directly to control and adjust the level and sequences of production

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operations. Such emerging capabilities are covered by the terms 'computer-aided design and engineering' (CAD and CAE) and by the more encompassing 'computer-aided manufacturing' (CAM).

A 'tertiary level' of information technology applications is still in its earliest stages of development, with the volume of speculative discussion far overshadowing actual experience. This stage would involve the integration of all planning, operations and performance evaluations for entire firms, including those with multiple plants and international activities. The relevant acronym is CIM, or 'computer-integrated management'.

ON THE CAPABILITIES, REQUIREMENTS AND LIMITATIONS OF PRIMARY LEVEL APPLICATIONS

A. Components of such applications

The earliest applications of information technology were usually instigated by accounting and finance staff in order to cope with their need to process large flows of essentially repetitive categories of data. Resulting benefits encouraged the gradual development of similar capabilities for other functions having similar needs, including production control, inventory management, procurement and personnel. Although such additional applications were initially carried out on the computing facilities of the financial groups, independent facilities for other functions have been provided progressively by many firms.

A second stage of development in manufacturing industries commonly involved the provision of different types of information technology facilities in order to support the needs of research and engineering. These usually require highly complex and varied processing of wide arrays of small batches of non-repetitive data.

The latest stage of development has involved response to yet another sector of needs. This has involved the distribution of small computers to an expanding array of managerial and other personnel to facilitate specialised data processing and data analysis, including direct access to relevant data banks for needed information.

Each of these stages of adoption and utilisation by industry is still growing briskly as the early sequences in large firms are being imitated by smaller firms as a result of improvement in equipment capabilities, reduction in equipment costs and increasing awareness of the potential benefits of such applications.

B. Requirements for supporting such application

The first stage usually required investment in central computing facilities and communication links as well as in programming and maintenance staffs. In addition, substantial allocations also had to be made to training successively broader arrays of prospective users of such new capabilities. Sequential later stages have necessitated similar additional outlays for equipment, specialised personnel and training. Such proliferation of information technology resources has also usually encouraged the organisation of a central staff to advise management on emerging needs and problems, to help the separate operations to achieve effective functioning, and also to facilitate co-operation among them.

However, as the attractions of novelty have begun to fade, two critical questions concerning information technology applications have attracted increasing attention:

1. To what extent are the costs of expanding such applications justified by their economic benefits?
2. To what extent would integration of the multiple sub-systems permit the reduction of associated investments and costs while also increasing the usefulness of such operations to direct users as well as senior management?

Despite the widespread emphasis on 'rational decision-making' we have not yet found any persuasive factual approaches by managements to evaluating proposals for additional applications of information technology, nor even for evaluating the results of past adoptions. In one of our research projects, I met with the senior capital allocations officials of five major US firms to inquire into the bases for their responses to such requests. After considerable evasive discussion, the essentially common response came to the following:

> Although we cannot evaluate the eventual returns from such new capabilities, because their multiple effects cut across various operational and cost categories, but because it would obviously be unwise to keep delaying access to what are widely regarded as potentially important advances, we must respond. However, because innovative proposals invariably exaggerate both the prospective benefits and capital requirements, we allocate only about one-half of whatever amount is requested. Then we can consider successive later requests on the basis of the justifications provided by the results of the initial allocations.

Such a continuing commitment to a piece-by-piece introduction of new manufacturing capabilities reflects the results of past experience, with advances involving the acquisition of replacements for, or additions to, existing units of equipment whose contributions can be assessed separately from those of other units. This approach is likely to be seriously misleading in evaluating the potential of integrated systems of manufacturing, such as are represented by the secondary level of information technology applications, as will be discussed later.

In considering the prospective benefits of integrating the multiple sub-systems of information technology applications in a plant, it is important to recognise the often extended and costly efforts that would be required to re-program and integrate all of the data flows and analytical processes involved. As for resulting benefits, these have been limited in many firms by the relative infrequency with which the distinctive needs of separate functions require access to various other data sectors and also because the availability of small computers with increased capabilities has reduced the need for access to the central computer. Hence, selective integration of some sub-sectors on the basis of significant benefits may represent a more prudent course.

