PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Future of Batch Manufacture [and Discussion]

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The future of batch manufacture

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Approximately 75 % of all metalworking manufacture in the United States is in small lot batches and that percentage is expected to increase in the future. In the usual batch-type production shop, a typical part in process spends only about 5 % of its time on production machines and of that 5 %, only about 30 % is actually spent as productive time in shaping the part. Obviously, both the rewards and the potential for increased productivity and efficiency of batch manufacture in the future are very great indeed.

How are these rewards and this potential to be realized? It is quite evident that application of the digital computer to online automation and optimization of batch manufacture holds great promise for doing this. The reason for such is that the computer provides, for the first time in history, a means for automating the software component of batch manufacture – the automatic handling of the information flow and the moment-by-moment analysis, planning and control of manufacturing operations. It is the lack of this very capability – the dependency on 'manual' manipulation of the software component – that accounts for the highly inefficient situation noted above.

To realize this potential of the computer requires a wholly new approach to both the software and the hardware components of manufacture – a systems approach, to bring into being what may be called the computer-integrated manufacturing system. Such a new approach to the combined hardware and software of batch manufacture will require the combination and exploitation, on a systems engineering basis, of many currently embryonic new aspects of manufacturing technology, such as direct numerical control, multi-station manufacturing systems, group technology or cellular manufacture and integrated manufacturing software systems. A Delphi-type technological forecast recently completed by the C.I.R.P. throws some light on the likelihood and timing of the realization of the computer-integrated manufacturing system. According to this forecast, the probability of this approach being operational and well along toward general use by the 1980s is very high.

1. Considerations in batch manufacture

When one discusses batch manufacture, one is dealing with a major segment of modern industrial manufacturing. For example, in the United States, approximately 75 % of all metalworking manufacture consists of lots numbering less than 50 pieces. Further, the metalworking industry employs almost 40 % of the total employment in manufacturing in the United States and is said to account for approximately 15 % of the gross national product, while manufacturing as a whole accounts for only some 30 %. Thus batch manufacture is not only carried out in small, back-street workshops, but is also a major activity of medium-size manufacturing plants and, in fact, even of many very large manufacturing corporations.

It may be thought by some that, because batch manufacture is an old and established practice, dating back to the industrial revolution, its long period of development should have resulted in its being a rather well optimized and productive activity. This, however, is hardly the case. For example, Carter (1971) has pointed out that, when the life of the average workpiece in batch-type production shops is analysed, only about 5 % of its time is actually spent on production machines and, of that 5 %, only about 30 % is actually spent as productive time in shaping the part, as shown in figure 1. This is hardly an optimum, productive situation. Indeed, the potential for improvement of the productivity and optimization of batch manufacture in the future is very great indeed, and with it the corresponding potential for economic and social reward.

Why have these potentials failed to be satisfied over all these years? It is largely because the major advances serving to improve the productivity and efficiency of batch manufacture – namely its gradual mechanization and automation – have been primarily in the field of manufacturing hardware. There has been little corresponding advance in the mechanization and automation of the 'software' component of batch manufacture. This component, in its broadest sense, encompasses such things as:

(1) Manufacturing data and information on product design characteristics and on the costs, capabilities and performance associated with installed manufacturing equipment and processes.

(2) Procedures and logic for data and information analysis, production planning and production control.

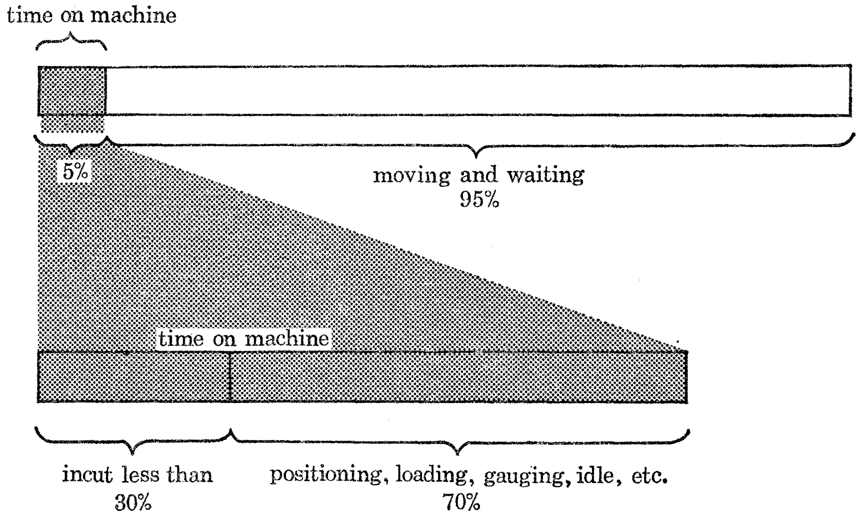

FIGURE 1. Life of the average workpiece in batch-type production shops according to Carter.

The handling of this software component – of the information flow and the moment-by-moment analysis, planning and control of manufacturing operations – has had to continue to be done primarily by slow and laborious human mental processes. Quite evidently, as long as such a situation exists, full automation and true optimization of batch manufacture is not possible. Here obviously are major technological problems which must be solved – the problems involved in mechanizing and automating the information-intensive software component of batch manufacture – if its true potentials are to be realized.

Were these the only considerations affecting the future of batch manufacture and clamouring that it change, industry might continue to be able, in the future, to muddle through with its present method of operation and past directions of development in batch manufacture. However, today, batch manufacture is beginning to be challenged as well by a host of additional problems which are as dominant, persistent and viable as those above. Further, these are not just technological in nature but also economic and social. These take the form, first, of a series of developing long-range technological, economic and social trends. Some of the more evident and important of these trends are as follows.

(a) *The trends*

(i) *An exponential rate of advance of technology*

This trend is resulting primarily from the fact that each technological advance breeds multiple other advances, providing possibilities for exponential economic growth.

