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THE USE OF CAD/CAM SYSTEMS IN MANUFACTURE

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1. Abstract

Theoretical and academic work on CAD/CAM systems has supposed that the standard NC and APT-like interfaces would be adopted. Recent experience has shown that most economically viable industrial CAD/CAM systems are not following this pattern. A plea is made for modularity as a means of slashing development costs and facilitating technology transfer.

2. The CAD/CAM Interface

Design is an activity which precedes manufacture. In a sequential approach to the automation of an industrial facility, it is the first block in the flowsheet. The link to the next blocks may then be called the Design/Manufacturing interface, which in the traditional scheme of things consists of:

- drawings,
- lists,
- instructions, and
- descriptions.

In actual fact even the most established and conservative industries do not rigidly follow this pattern and the interface is a far more complex, bidirectional one. The (varying) constraints of the manufacturing facility, feedback about the difficulties encountered in implementing design specifications and technological instructions are some of the important manufacturing inputs to design. Nevertheless, the first attempts at computer-based interfaces between the computer-assisted implementations of the two major activities have been of the open-loop type.

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2.1 The Traditional Approach

The first, and in many industries dominant, mode of information output from the design process is to emulate the traditional manual output of a design department. The computer will then be expected to produce drawings according to the accustomed drafting standards of the industry and print-outs of parts lists, machining and assembly instructions, etc. in a way as closely analogous to hand-drawn and typed documents as is technically feasible. Though facilitating the introduction of CAD into a traditionally-based industry, this approach imposes many unnecessary tasks on the computer system. At the same time it wastes the potential of the computer as a readily accessible repository of design information for subsequent phases and as a vehicle for live interaction with them. In a sense this is like building a motor car to look like a horse-drawn carriage.

During a recent world-wide survey [5] of Computer-Aided Design conducted on behalf of the International Institute for Applied Systems Analysis we found in some of the world's most industrially sophisticated countries striking examples of how far traditional organizational, financial and incentive systems have tended to perpetuate the separation of design and manufacture. In one large vehicle factory, the development of prototypes of their product was the responsibility of the Engineering Service, who produced NC control tapes for machining the prototypes as part of the CAD process. The production service, however, being a completely different organization with different computing facilities, received only drawings, from which they again manually input information to another computer, to obtain the technological programmes. In the design facilities of one very large computer manufacturer, CAD is used extensively to design logic circuits which are output as logic diagrams. The artwork is hand-designed and re-entered into the computer system by digitizers in the production area. In another instance, in a large design office, steel structures were described accurately within a computer for stress analysis, but the same information had again to be manually extracted from drawings by the builders who then used a computer to control their parts production.

While the traditional engineering drawing will take a very long time indeed to be fully replaced by more appropriate, computer-based modes of documentation, the approach outlined above is evidently unsatisfactory and (though at present widely used) can not be regarded as a solution to the problem.

2.2 Interfaces Imposed by Manufacturing Technologies

While there have been many experimental attempts over the past fifteen years to achieve a direct, computer-based link between the processes of design and manufacture, most of these have been in research environments or in certain parts of the aerospace industry where the economics of these schemes were secondary considerations. More recently, however, a range of industries has emerged where the implementation of integrated, computer-based systems of design and manufacture has become an indispensable condition for achieving or retaining a competitive position on the world's markets. These are primarily electronics, shipbuilding, and certain types of die-making.

A common feature of these three fields, in which the implementation of CAD/CAM systems has been most rapid, has been that the CAD/CAM interface has evolved in an ad hoc manner. Our previously entertained notions that it would develop along the lines of the standardized interfaces (e.g. CLDATA) which the NC community has been striving to establish for so many years, have been disproved and the deciding factors seem simply to have been the types of NC equipment, the NC programmes and programming techniques most readily available. In fact, in many cases, the development of the integrated systems as a whole has followed along similar lines and--contrary to the theoretical expectations--has yielded industrially satisfactory results.

In the electronics industry the main items of NC equipment used in the manufacturing facilities are:

- plotters (drafting machines),
- drilling machines,
- wiring machines, and
- testing machines.

Of these only the drilling machines in any way resemble the metalworking NC machines for which the NC programming languages were originally developed, and even there the adoption of a format designed for a very large variety of hole sizes, differing feed rates, rates of revolution, pecking depths, lubrication and coolant conditions, complicated geometrical hole patterns, etc. would evidently be out of place. Consequently no uniform format has emerged. The CAD/CAM interface is different in each factory, depending on the traditions, and more particularly the brands of NC equipment available.

Many large integrated systems have been developed on this basis [1, 3, 6]. The unifying data base has generally been at a much higher level (usually the logic level) than the CAD/CAM interface, as the latter was mostly limited to the generation of punched tapes at "controller-code" level.