C. Limitations of such applications

The most fundamental limitation on the benefits of advances in data processing and distribution capabilities in manufacturing operations derives from the fact that they can help to achieve only more of the built-in capabilities of given production systems; they cannot significantly enhance such potential. As long as products and production processes remain unchanged, the essentially passive supporting function represented by data flows means that improving their speed, coverage of detail and complexity of analysis is likely to have only minor effects on resulting competitiveness.

Hence, although all improvements in information systems tend to be regarded as self-justifying by many information specialists, a more objective view suggests that resulting benefits depend on the extent to which they serve two purposes: providing the bases for improved managerial decision-making, and facilitating the utilisation of new system potential.

With respect to the first of these, maximising detailed information flows can easily become counter-productive by swamping recipients with masses of largely irrelevant data and thereby discouraging their searching for the useful bits which may be embedded. Thus, a variety of officials at a major oil company told us that they were merely crossing their names off the routing slips attached to the increasingly voluminous computer print-outs coming across their desks, hoping that someone else was finding such material useful. To ensure usefulness, information systems should be designed to provide outputs to each sector of management responsive to their distinctive needs as determined by their planning, control and evaluation functions. Hence, information system designs should be determined primarily not by efforts to maximise utilisation of the increasing capabilities offered by advances in information technology, but rather by utilising such capabilities to serve the responsibilities of each category of recipient.

The greater potential of applying advances in information technology to manufacturing is rooted not within the growing internal capabilities of this technology, but in integrating such capabilities with the development potential of the operating systems to which the information technology is applied in order to produce a *combined* system with superior capabilities. A major advance in this direction is represented by the second level of information technology applications to which the discussion will now turn.

ON THE POTENTIAL AND REQUIREMENTS OF SECOND LEVEL APPLICATIONS

A. Basic characteristics

As indicated above, second level applications of information technology in manufacturing involve the integration of advances in the capabilities of computers and computer programs with advances in manufacturing processes and equipment so as to guide and control the production operations of entire plants or of major components of such plants. This approach is commonly referred to as computer-aided manufacuring, or CAM.

CAM has been widely discussed for more than a decade with models of how it should be organised, applied and evaluated. And yet, although one can find numerous bits and pieces of applications — including some computerised manufacturing 'cells' and even a few groups of machines — complex integrated systems are still rare in the US and in most other advanced industrial countries. Among the few well-known examples are: the General Electric locomotive plant in Erie, Pennsylvania; the new Westinghouse plant in West Texas; the Chrysler van plant in Windsor, Canada; and older and more limited applications by Caterpillar, John Deere, Ingersoll, Allen-Bradley, Boeing and MBB's military aircraft plant in West Germany.

Why has this enormously powerful technology — perhaps the most important contribution to increasing the productive efficiency and reducing the costs of manufacturing industries over the next 10-15 years — developed and diffused so slowly? My studies,[1] primarily in the US and Japan, suggest that it has been due to the discovery that the tasks involved are far more complex, time-consuming and costly than has been widely recognised. As a result, far greater resources will have to be committed if major advances are to be achieved, as is shown by some Japanese experiences which will be cited later.

B. On the benefits of computerisation in manufacturing

CAM tends to revolutionise manufacturing in four important ways. First, it enables production equipment to operate at higher speeds and to yield higher and more consistent product quality than manually-controlled operations. Second, it permits a production line to shift rapidly from making one product to any of a variety of others by automatically shifting the instruction tapes in the computer. This capability sharply increases the cost efficiency of shorter production runs, which have been estimated to represent more than 80 per cent of manufacturing product output.

A third important advantage is that CAM enables a given production line to adapt to the inevitable market pressures for changes over time both in product designs and in product mix. This capability serves both to extend the economic life of capital facilities and to help maintain higher average levels of capacity utilisation than narrowly specialised and mechanically automated systems. The latter are capable of only very slight adjustments in product and process, although they are very cost effective if high utilisation rates can be maintained for years. For example, Ford's eight-cylinder engine plant, reputed to be the most efficient in the world, had to be closed some years ago because it could not be modified economically to produce the smaller engines needed as a result of the energy crisis during the 1970s.