(ii) *Rapidly rising human expectations, material wants and basic needs*

This trend is resulting in part from the fruits of rapidly advancing technology whetting the appetite for still more, in part from rapidly rising standards of living generated by that same rapid advance of technology, and in part by the continuing growth of individual political freedom throughout the world.

(iii) *Increasing creative innovation*

This trend is resulting primarily from the foregoing trend, since such innovation is becoming recognized today as the prime means for satisfying rising human expectations, material wants and basic needs. It particularly involves understanding the process of technological change and responding favourably to it.

(iv) *Rapid proliferation of number and variety of products*

This trend is being brought about both by the exponential rate of advance of new technology, which spawns new products and product changes at an every increasing rate, and by the demand that products be more specialized (e.g. computers precisely tailored to every different application) or more individualized (e.g. the proliferation of automobile models) in response to rising human expectations, wants and needs.

(v) *Decreasing lot sizes in manufacture* (*i.e. increasing batch manufacture*)

This trend is resulting primarily from the foregoing trend and, as previously indicated, 75 % of all metalworking production already is in small lot batches.

(vi) *Increasing complexity, performance and reliability* (*and thereby, cost*) *of manufactured products*

This trend is resulting primarily from the demands placed on products by both exponentially advancing technology and rapidly rising human expectations, wants and needs. It, in turn, rapidly increases capital investment and risk in manufacture.

(vii) *Increasing complexity and rapid obsolescence of technological knowledge*

This trend is again a direct result of the exponential advance of technology. It is particularly acute in the field of manufacturing technology.

(vii) *Increasing reliance on machines to do routine* (*non-creative*) *tasks*

This trend is resulting primarily from two factors, namely, the growing technological complexity of the tasks to be done and the growing recognition of and respect for the uniqueness of the creative abilities of human beings as distinguished from their machine-like physical and mental abilities, all as reflected in the foregoing trends. This is a very old trend when one considers physical tasks and their increasing mechanization and automation over the years. However, it has a wholly new aspect to it when one considers the mechanization and automation of mental tasks.

As a result of these developing but persistent trends, batch manufacture is today beginning to be challenged by a developing series of technological, economic and social needs which call for significant change in its methods of operation and for new directions in its development. Some of the more evident and important of these needs are as follows.

(b) *The needs*

(i) *Increased accuracy and precision in manufacture*

This need arises mainly in response to the trend to increasing performance and reliability of manufactured products – one way to obtain such in products is through manufacturing their components to closer tolerances or greater precision.

(ii) *Increased productivity of manufacturing processes and equipment*

This need arises partly in response to the trend to rapid proliferation of number and variety of parts and partly, of course, due to normal economic pressures. However, its attainment is greatly complicated by the trends to decreasing lot sizes and increasing complexity of products.

(iii) *Increased versatility of manufacturing processes and equipment*

This need is generated by quite a number of the foregoing trends, namely, the trends to rapid proliferation of number and variety of products, to decreasing lot sizes in manufacture and to increasing complexity of products.

(iv) *Interdisciplinary transfer and use of world-wide technological knowledge*

This need arises largely in response to the trend to increasing creative innovation which requires breaking of the inhibiting barriers between previously neatly compartmented scientific, technical and industrial disciplines, world-wide. It is in turn generating new organizational forms within industry.

(v) *Increased industrial involvement in technological education and information transfer*

This need is generated to some extent by all of the trends enumerated in the preceding subsection, but most specifically, of course, by the trend to increasing complexity and rapid obsolescence of technological knowledge.

(vi) *More challenge, meaning, and satisfaction in industrial jobs*

This need arises primarily from the trends of rapidly rising human expectations, wants and needs and of increasing creative innovation. Fortunately, its realization is considerably aided by all of the other trends enumerated as well as by all of the foregoing needs.

2. The developing response

The world of batch manufacture, faced with the challenge of the varied problems and needs described above, is indeed trying diligently to develop adequate response to them. Close and thoughtful analysis of these has been coupled with continuing exploration of various possible types of response. Such analysis and exploration has examined and tested the various kinds of capability which it might be possible to bring to bear on batch manufacture to meet these problems and needs. Out of this thoughtful analysis, exploration, examination and testing has come, already, the finding that the most promising of these possible kinds of capability is that offered by the digital computer. Its capability has been found to be potentially best able to provide an overall solution to these various problems and needs – and to offer the greatest potential gain in the solution of each of them. This is due in large part to the fact that that capability has powerful potential to provide both the hardware and the software components of batch manufacture with two essential, powerful faculties, namely: (1) on-line variable program automation; (2) on-line moment-by-moment optimization. However, thoughtful analysis and examination of this capability also has lead to the conclusion that, to realize the actual potential of the digital computer to provide a solution to these problems and needs requires a wholly new approach to batch manufacture.

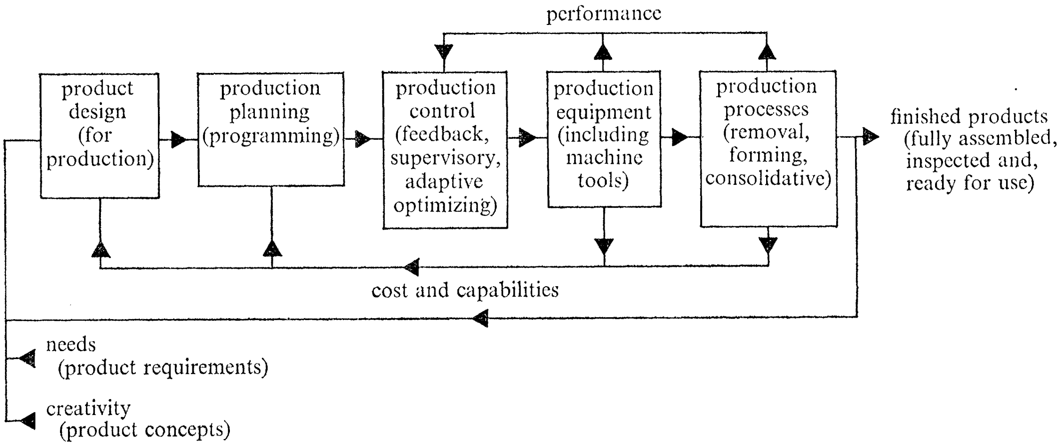

FIGURE 2. The computer-integrated manufacturing system.

