The future of CAM systems

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INTRODUCTION

A recent Delphi-type forecast1 of the future of manufacturing carried out by the International Institution for Production Engineering Research (CIRP) resulted in 94 forecast events on which good consensus was obtained. Of these, 24, or over one-fourth, strongly indicated that the computer-integrated automatic factory would be a full-blown reality well before the end of this century. The three key events which summarize this aspect of that forecast are as follows:

1. By 1980 (median), a computer software system for full automation and optimization of all steps in the manufacturing of a part will be developed and in wide use.
2. By 1985 (median), full on-line automation and optimization of complete manufacturing plants, controlled by a central computer, will be a reality.
3. By 1990 (median), more than 50 percent of the machine tools produced will not have a “stand-alone” use, but will be part of a versatile manufacturing system, featuring automatic part handling between stations, and being controlled from a central process computer.

Thus it is evident that the major event expected to occur in the future of computer-aided manufacturing (CAM) systems is the eventual implementation of such factories.

What are the factors and incentives at work today that provide the motive power for such a major change in manufacturing? One is, of course, the fact that the technology needed for that change now seems feasible because of the rapid growth of the capabilities of the digital computer. However, equally important are the economic and social incentives. Both of these latter factors are contributing strongly to the prospects for early realization of the computer-integrated automatic factory.

ECONOMIC INCENTIVES

Manufacturing normally contributes approximately 30 percent of the gross national product of modern industrialized countries. Yet, in spite of that, manufacturing, although normally thought of as a highly productive and efficient activity, is not generally so. For example, this is clearly true of batch-type metalworking manufacturing, which normally accounts for about 40% of total manufacturing employment. The mass production type manufacturing systems (e.g., automotive transfer lines, etc.) account for less than 25 percent of metalworking parts manufacture. In fact, 75 percent of such parts are manufactured in lots consisting of less than 50 pieces. Carter has revealed that, when the life of the average workpiece in batch-type metal cutting production shops is analyzed, only about 5 percent of its time is actually spent on machine tools and, of that 5 percent, only about 30 percent (or 1.5 percent of the overall time) is actually spent as productive time in removing metal. This result is illustrated graphically in Figure 1. This situation can hardly be called economic or productive. Further, it truly pinpoints the two main areas where by far the greatest improvement in the economy and productivity of metalworking manufacturing can be made today. The first of these is reduction of time of parts in process in the shop, and thus of the resulting extremely high inventory of unfinished parts on the shop floor, and of finished parts waiting for others in process so that assembly of the product can proceed. It is evident from Figure 1 that this inventory could potentially be reduced by up to 90 percent. Resulting reduction of indirect capital and labor costs and improvement of productivity could be enormous. Here indeed is a major incentive to implementation of CAM systems and the automatic factory.

The second area of potentially great improvement is that of percent machine utilization. The 30 percent machine utilization indicated by Figure 1 must be combined with the fact that the average machine spends approximately 50 percent of its time waiting for parts to work on (because of the 95 percent time in transit shown in Figure 1). As a result, the average machine tool in a batch-type shop is being utilized productively (i.e., is actually cutting metal) only about 15 percent of the time. Thus it is evident that this utilization could potentially be increased by 600 percent or more. Resulting reduction of direct labor and overhead costs and increase of productivity could be enormous. Obviously this provides another major incentive to implementation of CAM systems and the automatic factory.

Another major economic consideration today is the rapidly rising cost of manufacturing labor relative to manufacturing productivity. This is illustrated by the data
in Table I, for the major industrialized nations of the world, for the period 1965-1970. In the past four years the situation has become even more uneconomic than that shown in the table, due to the even more rapid rise in wages in the current inflationary world economy, and the notable failure of manufacturing productivity to increase at a comparable rate. Quite evidently, this situation can only be reversed by improving the rate of increase of manufacturing productivity, decreasing the degree of labor intensiveness of manufacturing, or both. Both of these can be accomplished by increased implementation of CAM systems and therefore offer an additional major incentive to advancement of such technology.

**SOCIAL INCENTIVES**

Today, major social factors are also emerging which provide strong incentives for early implementation of CAM systems and the computer-integrated automatic factory. Among these trends, three sets of changing attitudes toward manufacturing are particularly significant, namely those of workers, those of employers, and those of government.