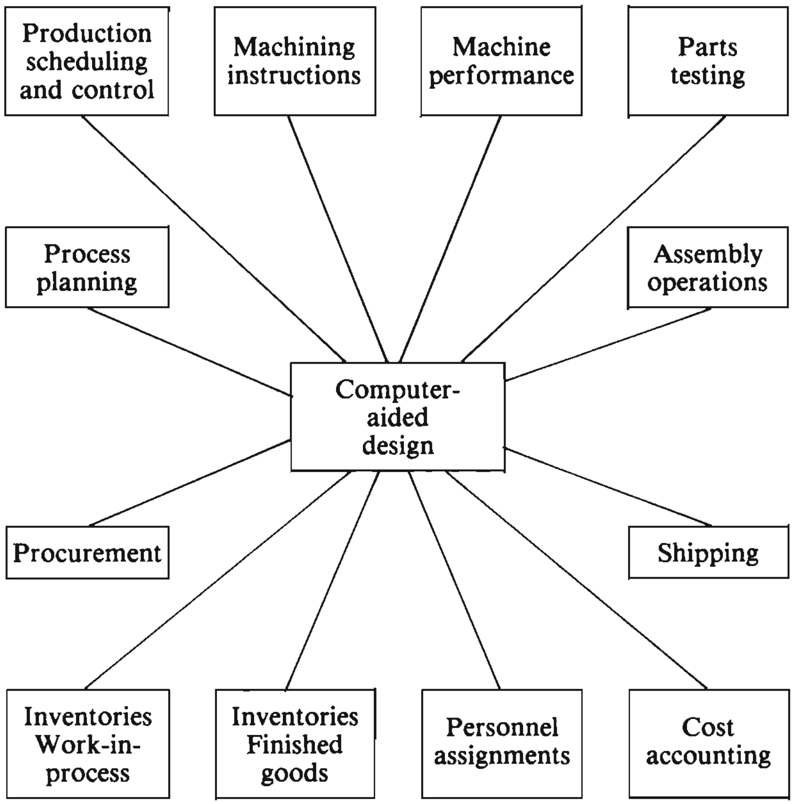
Finally, CAM also provides the basis for a hitherto unprecedented degree of integration of all stages of operation from design through production and testing. Moreover, it also facilitates combining such integrated operations with a variety of management controls, as will now be summarised.

C. On the dimensions of such computerisation

Computer-aided manufacturing in action begins with computer-aided design (CAD). This process involves designating certain points on a screen and pressing various keys to guide the computer in drawing specified configurations around them, including dimensions and component details. This speeds the process of designing a part, facilitates exploring alternative designs, and can provide for automatic designs of scaled-up or scaled-down versions of the original. The key point to be understood is that in order to project the resulting design on its screen, the computer must generate and store the equivalent of a detailed mathematical model of all of its features. It is this data base which can then be used as the input for controlling the array of production processes which shape the final product.

For example, as shown in Figure 1, the resulting computer model of the product's dimensions and configurations may be built into

FIGURE 1
Potential Applications of Design Data Bases



computer programs which can generate such requirements as:

a. a schedule of the sequence of machines to be used in producing each part;
b. specific operating instructions for each machine as well as identification of the tools required to perform such operations;
c. dimensional criteria for testing conformance of specified operations, as well as of the finished parts, with design requirements;

d. production schedules specifying individual machine assignments to accord with the estimated machining time required for each part and with previously scheduled machine loadings as well as delivery dates;
e. estimates of the unit cost of each operation, including the wages of the operator;
f. and combining the design data with material specifications and planned output, along with expected waste and scrap rates, to generate procurement requirements.

However, tracing such information flows in only one direction understates available potential benefits because all such flows move in both directions. For example, engineers can use them to explore the relative costs of alternative processing sequences and machining instructions. Also, inventory adjustments and manpower allocations can be adapted to variations in production and distribution schedules. Illustrative programs have already been developed for each of the foregoing possibilites. But few plants are actually using many of them on a widespread and continuing, rather than an experimental, basis. There can be little doubt, however, that the future will see increasingly rapid realisation of such potential, with profound effects on the requirements for remaining competitive.