What is the nature of the new approach required? Gradually, over the years since the advent of the computer, a concept has evolved which provides the needed solution. In 1931 the author (Merchant 1961) proposed, in rudimentary form, the concept of the systems approach to manufacturing and intimated how it might be used as a framework for meeting this emerging challenge. This concept has been developed and elaborated on in later papers by himself (Merchant 1966, 1968, 1970*a*, *b*; Tanenbaum 1967) and many others resulting in the emergence of the concept of the computer-integrated manufacturing system. This system of the future may be defined as follows:

The *computer-integrated manufacturing system* is that closed loop feedback system the prime inputs to which are product requirements (needs) and product concepts (creativity) and the prime outputs of which are finished products (fully assembled, inspected and ready for use). It is comprised of a combination of software and hardware, the elements of which include product design (for production), production planning (programming), production control (feedback, supervisory and adaptive optimizing), production equipment (including machine tools) and production processes (removal, forming and consolidative, including assembly and in-process inspection). It can be realized by application of systems engineering and the digital computer and has the potential of being fully automated (by means of versatile automation) and of being made largely self-optimizing (adaptively optimizing).

Figure 2 shows a schematic diagram of such a system, including its major loops. Because it is an overall closed-loop system, it provides the necessary two-way communication and information flow required for both on-line optimization and variable-program automation to be implemented, in keeping with the discussion above.

This approach can provide integration of the simulation (including simulation of socially harmful side effects), development, design, manufacture and marketing of products into a single highly versatile system which can be optimized continuously with respect to overall product costs and profits and can eventually be highly automated. It provides a means for arriving at the proper balance in the utilization of the unique creative abilities of man and the physical and logical capabilities of machines in the overall task of satisfying human expectations, wants and needs through the supplying of useful products. As such, it provides maximum potential for assuring overall effective response to all of the foregoing problems and needs in the conduct of batch manufacture. It has thus become the general goal towards which many of the industrialized nations of the world are striving in their development of improved capability in batch manufacture for the future.

3. Probable nature of operation

Actual realization of such an operating system in batch manufacture still lies well in the future, and will be an evolutionary process. Nevertheless, we can already visualize that its operation, and the role of computers within it, will be somewhat as follows.

The process of designing a product will be carried out by iterative communication between men and computers, a man supplying the design concepts and requirements and doing the creative work, and a computer supplying stored and standardized information and carrying out the design calculations. During this design process the computer can, through the internal loop labelled 'cost and capabilities', be constantly calling for and taking into account information on the manufacturing costs and capabilities (equipment and process costs and capabilities) required to produce each of the alternative design features, so developed, on the true manufacturing elements of the available system. It then uses that information to find a design which not only satisfies the product requirements but which also can be manufactured at minimum cost and with maximum producibility.

Almost simultaneously, the production planning part of the system is using this information to set up an optimized production plan for the manufacture of the product, choosing proper equipment and processes, sequence of operations, operating conditions, etc. This numerical information is in turn used to control the array of automatic machines which do the actual manufacture and assembly of the product. These are machines capable of setting themselves up, automatically handling parts, selecting their own tooling, and carrying out automatically a variety of fabrication processes of the removal, plastic flow, and consolidation types. Self-optimizing, they feed back information to the control system through the other internal loop labelled 'performance'. This system, as it constantly receives this information of the actual performance of the equipment and processes, compares this with the 'ideal' performance planned in the earlier phase. Then, as it finds that performance beginning to depart from the planned optimum, it overrides the original plan, performing dynamic scheduling, adjusting operating conditions of the machines and processes, etc., as necessary to maintain optimum, minimum-cost performance.

Meanwhile, the machines also carry out automatic in-process inspection of the product at each stage of its manufacture, so that any impending deviations from the original specifications are automatically corrected and held within prescribed tolerances. Thus, the final assembled product is turned out fully inspected and in full conformity with the original design concepts and requirements.

4. Implementation

Here then is the ultimate nature of the computer-integrated manufacturing system. How will it be implemented in batch manufacture? Examining this problem it becomes almost immediately evident that a single large central computer cannot be put directly on line with all the elements of such a system. If all of the myriad details of the activities going on in product simulation, development, design, manufacture and marketing were simultaneously being fed through the computer for action, not only would it require a central computer far more complex than anything conceivable today but, in addition, the rate at which the data would have to be transmitted and processed would exceed by far the capabilities of any known or anticipated transmission media. The logical approach, therefore, is to break the control system down into hierarchies, through using hierarchies of computers, interconnected. For example, there can be one such hierarchy controlling manufacturing itself, with computers of various degrees of sophistication and capacity interposed between the central computer and the manufacturing equipment. Some of the control hardware can reside directly at each machine, some can control groups of these machines through the individual controllers and, in very large systems, some may even coordinate batteries of these group controllers, tying all back to the central computer and thereby to the other elements of the computer-integrated manufacturing system.

Obviously, the prime hardware element in such a hierarchical system is the 'minicomputer' (using the term in its broadest sense) in myriad numbers and forms and with varying degrees of sophistication. It is the work-horse of the future, with large central computers playing a secondary role. However, the key element for success in this coming system of batch manufacture is not the minicomputer itself, nor its characteristics – it is the software by means of which it performs its tasks. It is this which must be developed from the ground up, starting at the shop floor, the design engineer's desk, the simulation and development laboratory, the sales engineer's office.