Yet the requirement for a meaningful and clearly defined lower-level interface (which really does lie between design and manufacture) is there. This should, among other things contain:

- the full artwork topology,
- pin interconnection lists,
- wire routing and coloring lists,
- component placement,
- parts lists, and
- diagnostic programmes and tables.

In the shipbuilding industry the CAD/CAM interface has almost everywhere [4, 9, 7] been determined by the (generally low-level and specialized) programming languages used for NC flame cutters (e.g. the Kongsberg ESSI, the Hitachi HIZAC, etc.) and most recently for NC pipe-cutting, and bending machines. While all shipbuilders who use CAD (and today only they can remain competitive) strive to construct a product data base upon which their technological, management, scheduling, etc. functions can draw, this is in each case different in content and format. This is all the more astonishing as even the geometrical representations used are mathematically identical from Poland to Japan, from the GDR to Britain to the US.

In the case of car bodies, the reason for the frequent departure from the previously expected APT input language interface has been different; it has lain not so much in the use of special NC tools not easily amenable to APT-like programming, but rather in the overall requirements of the integrated design and manufacturing process. Some procedures, for instance include the need automatically to input shapes from a model [8], others require the machining of a model as part of the design process [2]. In both cases the enforcement of standards created to satisfy completely different requirements would not be useful. Consequently the commonalty of the CAD/CAM interface is again degraded to the (at best ISO) punched tape level.

2.3 Planned CAD/CAM Interfaces

The third possibility is to deliberately plan the CAD activity as one component of a computer-based, integrated design and manufacturing scheme from the outset. The basic characteristic of such a scheme should be a shared file system into which the design process feeds data that can be extracted by the subsequent phases and itself is able to draw on data from the other areas. This renders the structure and content of the files produced in the design process of prime importance.

In the mechanical engineering industry, for instance, the outcome of the design process should typically yield such information as:

- The shapes of the components to be machined,
- The machining sequences on each machine tool,
- The sequence of machine tools for machining the parts,
- Tooling data,
- Machining data (feedrates, etc.),
- Blank material requirement of each part,
- Machining times per part per machine,
- Parts, materials and tools required for assembly,
- Assembly sequence,
- Assembly operation times,
- Measuring instructions for components and assemblies, and
- Testing and checking instructions.

It may well be contended, that much of this information is at present not generated in the design stage, but in other phases such as production control, process planning, etc. It should, however, be emphasized that if the integration of the CAD and CAM (and the Management and Accounting) functions of industry is to yield more than the arithmetical sum of the automated parts, the boundaries of the "horse-drawn carriage" epoch must of necessity be blurred. This, in fact, is what "integration" is about.

3. A Systems Approach

The fundamental necessity is to recognize that the CAD and CAM subsystems of an integrated manufacturing system are in fact components of a single unified system. In order to build such a system it should first be designed and checked as a whole, then decomposed into subsystems and the interfaces and functions of each of these can then be defined in a "top-down" fashion. Such a clean solution would, however, in the case of the integrated manufacturing systems we are discussing, be faced with unsurmountable difficulties. These are due partly to the sheer size and complexity of the systems, partly to the constant emergence of newer and yet newer system components, facilities, etc.

For lack of a "master plan" type of overall integration design, the next best thing is to achieve an intelligent summary of what is extant and presently expected. These items of knowledge can then be used to construct a hierarchical system model which will check the input and output data and operating functions of each subsystem.

At present a joint activity has been launched between the appropriate Working Group (WG 5.3) of IFIP (The International Federation for Information Processing) and IIASA. The object is to collect extant or desired module descriptions in computer-readable format and then to include them as components of hierarchical systems development programme. This will analyse all inputs and outputs of subsystems and check the information flow and direction against the data for the rest of the subsystems. Thus a set of primarily important inter-module communication links will have been obtained, and a representation of the data that pass along them. These data in effect comprise the interfaces between the system modules.

The new standards that should emerge from this activity, would no longer be tied to one or another form of implementation, a particular manufacturing process, or certain types of equipment. They should be flexible enough to cater for the unforeseen needs of the future. (For instance, design output data on part geometry, on assembly methods and sequences, should be sufficient for the automatic extraction of adequate information for programming a robot to carry out the assembly.) And the new standard interfaces should include the old interfaces as compatible sub-sets as well.

Is there any point in having standards at all if they are so difficult to achieve and will necessarily be so vague on many details? During the course of CAD Survey visits to eighty-five organizations in fifteen countries [5], industrial experts everywhere pointed to the enormous amounts of effort wasted on re-inventing wheels all round. If subsystem interfaces are made not only efficient, but also (to some extent at least) compatible with each other, these costs can be slashed. This is why the construction of computer models of integrated manufacturing systems is important and the emergence very soon of some standards appropriate to state-of-the-art requirements is eagerly awaited.

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