D. CAM development strategies

Computerisation in manufacturing has proceeded in most cases through limited applications in one or a few plant operations on the initiative of innovative engineers or managers. But such a 'bottom-up' approach tends to have limited potential. This is attributable, in part, to the fact that the required investment in computers and programming for such introductory applications could usually support wider applications with less than proportionate additional outlays — thus minimising the net benefits of narrowly limited applications. Moreover, independently developed and localised applications usually cannot be integrated without redesigning and re-programming them, even if the objective is merely to co-ordinate successive operations. In addition, efforts to move CAM applications to higher organisational levels so as to co-ordinate still broader sectors of production operations usually face significant delay and resistance at each step, reinforced by renewed need to redesign and re-program the enlarged system.

The resulting highly localised and very modest benefits commonly achieved in most plants, together with the repeated interruptions and objections encountered at each proposed further extension of the system, helps to explain the extremely limited progress achieved even years after the initial applications. These factors also account for the frequency with which one encounters small encapsulated applications which have been unable to break out of their cocoons. What then are the requirements for developing effectively integrated applications of CAM?

The first and most critical requirement is to develop senior management understanding of, and support for, such an undertaking. One reason why this is essential is that substantial CAM systems require heavy investment for extended periods before significant returns are likely to result. Another reason is that such applications are likely to require the employment of new kinds of technical specialists, contrary to the desires of existing staff concerned about the resulting effects on their future status. In addition, a commitment to CAM may encourage shifts in organisational arrangements in order to support the tighter integration of broader sectors of operations inherent in such systems. For example, in a study of a plant producing equipment for the nuclear power industry, we found that much of the potential benefit of an outstandingly effective CAD operation was dissipated by the failure to re-organise manufacturing operations.

Another reason for requiring senior management support for developing a CAM system is that it may result in sharp reductions in employment requirements as well as shifts in the skill composition of the remaining workforce. Managerial support will also be required for the accompanying extensive re-design of existing information flows to support the required closer co-ordination of all production, cost, personnel, inventory and other control and evaluation data at various levels of managerial responsibility.

Given needed management support, the second critical requirement is to design the overall basic system to be implemented. This involves a 'top-down' perspective which identifies planned control and performance criteria at the level of the plant (or defined sector of operations) and for each of its identified major components. The subsequent planning for each such major component will have to define specifications concerning all of its input requirements, constraints and interconnections with other operations to ensure effective integration into the larger system as it is developed. But the sequence in which such major component sectors of the larger system are developed depends on managerial judgements concerning the relative benefits and difficulties offered by each, including the co-operation of the staff involved.

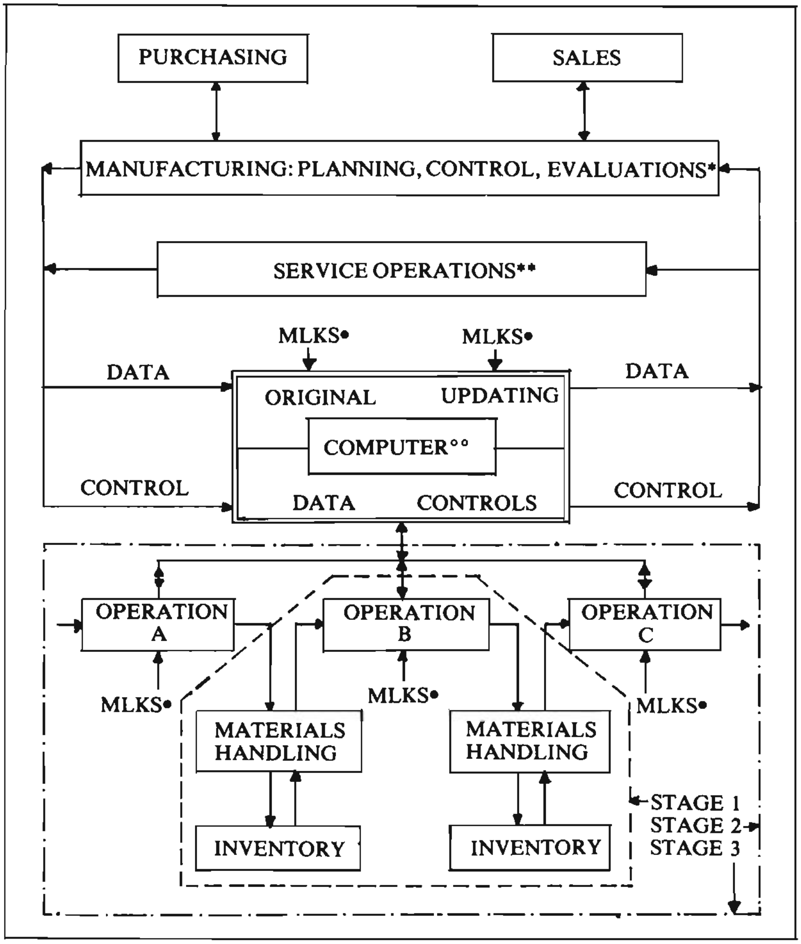
E. 'Second level' application requirements