5. Elements in the evolutionary process

Ultimate attainment of computer-integrated batch manufacture, based on the computer-integrated manufacturing system, will be an evolutionary process, with many individual elements of the system developing and being implemented within that growing system. Some of these elements are already evolving.

(*a*) *Direct numerical control*

One such element is direct numerical control of machine tools. Here a single minicomputer serves as a central unit to control and coordinate the operation of a number of numerically controlled machine tools on-line. This in turn makes it possible to couple each individual machine to this central unit through a still smaller minicomputer. That in turn makes the full versatility of the computer directly available at each machine to supply all its immediate control needs, including control of its machine functions and local adaptive control of its metal-working processes and, eventually, its accuracy. Thus, what is developing is a hierarchy of computers, of various degrees of sophistication and capacity, such as that discussed in the preceding section. Bjørke (1971) has illustrated the basic framework of such a system in the manner shown in figure 3. Such d.n.c. systems for use in batch manufacture are being actively developed in most of the industrialized countries of the world today and a number of them are already in use in batch manufacture in industry.

(*b*) *Multi-station manufacturing systems*

A second element in this evolution, that of the manufacturing equipment itself, is also already beginning. This is taking the form of, presently, somewhat experimental integrated systems of numerically controlled machine modules, each capable of doing somewhat specialized work, and all coupled together by means of versatile automated workpiece transfer and handling devices and under computer control. Perry (1970) has illustrated a rudimentary form of such a system in the manner shown in figure 4. Williamson (1968) and others are developing systems based on similar or related concepts. The net result of such an approach should eventually be a highly versatile system, capable of accepting a wide variety of workpieces and operating on a large number of them simultaneously, thus greatly reducing capital costs per unit of work turned out in batch manufacture. These systems seem to offer excellent potential for applying direct numerical control of a hierarchical nature, as described above. Thus they may well be the forerunner of systems offering automatic set-up, automatic part handling and automatic assembly referred to earlier in the paper.

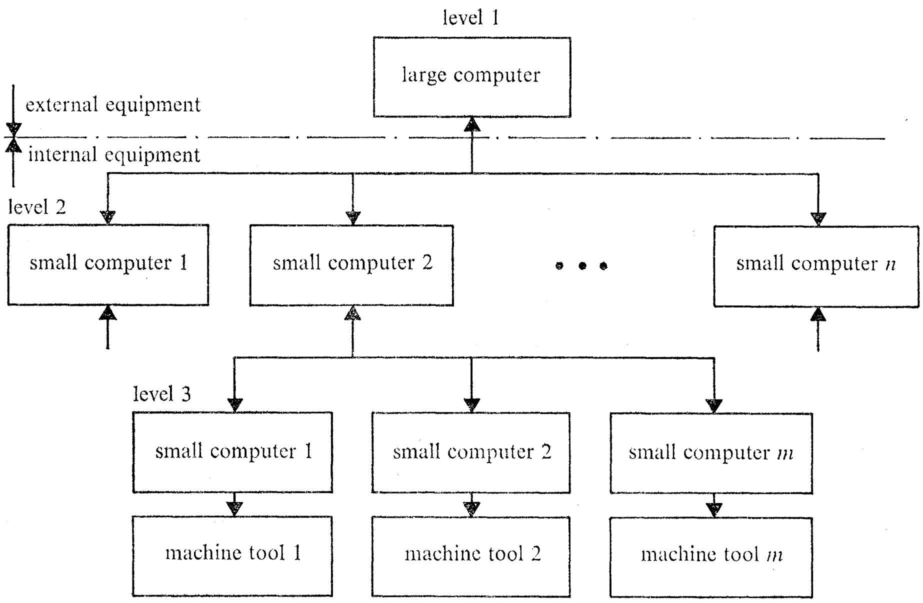

FIGURE 3. Basic framework of a direct numerical control system according to Bjørke.

(*c*) *Group technology and cellular manufacture*

A third important element in this evolution of batch manufacture is the on-going development and application of group technology and its related activity of cellular manufacture. Group technology deals with the organization and analysis of information describing the characteristics of manufactured parts, particularly their shape, dimensional tolerances, surface finish and material characteristics (i.e. the main characteristics which influence their manufacture). It thus provides a wealth of information about the relationships which exist between the various characteristics of manufactured parts and also provides a basis for grouping of parts having similar characteristics into 'families'. It is therefore a great aid to defining the characteristics which manufacturing processes and equipment should have if they are to be suited to the manufacture of such parts, and also to selecting appropriate manufacturing processes and equipment for the manufacture of any given part. In this latter connexion it has been used to define families of parts having similar manufacturing requirements, thus providing a basis for cellular manufacture. This latter type of manufacture consists of so organizing manufacturing manpower and equipment that all members of each given family of parts can be made,

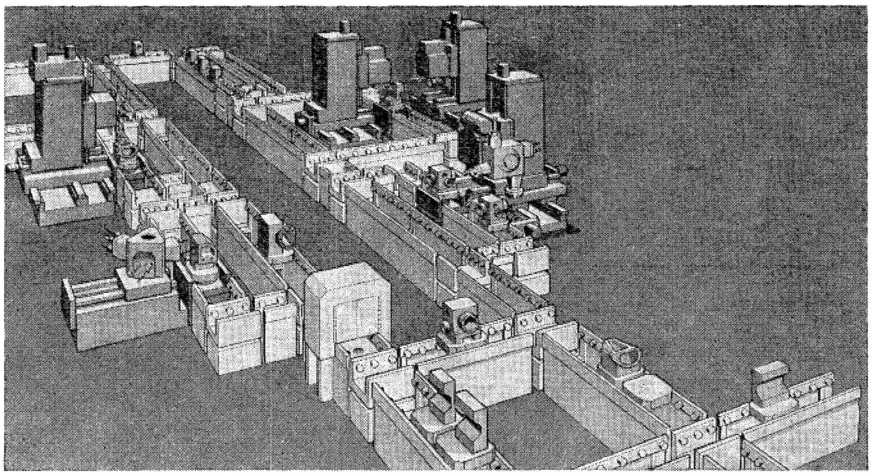

FIGURE 4. A computer-controlled multi-station manufacturing system according to Perry.