Concerning the first of these trends, there is a steadily increasing reluctance of workers to continue to expose themselves to the manufacturing environment. Thus today, in all the major industrialized countries of the world, there is an increasing shortage of manufacturing workers. This is heightened by the growing opportunities for and rewards in employment in the service industries. This trend is dealt with by Bell in discussing the coming of the post-industrial society. For example, this type of trend occurred first in the field of agriculture. In the United States, as the manufacturing industry developed, the percentage of the work force employed in agriculture declined from 90 percent in 1790 to 4 percent today. Meanwhile, the percentage of the work force employed in manufacturing rose correspondingly during the 19th century. However, in recent years it has begun to decline—from 30 percent of the work force in 1947 to 24.9 percent in 1968. The U.S. Bureau of Labor Statistics projects that by 1980 the percentage will decline further to 22.4, and a Rand Corporation forecast projects that by the year 2000 only 2 percent of the labor force will be employed in manufacturing. Quite evidently, this trend represents a major incentive to implementation of CAM systems for purposes of increasing the automation of manufacturing.

Concerning the second of these trends in attitudes toward manufacturing, namely those of the employers, they are now clearly recognizing the human need for the nature of work to be such as to assure the worker of deep satisfaction from performing it (as well as freedom from unpleasant or harmful conditions). Thus much attention is being directed to methods of accomplishing this. Here the pioneering work of such investigators as Herzburg on job enrichment is proving most useful. Herzburg’s significant finding, illustrated in Figure 2, is that, while the so-called hygiene factors of a job (i.e., company policy and administration, supervision, work conditions, salary, etc.) can cause dissatisfaction if they are not satisfactory, they can do little to provide on-going job satisfaction. Instead, such satisfaction derives from the adequacy of the so-called motivator factors of a job (i.e., opportunity for achievement, recognition, responsibility, advancement, growth, etc.). The major feature of jobs which provide such opportunities is participation in decision-making. Thus this trend provides a major incentive to implementation of CAM systems for purposes of accomplishing computer-based automation of manufacturing, in view of the endless opportunities it offers for participation in decision-making through interactive type software programs and similar features. In addition, of course, the opportunity it offers for freeing workers from unpleasant, harmful, potentially dangerous or exhausting conditions on the job is tremendous.

The third significant trend in attitudes toward manu-

**TABLE I—Rates of Change of Productivity and Labor Costs in Manufacturing**

<table>
<thead>
<tr>
<th>Country</th>
<th>Output per man-hour</th>
<th>Compensation per man-hour</th>
<th>National currency</th>
<th>U.S. dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>6.8</td>
<td>8.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Canada</td>
<td>3.5</td>
<td>8.3</td>
<td>4.6</td>
<td>5.1</td>
</tr>
<tr>
<td>France</td>
<td>6.6</td>
<td>9.5</td>
<td>2.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Germany</td>
<td>5.3</td>
<td>8.7</td>
<td>3.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Italy</td>
<td>5.1</td>
<td>9.1</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Japan</td>
<td>14.2</td>
<td>15.1</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Netherlands</td>
<td>8.5</td>
<td>11.1</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Sweden</td>
<td>7.9</td>
<td>10.6</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Switzerland</td>
<td>6.2</td>
<td>6.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>3.6</td>
<td>7.6</td>
<td>3.8</td>
<td>0.2</td>
</tr>
<tr>
<td>United States</td>
<td>2.1</td>
<td>6.0</td>
<td>3.9</td>
<td>3.9</td>
</tr>
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1 Wage earners only.
Factors characterizing 1844 events on the job that led to extreme dissatisfaction

<table>
<thead>
<tr>
<th>Percentage Frequency</th>
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</thead>
<tbody>
<tr>
<td>50% 40 30 20 10 0</td>
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</table>

- Achievement
- Recognition
- Work itself
- Responsibilities
- Advancement
- Growth
- Supervision
- Relationship with supervisor
- Work conditions
- Salary
- Relationship with peers
- Personal life
- Relationship with subordinates
- Status
- Security
- Company policy and administration

Factors characterizing 1753 events on the job that led to extreme satisfaction

<table>
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<th>Percentage Frequency</th>
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<tr>
<td>50% 40 30 20 10 0</td>
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- Achievement
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Figure 2—Satisfaction and dissatisfaction factors in jobs according to Herzberg