One of the major application requirements is to make very extensive adjustments in the organisation and functioning of the operations concerned. Despite the apparent clarity of the logic involved, the introduction of CAM systems of any complexity requires confronting large masses of details along with many alternatives at most stages of sequential decisions. Inexperienced analysts can easily underestimate these difficulties. For example, in our studies of robotics applications, we found that a major reason for the surprisingly slow rate of diffusion of this promising technology — and for the widespread under-utilisation of robots after adoption — is their requirement for absolute standardisation of preceding operations. Even merely substituting a robot for an operator in feeding parts to a machine requires that the parts be available to the robot at the identical location, that each be presented in the identical orientation and that its conformance with dimensional and quality specifications be assured. Thus, the customary dumping of parts into tote boxes for movement to the next operation must be completely replaced.

Moreover, such requirements for precise conformance with production specifications, with the planned timing of product movements and with their delivery locations apply to each preceding stage of operations within the CAM sector. This reinforces the previously noted superiority of beginning with an overall system design in place of the 'bottom-up' approach of trying to introduce computerised controls independently at random points within an integrated production process. In short, CAM may be regarded as a contagious process that keeps offering growing benefits as it encompasses increasing proportions of a production system, but only in return for ensuring increasing standardisation of all aspects of the operations encompassed. For example, as illustrated in the lower half of Figure 2, effective computerisation of Operation B would require integrating it with the inventory and materials handling operations feeding into and out of it. But resulting benefits could be significantly enhanced if such integrated controls could also be extended to successively preceding and subsequent stages of the production process.

An even more critical requirement is to retain flexibility in the operational capabilities and thus achieve major advantages over the highly efficient large scale plants built during the 1960s and 1970s in some mass production industries. Because these relied on very narrowly specialised mechanical automation, they could not be adapted economically to market pressures for more frequent and substantial changes in product designs and product mix, as was illustrated by the automobile engine plant cited earlier. On the other hand, it is important to recognise that increasing the flexibility of each operation obviously multiplies the difficulties of ensuring effective integration of the resulting system, which may encompass dozens and even hundreds of operations.

FIGURE 2
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 and design	Inventories	M-Materials	Data management
Production methods	Materials handling	L-Labour	Programming
Planning and control	Maintenance	K-Capital	Applications development
Production	Heat and power	S-Salaried	Maintenance
Maintenance	General supplies		
Inventories			
Quality			
Personnel			
Cost accounting			

Such production problems will undoubtedly be overcome in time, but only after painful and costly efforts. It took three years for the Caterpillar Tractor Company to make one small flexible manufacuting unit producing one component for motors function effectively and five years before its capabilities were fully recognised (even by the engineers involved) and finally utilised. A flexible manufacturing system, used in a General Motors plant to weld gasoline tanks was still functioning only fitfully 18 months after installation.