from start to finish, in a corresponding 'manufacturing cell'. Each cell consists of a group of people operating a number of machine tools which, taken together, are capable of all the manufacturing operations necessary. Both group technology and cellular manufacture appear destined to play important roles in the evolution of the computer-integrated manufacturing system. The main role of group technology appears to be developing in the realm of the input from the design to the production planning portion of the system. This input must provide a complete workpiece description for each part to be manufactured, including all information pertinent to the economic manufacture of the part. This input must in turn be generated by the computer-aided design module of the system. In most of the development work now being done on software for such integrated systems, it has been found that the method best suited to generating a workpiece description in the computer-aided design module, which is at the same time compatible with the input needs of the production planning module, is to use a modified form of group technology. This consists of working, in the design module, with standard geometrical shapes plus individual topological elements and combining these to build up the description of any given workpiece. Such techniques as algebraic technology and pattern processing are employed to do this. The result is a classification 'vector' for the workpiece which is ideal for input to the production planning module.

It is evident that as this group technology approach to coupling computer-aided design with computer-aided manufacturing in integrated manufacturing software systems evolves, it will provide an ideal basis for implementing cellular manufacture in the computer-integrated manufacturing system. The resulting group-technology-based workpiece description allows easy automatic computer classification of the resulting workpieces into part families and easy automatic generation of production planning and control information for use in cellular manufacture of them.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Further, the evolving computer-integrated manufacturing system provides excellent prospects for overcoming some of the problems which still plague cellular manufacture today. Take for example the difficult management and communications problem. To overcome this, such practices have been used as placing the desks of the engineers and other office personnel related to the functioning of a cell physically at the shop floor location of that cell. These men are then made nominally responsible to the cell supervisor, while at the same time remaining organizationally responsible to their overall plant functional managers. The factory-wide on-line supervisory control and communication network provided by the computer hierarchy and integrated software system of the computer-integrated manufacturing system should nicely solve such problems, eliminating the need for physical proximity to the cell of supporting office personnel and for dual management responsibility in its operation. Thus it seems evident that cellular manufacture will be a continuing important feature in the evolution of the computer-integrated manufacturing system for batch manufacture.

(*d*) *Integrated manufacturing software systems*

A fourth element in this evolution, and one which is perhaps the most difficult of all, is also already under development. This is the manufacturing software itself, needed to operate and control computer-integrated batch manufacture of the future. This requires combination of computer-aided design software with production planning and production control software (such as is now used to optimize manual conduct of batch manufacture from computer output), with numerical control type software (such as is now used to control the automated operation of individual machines or groups of machines) and with management information system software. While all these types of software are now in existence and use in elementary forms today, they currently have little in common. Their integration and overall development therefore may indeed prove to be the main factor limiting the rate of evolution of the fully automated, self-optimizing, computer-controlled manufacturing system for batch manufacture.

Extensive work is therefore currently underway in many quarters to develop the needed comprehensive software systems. For example, Opitz (1969) and Nissen (1969) have both given some indication of the extensive efforts underway in Germany and Norway in these directions. The comprehensiveness of these efforts may be judged from figure 5. The main body of the table indicates the scope of the required effort on development of integrated manufacturing software for batch manufacture as envisioned by Opitz and the right-hand column, headed 'NAKK activities', indicates the scope of the work being undertaken in Norway in the development of their Autopros and Autoplan software systems.

(*e*) *Enhanced technological education and information transfer*

A final element in this evolution, enhanced technological education and information transfer, although not new, is today undergoing rapid change and development. This is because of the tremendous challenge to the batch manufacturing industry posed not only by all of the problems and needs enumerated in the early part of this paper, but also by the challenge of the developing computer-integrated manufacturing system itself. Thus we find industry becoming increasingly involved in technological education and information transfer. This is taking two main forms. The first is increased encouragement to and cooperation with academic institutions and technical societies in their work of developing higher quality, more professional technical personnel and of generating and disseminating new technology and technical information about such. The emphasis there is on manufacturing engineering and systems engineering as the disciplines presently the weakest in relation to the needs of a systems approach to manufacturing. The second form is the development by industry of comprehensive in-house technological planning/education/information systems designed to keep its professional technical personnel and programs abreast of new technology.