Manufacturing is the changed attitude which governments throughout the world are taking toward freeing workers from unpleasant, harmful, potentially dangerous or strenuous conditions. In most of the industrialized countries of the world, government is no longer playing the essentially passive role of requiring that, as technology to accomplish improved working conditions is developed, it be put to use. Instead it is now playing the very active role of requiring that such technology be developed. For example, in the United States, the relatively new Occupational Safety and Health Act in effect requires such things as:

1. Technology be developed to eliminate the necessity for a worker to ever insert his hand, arm, or any part of his body into a potentially dangerous area of a machine (such as a press)

2. Technology be developed to keep the noise level in a factory below 90 dBA (Bollinger has excellently summarized the current status of the international attack on this and other aspects of the problems of noise in manufacturing).

Here again, requirements such as these provide strong incentives to implement CAM systems for automation of manufacturing.

PROGRAMS AND STRATEGY

Most of the industrialized nations of the world today are aware of the foregoing powerful incentives to change the character of manufacturing through implementation of the automatic factory. Likewise, many of them are equally aware of the potential of the digital computer to accom-
As a result, many countries have organized CAM research and development (R&D) programs of considerable scope to try to realize that potential in their own manufacturing industry. The main, long-range objective of these programs is, of course, eventual realization, in that industry, of the computer-integrated automatic factory.

Although realization of the fully computer-integrated automatic factory, through implementation of the concept of the computer-integrated manufacturing system, is the long-range goal of the national programs, it is well realized that to get from today's industrial methods, know-how and installed equipment to that goal requires an evolutionary, rather than a revolutionary, process. The strategy being followed, therefore, is to develop and implement a series of viable, economic steps, in the form of short-range programs of R&D on CAM, each having two essential characteristics, namely:

1. Potential for sufficient economic return to justify it by itself and to generate the capital to support development and implementation of the next.
2. Compatibility with eventual attainment of the goal of implementation of the computer-integrated automatic factory.

Out of the variety of such programs being pursued, the following seem to be receiving a major part of the attention and effort, world-wide:

1. Integrated manufacturing software systems
2. Group technology and cellular manufacturing
3. Computer control
4. Multi-station manufacturing systems
5. The computer-integrated automatic factory itself.

### Integrated manufacturing software systems

This program of CAM R&D is directed toward development of modular, interfaced, compatible, CAM software systems for on-line computer-based optimization and eventual on-line versatile computer-based automation of complete manufacturing plants. The early economic payoff comes through application of the individual modules, as developed, to increasing on-line optimization of conventional manufacturing plants.

Both Europe and Japan are hard at work developing such software systems for their own use. For example, in Europe, West Germany and Norway are both developing national integrated software systems for metal cutting manufacturing. The “blueprint” for such is the diagram of Figure 3. The Japanese have indicated that they are basing their work in this field on pattern processing.

### Group technology and cellular manufacturing

This supplement to CAM consists of the layout and organization of a factory and its manpower and equipment on a part-family and product-line basis (rather than a functional basis), using group technology information concerning geometrical and processing similarities between parts to establish the families. This has the eventual CAD/CAM benefit of providing a compatible, economic base for evolution of such factories through increasing use of hierarchical computer control and multi-station manufacturing systems. However, implementation of this technique provides immediate economic benefits from decreased manufacturing lead time, decreased inventory of parts in process, and increased job satisfaction of workers.

This type of program is being actively pursued in both Japan and Europe. Japan is developing its own national part classification system for use in establishing group technology families and is testing it in industry. In the Netherlands, the Metals Institute of TNO is developing, and is testing in industry, a computer-based software system for automatic classification of parts into group-technology families and automatic layout of factories into group-technology cells based on those families. The system will also then carry out automatic production planning for manufacture of those parts and will eventually also provide automatic programming for numerically controlled machining of them. In Britain much R&D and im-

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**Figure 3**—Scheme for development of integrated manufacturing software according to Opitz and Nissen. The computer-integrated automatic factory itself.