F. Some economic and managerial effects of 'second level' applications

CAM tends to generate a variety of conflicting pressures on the composition of manufacturing costs. It tends to lower unit material costs by decreasing wastage and product rejection rates. But resulting savings may well be offset, at least in part, by requirements for more consistent, and often higher quality, materials which usually command higher prices. CAM also tends to lower unit wage costs by sharply reducing direct labour inputs and their average level of skills. This is likely to be offset in part by increases in personnel for computer servicing and maintenance as well as for programming and engineering. For example, a visit to the Yamazaki machine tool plant in Japan revealed an almost complete elimination of direct labour on the production floor, but the addition of a new adjoining building to house the expanded engineering staff.

Fixed investment requirements tend, of course, to be increased by a shift to CAM. However, the resulting effects on fixed charges per unit of output may be largely or fully offset by accompanying increases in productive capacity and by helping to achieve higher average levels of capacity utilisation through the increased flexibility of the product mix. Such flexibility also serves to increase the effective working life of the facilities by increasing the firm's ability to adapt to longer term changes in market demand for altered product design and product mix.

Achieving the gains in production efficiency and flexibility offered by CAM requires substantial investments not only in computer and related communication facilities, but also in appropriate production machinery, tooling and transfer equipment, as well as in related instrumentation and controls. As a result, the ratio of fixed costs to total costs will be raised, increasing the penalties of fluctuations in capacity utilisation rates — a continuing risk in most manufacturing industries. Moreover, CAM operations also entail sizeable costs for programming to translate design and output requirements into instructions for guiding the operations of each machine, transfer unit and testing operation. Beyond that, provisions must be made for production scheduling, inventory management and workforce assignments. Finally, to achieve effective utilisation, comprehensive efforts also have to be made to train all affected levels of supervisory and operating personnel in the potential and requirements of utilising CAM systems effectively.

In order to provide realistic perspectives on the potential magnitude of such requirements, it may be helpful to cite Nippon Steel Corporation's program to develop an integrated information technology system to guide and control the total production operations of its Kimitsu works, one of the largest steel mills in the world. During my last visit in 1983, the project had been underway for more than three years, had employed a staff ranging between 250 and 400 — mostly college graduates — and was scheduled for completion within another year. Such allocations are 8-12 times as large as those which had been encountered by our studies even in leading US firms.

In considering whether to undertake such heavy and extended commitments, management must also recognise the very considerable risks and uncertainties faced. Initial estimates of both have often proved inadequate. Expected benefits may also prove overly optimistic, especially when inadequate attention is given to the likelihood that competitors may be undertaking equally, and perhaps even more, ambitious applications of CAM. On the other hand, inaction is even more certain to result in progressively declining competitiveness.

Such possibilities may be illustrated by some recent developments in the US automobile industry. As foreign producers kept increasing their share of the domestic market, despite local efforts to increase competitiveness through incremental improvements in productivity, costs and quality, it became apparent that more far-reaching measures would be necessary. Accordingly, General Motors announced a multi-billion dollar commitment to build a plant which would compete effectively with Japanese and Korean, as well as other foreign, auto manufacturers. But within two years of the planned completion date, it was reported that this Saturn plant was encountering major failures in seeking to integrate supposedly sequential operations and, even more serious, that it was unlikely to achieve more than one half of the planned reduction of $1500 per car necessary to eliminate its cost disadvantage relative to the Japanese when the project was initiated. Thus, the plant may be producing cars in 1990 costing at least $750 more than the Japanese cars cost in 1985, even if the latter fail to achieve any additional cost improvements during these five years.

This example may be much less significant as a harbinger of continuing decline in the competitiveness of US manufacturing than as evidence of the magnitude of the difficulties to be overcome in transforming present manufacturing industries into highly automated operations capable of substantial flexibility in product design and product mix, and also of responding to the continuing major advances likely to be achieved by this new technology. In recent years, newly developing countries have increased their share of international markets not only in mature industries, such as textiles, steel and automobiles, but also in newer industries involving electronics, primarily because of efficient, hard-working labour paid at very much lower wage rates. CAM offers the possibility of reducing and even offsetting such advantages through the greater access of advanced industrial nations to the investment capital and the large supplies of scientists and engineers, as well as highly skilled labour, needed to service and to keep improving innovative capabilities.