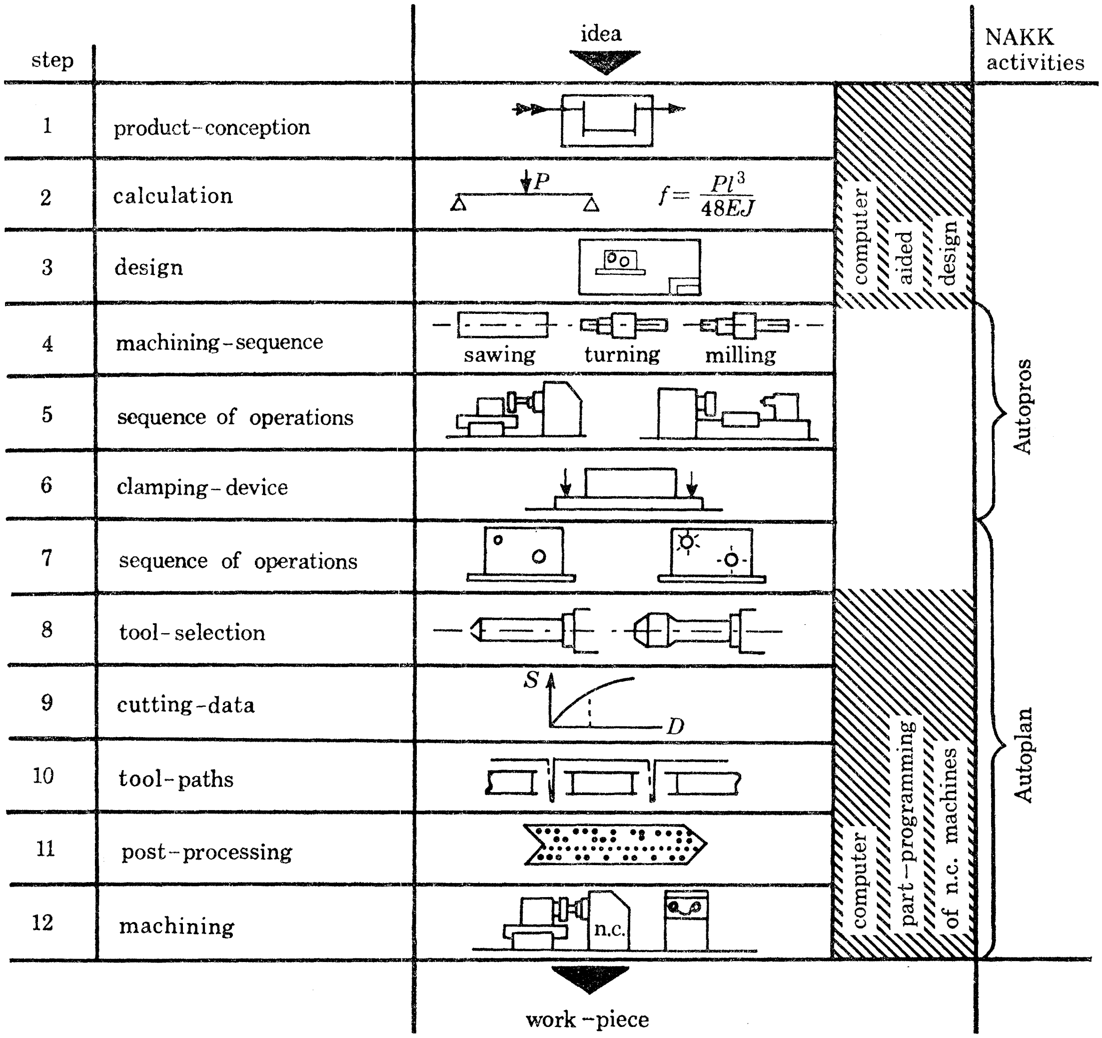

FIGURE 5. Scheme for development of integrated manufacturing software for batch manufacture according to Opitz and Nissen.

6. FORECAST

As we consider the future of batch manufacture in the light of the prospects for realization and implementation of the computer-integrated manufacturing system as outlined in the foregoing sections of this paper, the final question which naturally arises is that of how soon the various phases and elements of the systems development described there may be expected to materialize. Considerable light is thrown on this subject by the results of a technological forecast of the future of production engineering recently completed by the International Institution for Production Engineering Research under the guidance of the author (Merchant

Table 1. C.I.R.P.-Delphi forecast events pertinent to realization of the computer-integrated manufacturing system for batch manufacture

1980

A computer software system for full automation and optimization of all steps in the manufacturing of a part (selection of machining sequence, selection of machine tools, clamping, selection of sequence of operations, tool selection, selection of optimum cutting conditions, numerical control of machining) will be developed and in wide use.

Complete in-process inspection of parts as they are machined will become a reality.

Sensors will be developed and put into use which are able to measure, instantaneously and continuously, the roughness of a surface as it is being generated by a cutting tool or grinding wheel, in-process.

Sensors and instruments will be developed and put into use which are able to measure and control, continuously and instantaneously, the exact dimensional position and characteristics of the surface being generated by a cutting tool or grinding wheel.

Machine tool control systems will use the laser extensively for in-process control of accuracy.

Feedback control to correct thermal deformation of machine structures will be widely used.

Fully self-optimizing adaptive control of e.d.m. and e.c.m. machines will be developed and in wide use.

1985

Full on-line automation and optimization of complete manufacturing plants, controlled by a central computer, will be a reality.

On-line process identification and a very quick adaption of manufacturing conditions relative to output requirements, i.e. on-line optimization, will be in wide use.

Automatic assembly will be extended to the greater part of mass-production operation by development of measuring, sorting, and self-selecting techniques.

Standard pallets for holding all components will be generally used.

Fully self-optimizing adaptive control of machine tools will be developed and in wide use.

Methods will be developed for control of thermal deflexion, and roll, pitch and yaw errors in the machine itself (with less reliance on in-process gauging, which is very awkward in automated versatile manufacturing systems).

In-process adaptive control of surface roughness in machining and grinding will be developed and in wide use.

Techniques and equipment will be developed in which forming processes and other fabricating processes, such as machining and physical and chemical processes, are combined in a controlled manner and under an optimum condition.

Over 50% of machine tools for plastic forming will be automatically operated.

Consolidative type forming processes will be developed and come into use, in which parts are built up incrementally in a controlled manner from small fibres, particles or other elements.

Machine tool structures will be built up from combinations of metals and non-metals, in matrices or bonded together, to give proper thermal stability, static and dynamic stiffness and wear and noise characteristics.

1990

Computer software systems (adequately standardized for compatibility of items purchased from different sources) will be generally commercially available. (These are systems of manufacturing software.)

More than 50% of the machine tools produced in the future 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.

Automation of quality control by in-process inspection devices connected on line with a process-computer forming part of a larger manufacturing system will be a reality.

Reliable and practical sensors will be available for adaptive control of all current metal cutting operations, e.g. turning, milling, etc.

75% of industry will use group technology in manufacture.