<table>
<thead>
<tr>
<th>STEP</th>
<th>IDEA</th>
<th>NAKK-activities</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>PRODUCT-CONCEPTION</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CALCULATION</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>DESIGN</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SEQUENCE OF MACHINES</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CLAMPING-DEVICE</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SEQUENCE OF OPERATIONS</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>TOOL SELECTION</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CUTTING-DATA</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>TOOL-PATHS</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>POST-PROCESSING</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>MACHINING</td>
<td></td>
</tr>
</tbody>
</table>

**WORK-PIECE**

Out of the variety of such programs being pursued, the following seem to be receiving a major part of the attention and effort, world-wide:

1. Integrated manufacturing software systems
2. Group technology and cellular manufacturing
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Implementation of cellular manufacturing is going on, both in universities and in industry. For example, Ferranti Ltd. in Edinburgh has been busily engaged in implementing such in their manufacture of avionics equipment. Figure 4 illustrates one of their cells utilizing numerical control (NC) for producing a family of box-like parts of the general character of that shown at the bottom right of the figure. By going to cellular manufacturing, Ferranti has reduced the through-put time of parts in process by a factor of approximately 5.
Computer control

Much of the R&D on this aspect of CAM carried on in Europe and Japan is being given a particular emphasis. This emphasis is directed at evolution of computer numerical control (CNC) and direct numerical control (DNC) in such a manner that, as these bring computer power to the group technology cells on the shop floor (for purposes, initially, of serving only a limited number of NC machines), the computer power is also used to accomplish dynamic scheduling, production control, machine and operator two-way communication with the computer, etc. This encompasses all the machines in the cell and not just the NC machines. Thus, significant economic benefits should become possible very early in the evolution.

This type of program is being carried on very actively in both Europe and Japan. Figure 5 represents the Norwegian concept of the computer hierarchy appropriate to such. As CNC type minicomputer control of the individual machines in a cell is brought to bear at level 3, this in due time provides an economic basis for overall DNC of the cell at level 2 with a larger minicomputer. Eventually it becomes profitable to link all the cells in the factory with a large computer at level 1, providing an initial basis for overall on-line optimization and automation of the factory. Japan is reported to have the largest number of CNC/DNC systems already operating in factories of any country in the world. The number is reported to be on the order of 60.

Multi-station manufacturing systems

This program of CAM R&D involves evolution of the group technology cells in such a manner that, as the percentage of NC workstations operating under CNC/DNC in a cell increases, complete automation and the integration of tool and work handling and transfer within the cell as a whole becomes economically feasible. Such handling and transfer may be done by use of pallets, manipulators, or other means. For example, a metal cutting multi-station manufacturing system or cell, suitable for operation under CNC/DNC, as conceived by Perry, is shown in Figure 6. Thus, in time, each group technology cell is conceived of as evolving into a multi-station manufacturing system operating under CNC/DNC.

Both the European nations and Japan have a number of different types of multi-station manufacturing systems under development. For example, a basic pallet-type system having four different variations for different types of part families has been developed in prototype form in East Germany. However, Japan is reported as having developed the largest number of such systems; the number is said to be approximately 10.

The computer-integrated automatic factory

This program of CAM R&D is of course the final step in the evolution, whereby, through gradual full implementation of a computer hierarchy and an integrated software system, operations in all cells and at other work centers within a plant are dynamically programmed and coordinated for overall on-line optimization and automation of the plant's operations. This includes interfacing the system with computer-aided design in such a manner that initial programming of the automated optimum manufacture of a product is generated in the design stage, with the design optimized for minimum cost of manufacture.

The only nation to date having an announced national plan for accomplishing this by a given date is Japan. Their plan, which goes by the name “Methodology for Unmanned Manufacturing”, calls for the development, construction and operation of a prototype "unmanned" machine-building plant by about 1980. The plant would be a 200,000 to 300,000 square foot factory staffed by a control crew of only about 10 persons, as compared to the...
normal complement of 700 to 800 workers. The cost of the project will be approximately $100 million.

CONCLUSION

It seems evident that the combination of the powerful technological, economic and social factors and incentives and the concerted national R&D programs active today will indeed make the computer-integrated automatic factory a reality well before the end of this century. Thus all of us who are engaged in advancing the state of the art of CAM systems have exciting and challenging opportunities ahead. Further, in view of the very substantial economic and social benefits which can come from implementation of CAM systems and the resulting eventual realization of the computer-integrated automatic factory, as described above, we have a major responsibility to direct our efforts toward cooperation on a national scale to attain that goal as rapidly as possible.

REFERENCES