ON THE POTENTIAL AND REQUIREMENTS OF THIRD LEVEL APPLICATIONS

The early stages of third level applications of information technology involve integrating a firm's production operations — as reviewed in second level applications — with procurement and distribution operations as well as with all staff and service functions, as is illustrated in Figure 2 as a whole. Such comprehensive coverage is being referred to as computer-integrated management or CIM. A still more advanced stage of such applications would encompass the total operations of major firms, including multiple production plants as well as widespread and even international procurement, distribution and financing operations.

As yet, few firms seem to be in the process of developing significant, though still partial, advances towards even the early stage of CIM systems. Hence, serious consideration of more advanced stages would seem to be visionary. It may be of interest, therefore, to call attention to the fact that the Nippon Steel Corporation initiated such an undertaking several years ago. Specifically, they transferred the director of its Kimitsu project, which was cited earlier, to initiate development of a prodigious company-wide system of computer-integrated management. In recognitiion of the magnitude of the project, plans called for the allocation to it of 2500-3000 staff for eight years. However accurate or inaccurate such preliminary estimates should prove to be, their most important implication is that Nippon Steel's experience with the earlier project has resulted in an awareness of the enormous scale of such requirements which seems to be almost universally unrecognised as yet in the industrial world.

SOME CONCLUDING OBSERVATIONS

Our analysis of competitive pressures in a variety of industries suggests that there will undoubtedly be increasing efforts to utilise the capabilities of each of the three levels of information technology applications. So far, our field studies have identified widespread applications of only bits and pieces of the primary level, most commonly centring around order entry, production control, accounting, engineering and personnel functions — and usually on an unintegrated basis. Second level applications are much less common, of course, beyond computer-aided design and some other single department applications, such advances still being dominated by a relatively small number of major firms. To our knowledge, third level applications are still in the hypothetical stage, except for Nippon Steel's pioneering venture.

Recent experience suggests that progress will continue to be slow. One reason is that efforts to develop advanced CAM capabilities in existing plants are likely to offer only limited rewards — as has already been indicated by applications of robots, which represent a much simpler undertaking. Although applications in new plants designed for CAM offer attractive potential, these are likely to be realised only after heavy investment over extended periods has enabled management and engineers to learn how to develop modified or new products, production methods and equipment so as to exploit fully the potential of this powerful new technology. Hence, only a relatively few firms with large resources and progressive management are likely to make serious commitment to developing such potential within the next few years — and even these may be inhibited by the fears of labour, and even of many technical specialists and managers, that such advances may threaten their future prospects. However, it is likely that an increasing number of small new firms without past commitments to exisiting facilities and staff will be eager to explore such fresh opportunities for gaining competitive advantage.

Because of resulting threats to the competitiveness of their industries, employment levels, national income and foreign trade balances, national governments may be expected to seek a more active role in accelerating the development and utilisation of these new capabilities. Governmental support for developing improvements in computer capabilities, instrumentation, automated programming and communication links is already widespread internationally. Moreover, some governments have also provided subsidies or loans to help finance the introduction of these CAM advances into selected plants as demonstration and development projects. But more far-reaching governmental programs have also been inhibited in a number of countries by political pressures responsive to perceived threats to employment levels and to the viability of older plants. At any rate, most such programs have been too limited in scope to have had much impact as yet on industry at large — and many have also failed to deal effectively with the influential determinants of relevant managerial decisions.

After all, the key determinants of the extent and vigour of CAM development efforts in any operating system are management judgements concerning emerging needs and the most effective means of responding to them. If management accept the capital budgeting methods which business schools have promulgated so assiduously, it is bound to discourage proposals for innovative programs which are unlikely to come to fruition within two years or less. Specifically, using 'discounted cash flow' or the more modern 'net present value', methods of evaluating proposed capital allocations with annual discount rates of 25 per cent (or even higher), virtually ensures rejection of undertakings like major CAM development proposals which, regardless of how critical they may be to strengthening the long term competitiveness of the plant, are unlikely to yield returns within such relatively short periods that are even equivalent to market rates of interest. Resulting pressures for relatively short term capital investment also tend to be reinforced by older officers contemplating retirement before major new systems would be likely to achieve superior rates of profitability. Heavy commitments to innovative technological advances are also unlikely to appeal to senior management dominated by financial and marketing expertise. Taken together, the above considerations add up to a formidable array of resistance to the commitment which seems necessary to rebuild or maintain the technologoical advance which is essential to support market competitiveness. Resulting resistance tends to be powerfully reinforced by the unavoidable substantial risks involved in developing and learning to adapt and utilise new technologies to the point of achieving commercial success.