75% of all machine tools will be designed using computer graphics and conversational programs.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

1971). This forecast was developed by use of the Delphi method, participated in by a large percentage of the members of C.I.R.P. This method makes use of anonymous iterative reply, by the participants, to a series of questionnaires designed to reach a concensus of opinion on what significant events may be expected to happen in the future and by what year. General experience to date with this method in a number of fields suggests that it produces generally reliable forecasts of the future.

Table 1 lists all of the events pertinent to realization of the computer-integrated manufacturing system on which good concensus was obtained in that C.I.R.P. Delphi forecast. These are grouped according to the median year in which they are expected to happen.

It is quite evident from the foregoing that, if the forecast quoted there is indeed reliable, virtually all of the prospects described in the present paper will be realities before the end of this century! Further, substantial implementation and application of computer-integrated batch manufacture will already have been accomplished by the 1980s.

7. Conclusion

It is evident that batch manufacture is now entering a new era, one full of challenge, excitement, innovation, and rapid change. We who are privileged to be working in this field today are now undergoing a rich and rewarding experience and one that should remain so for many years to come. It is a pleasure to be a part of such an undertaking.

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Discussion

Sir Richard Young (*Alfred Herbert Ltd, Coventry*) said that in Britain as in the U.S.A. batch manufacture was responsible for 40 % of the Gross National Product. The decrease in the stock of machine tools from one and a half million to less than a million, coupled with the need to switch possibly £5000M out of working capital into fixed capital, suggested to him that not only must there be a 'systems' approach in manufacturing industry, but a systems approach to the management of finance in industry and possibly to the management of the whole economy. He wondered if Dr Merchant had seen, perhaps in Norway, a beginning of the drawing together of the handling of industry and its technologies with the technologies of handling the economy. He would be grateful for ideas on the interaction of these systems approaches.

He forecast that in-process gauging would become an increasingly important aspect of manufacturing technology as would perhaps the development of more sensitive, versatile and cheaper drives. Simplified work handling and thermal control of machine tool structures were also important. Industry would look to the educators to provide a well-educated and capable work force.

Dr Merchant agreed with this analysis and added that although the systems approach to financial management was only slowly being adopted, technological advances would ensure its complete acceptance.

He noted that the University of Salford had already responded to the need for greater co-operation between education and industry by instituting an M.Sc. course in manufacturing engineering and systems engineering, which is being operated with the aid of and with guidance from industry.

Mr D. J. Falvey (*Group Technology International, George Road, Birmingham* 15) agreed with Dr Merchant's diagnosis of the problems of batch manufacture, but he believed that entrenched attitudes would prove a substantial obstacle to change. There is a threshhold problem and some people will have to be drawn across, struggling and screaming if necessary. The vision Dr Merchant offered seemed to him to be so far in advance of current thinking as to make its realization a very long-term prospect indeed.

He himself favoured a phased programme, whereby a move to a systems or cell approach could be made with existing machines. This could be based on an analysis of the operational and design features of the parts as they already exist. This first step would cut down the waiting time of each stage of production.

Once the cells have been defined by a close analysis of the components, the machine tool requirement is precisely defined, and it is then possible progressively, given that one has these families of components, to move to more sophisticated technical solutions to the problem. In this way, technique is made the servant and not the master. At present most people in production engineering, and machine tool manufacturers, are thinking atomistically rather than systematically, and as a consequence technology is the master instead of the system being the master. The threshhold problem can be overcome by using component flow analysis to analyse the components, the machines, the demand factor and the human aspects required for cellular production.

He asked Dr Merchant to clarify his reference to classification by shape which he thought was a fundamentally weak concept because there was no definition of how shapes ought to be classified.

Dr Merchant agreed that the cell system would be an important step in the evolution of the system he had proposed.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

He explained that the classification vector was based not just on shape, but on all the characteristics of the part including its material, its tolerances, its surface finish and so on. He had not intended the word topology to refer only to geometry.

Professor E. H. Frost-Smith (*Queen's University, Belfast*) said that he doubted whether Dr Merchant's predictions would be realized quite as quickly as he thought. For instance, the heart of the batch production system is the metal-cutting process, about which little is known. If the possibilities of this system are to be fully explored, more information is needed on the variables of the metal-cutting process and of their influence on the system performance.

Mr A. E. de Barr (*Machine Tool Industry Research Association, Hulley Road, Macclesfield, Cheshire*) recalled that forecasts made in the late 1950s had predicted that within a few years 75 % of the machine tools sold in the U.S.A. would be numerically controlled: in fact the figure is less than 1 %. He suspected that a similar fate awaited Dr Merchant's prediction that 50 % of machine tools would be fitted into computer manufacturing systems by 1985.

The obstacles are not of a technical nature: they are the financial ones to which Sir Richard Young had referred, and even more important, human and social. New systems will have to be acceptable to the shop floor; a managerial revolution is needed before capital-intensive, computer-controlled manufacturing systems can be put into operation; and changes in industrial structure will be required to make use of highly productive, concentrated units.

Dr Merchant replied that it was true that in quantity the percentage of numerically-controlled machine tools was low, but it did represent about a third of the production in value. Similarly, his own forecast referred rather to the capital that would be invested in computer-controlled manufacturing systems. In fact his company had made a research study parallel to that conducted by C.I.R.P. the International Institution for Production Engineering Research, and the results and forecast had been remarkably similar. The forecasts might be proved wrong, but there was a strong feeling among the people who make the important decisions that these things are going to happen.

Mr G. A. B. Edwards (*University of Manchester Institute of Science and Technology, Sackville Street, Manchester*) said that Dr Merchant had failed to distinguish between the system of production, i.e. the people and machines and their associations, and the system of organization of production, i.e. the system of control through the information flows and much of the software. Computers are being used to analyse the second system, but no attention is being paid to the problems involved in the system of production despite the fact that the industrial relations war in the outside world will have an important influence on future developments of manufacture. In this sense, he suggested, computers were positively counter-productive and appeared to be the tail wagging the dog.