To deal with such immediate and powerful pressures seems to require new approaches both by governments and by management. Government measures might include such possibilities as:

a. increasing support for extending the development of CAM technologies closer to the point of yielding practically applicable systems, at least in key manufacturing industries;
b. more effective support for providing industry with needed capital funds on attractive terms, perhaps through such means as guarantees for bank loans, subsidies to yield lower interest rates, and means of extending repayment periods; and
c. offering increased rewards for making such risky, long term investments; for example, by progressively reducing tax rates on profits in proportion to the waiting periods experienced before receiving them.

Management measures seeking to encourage and support such longer term commitments to ensure long term technological competitiveness might include such policies as:

a. Reserving a portion of capital investment funds for long term risky projects which cannot meet current capital budgeting 'hurdle rates'; for example, Caterpillar Tractor has helped to maintain its strong international position by reserving roughly 15 per cent of its capital allocations for advanced projects for which prospective profitability cannot be determined, but which are considered to represent potentially important leading edge innovations capable of significantly affecting future competitiveness;
b. revising corporate planning processes to require periodic consideration not only of proposals to maintain current competitiveness and profitability, but also of prospective changes in input and product markets likely to affect competitiveness over the next five years as the basis for initiating responsive measures; and
c. explaining and emphasising the importance of such longer term undertakings to employees and stockholders as well as relevant financial and governmental groups.

By way of providing a general perspective on the outlook for industrial competition, I shall conclude with the following experience. During my latest visit to Japan, I asked senior officers of major steel companies why they were continuing to make heavy investments in new facilities, in upgrading older facilities and in research. This was occuring despite their having operated at only around 70 per cent of capacity for several years and their expectation that this would continue at least for some time. Their replies focussed on three points. First, they asked whether I believed that the recession in steel demand would last forever — and I admitted that this seemed unlikely. Second, they asked if it was true that virtually all major US and European steel producers had ceased building new facilities and had also cut back sharply on research and development — and I agreed. Very well, they said, then wouldn't their own continuing improvement efforts ensure that whenever steel demand recovered, whether in the next two years or four years, they would be in a position to supply the newest and best products with the greatest efficiency? One executive then added, "As your Mister Shakespeare said, the issue is 'to be or not to be'. In a constantly changing world, this means that we must keep moving ahead or accept decline."

NOTES AND REFERENCES

1. For these and other studies by the author see B. Gold, 'Perspectives on continuing advances in automation: past limitations and emerging potentials', *Technovation*, 4, 1986; 'CIM dictates changes in management practice', *CIM Review*, March 1986; 'Analysing the effects of computer-aided manufacturing systems on productivity and costs', in A. Dogramaci and N.R. Adam (eds), *Managerial Issues in Productivity Analysis*, Kluwer-Nijhoff, Boston, 1985; 'Revising approaches to the economic evaluation of future manufacturing systems', in *Emerging Worldwide Trends in the Industrial Adoption of Advanced Manufacturing Techniques*, Proceedings of an International Conference sponsored by the US National Science Foundation, Illinois Institute of Technology, Chicago, 1985; 'Strengthening the foundations of investment strategy and capital budgeting', in M. Kaufman (ed.), *Handbook of Capital Budgeting*, Dow-Irwin, New York, 1985; 'CAM (computer-aided manufacturing) sets new rules for production', *Harvard Business Review*, November-December, 1982; 'Robotics, programmable automation and international competitiveness', *Transactions in Engineering Management of the Institute of Electrical and Electronic Engineers*, November 1982; *Improving Managerial Evaluations of Computer-Aided Manufacturing*, National Academy of Science Press, Washington DC, December 1981; and 'Factors stimulating technological progress in Japanese industries: the case of computerisation in steel', *Quarterly Review of Economics and Business*, 18, 4, Winter 1978, pp. 17-21.