For instance, there was a 54 % labour turnover at Volvo in 1969; 150000 cars were lost in the flowline at Fiat last year; the batch manufacturing system suffers from a 1:1 stock/sales ratio and delivery dates are being extended to ridiculous levels. People dislike operating certain production processes and they are changing the system. Analysis of software and part-programming will be meaningless if we forget that our systems will always be people-controlled, not computer-controlled.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Dr Merchant agreed that introducing the computer into the manufacturing organization as it is at present only compounded the problem. There must be an organizational approach to manufacturing and an analysis through systems engineering and systems technique of the proper organizational approach that will allow the capabilities of the computer to be fully employed. Volvo, for instance, have met the need for increased job satisfaction by delegating routine tasks to the machine and giving the workers creative roles in the production line.

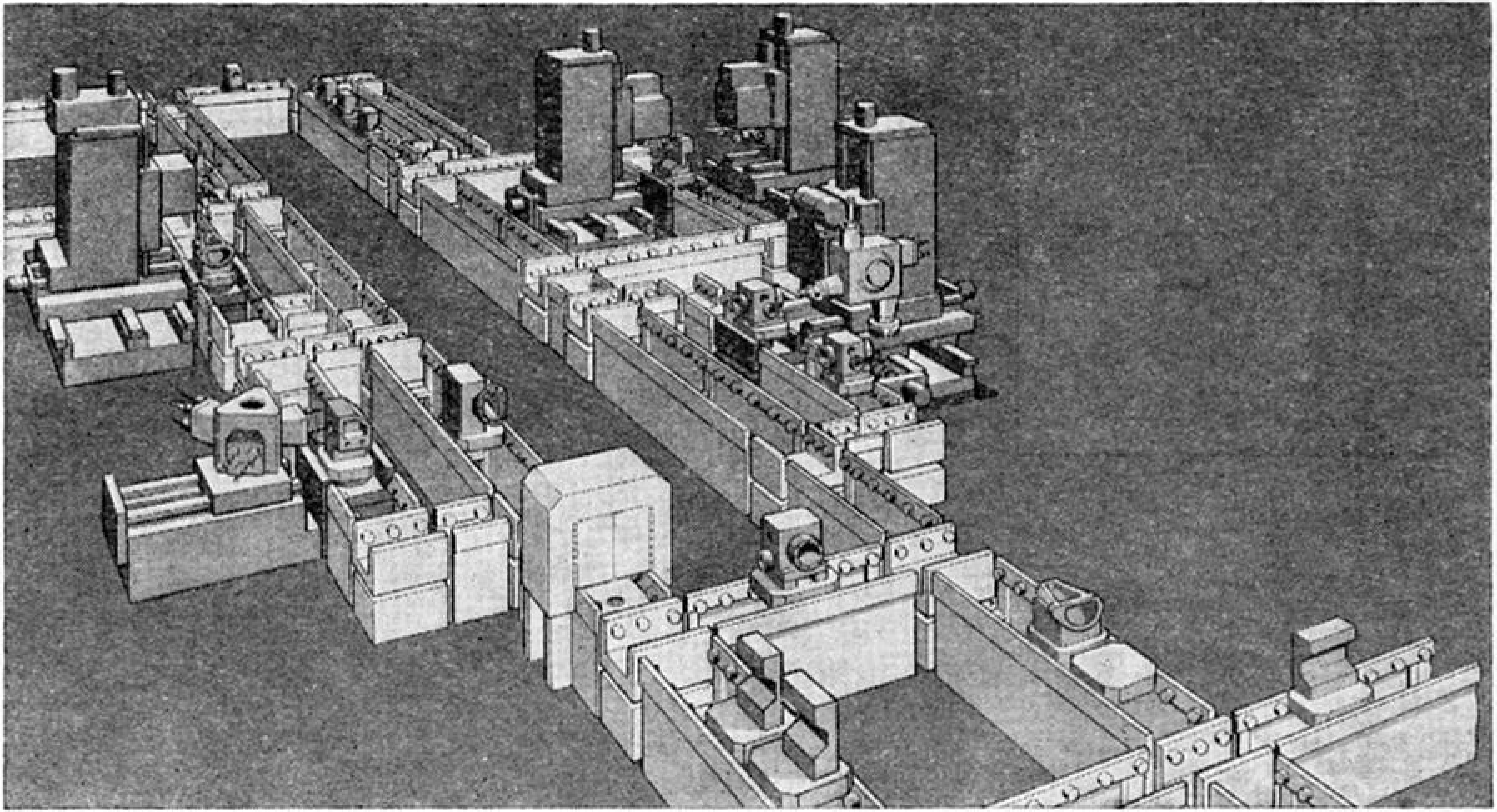
Dr I. D. Nussey (*I.B.M. United Kingdom, Hagley Road, Birmingham*) pointed out that the machine tool manufacturers who predicted in 1968 that by 1972 75 % of machine tools in the U.S.A. would be numerically controlled and that by 1975 about 50 % by value would be controlled by a central computer had a vested interest in selling machine tool systems of this kind. He had learned to take statements like these with a pinch of salt partly because people actually concerned with manufacture were often not consulted and partly because they failed to take into account the fact that software increases in cost at least exponentially with the number of lines that are written.

He asked Dr Merchant to clarify what he meant by 'optimized system' and whether he could be more specific with his forecasts for total systems.

Dr Merchant explained that the definition of 'optimized system' depended on the objective which the system sought to serve, whether this was minimum cost, maximum profit or maximum production rate.

On the second point, he had never intended to be specific because it had been pure speculation, but he thought that the development of the batch manufacturing system would be approached in a systems engineering manner and that possibly central service bureaux would be established, as they were being in Norway, to help small manufacturing plants take advantage of government-sponsored developments in the software field.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



IGURE 4. A computer-controlled multi-station manufacturing system according to Perry.