The Role of Process Planning in the Integration of CAD/CAM Systems

by

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ABSTRACT

In recent years CAD/CAM systems have gained wide acceptance in industry both in the U.S. as well as her major competitors in Europe and Japan. As experience in the use of these systems builds up, it has become increasingly evident that for them to operate most effectively, they must operate in an integrated way. This paper looks at the continuing drive to attain fully integrated CAD/CAM systems and explains the key role that process planning has to play in this endeavor.
INTRODUCTION

Today's industrial climate is one of intense competition with great emphasis being placed on reducing costs and improving productivity, product quality as well as reliability. To achieve these goals, manufacturers have had to adopt radical new production techniques. The use of the computer in various fields such as design, control and manufacture has been of particular importance. The new computer-based technologies have penetrated most areas of industry ranging from simple clerical functions like word processing to the most sophisticated applications like astronautics and the space-shuttle program. What has most encouraged the spread of this new technology is its evident efficacy in achieving greater productivity and hence improved competitiveness.

Experience in the use of various computer-based systems in industry has shown that while each can individually benefit the production process, these gains would be enhanced if the various systems were integrated. There are many functions in which at least some of the required information is common. In such cases, it makes sense to provide a means by which these functions can share the common information. This would be an important step in moving towards the goal of achieving a fully integrated manufacturing system.

Computer Integrated Manufacturing (CIM) is a major long term research objective including elements such as Robotics, Numerical Control, Computer Aided Design, Process Planning, Manufacturing Resource Planning and others. This paper is aimed at investigating the key role of process planning in this multiplicity of requirements [1].

COMPUTERS IN MANUFACTURING INDUSTRY

Computer Aided Manufacturing

Over the last two decades, the impact of computers in manufacturing industry has been profound. On the shop floor it is perhaps most evident in the form of numerically controlled (NC) and computer numerically controlled (CNC) machine tools. In these types of machine, all the manufacturing functions can be controlled using numeric data (hence the term numerical control) usually supplied to the controller via a punched paper tape or magnetic tape; or in the case of CNC directly from a computer.

For particular applications it is possible to further increase productivity by grouping a variety of these NC machines together with an automated materials handling system to form a manufacturing cell controlled by computer. This is referred to as a flexible manufacturing system (FMS). The components to be made in the system can vary considerably in shape and required machining processes. The workpieces can be handled either by robot or loaded onto pallets and automatically transported from machine to machine where the required processing is carried out. The productivity in such a system can be very high and it comes close to achieving completely automated manufacture.

Computer Aided Design

To integrate the whole production process also requires functions upstream of shop floor manufacture to be included. On this side, computers have made their greatest impact in the design office. Computer Aided Design and Computer Aided Drafting have become major tools in increasing efficiency and productivity in the design office. With implementation of CAD, all the design data relating to a particular component can be stored on a central database. This is of crucial importance. When design data for all components made by a particular firm is stored on the database, this can be used to retrieve the designs of other similar components and thus past experience is quickly applied to the new components while at the same time preventing 'reinvention of the wheel'.

In general, software particular to each type of application is required as there is as yet no general purpose software available to meet company-wide requirements.
Process Planning

What is required to link the design function to the manufacturing function is process planning. The best definition of process planning to date is that 'It is the subsystem responsible for the conversion of design data to work instructions' [2]. Process planning is a detailed and difficult task, traditionally carried out by highly skilled workers who have an intimate knowledge of a wide range of manufacturing processes and are themselves experienced machine operators.

By studying a drawing, the process planner is required to determine the operations that need to be performed on a workpiece to produce the specified component and the order in which they are to be carried out; establish the cutting conditions to be used and hence obtain the machining times and also determine the associated non-machining times (e.g. set ups, tool changing etc.). These can then be used as a basis to determine costs. A detailed knowledge of the particular working environment is essential since these decisions will inevitably be affected by such things as the capability of the machines, availability of machines, cutting tools, jigs and fixtures as well as labor.

It can be appreciated that when done manually, this can be a tedious and time consuming task. The problem is exacerbated by the fact that in general, process planning engineers tend to rely on personal experience and there is no formal universally accepted theory for process planning. Thus if several process planners with different industrial backgrounds are given the same component to plan, the probability is that each will produce a different solution to the problem (although each solution should be technically feasible and lead to the same end result). Even in the same firm, it will generally be found that no two process planners will plan a given component in the same way. More ironically, if a particular planner is given the same component on two different occasions, the process plans generated on each occasion will probably be different. Clearly a situation like this is undesirable since all the plans produced cannot be equally economical. The case for standardizing process planning procedures is unquestionable. The critical issue then becomes establishing a suitable standard to be followed [3].

It has become recognized that the application of computers in this field has great potential. By using a computer, the tedious and repetitive aspects of process planning can be speeded up and thus help to optimize the total manufacturing function by releasing the experienced planners and enabling them to concentrate on those creative tasks which are outside the scope of the computer [4]. At the same time, more consistent process plans can be obtained by applying a standard set of rules which increases confidence in the system and helps in the rationalization of production.

In the application of computers to process planning, two main types of computer-aided process planning have emerged, these being variant and generative process planning systems.

Variant Process Planning

This technique is based on the application of group technology (GT) principles. In GT, the components to be made are grouped together according to their similarity in shape and hence required machining operations. A group of similar parts is referred to as a family. All members of a family are then manufactured in a single GT cell. This helps to standardize tooling, minimize tool changes and optimize routing for each component. When applied to process planning, a representative member of a part family is planned in detail and the resulting process plan is stored by the computer. If a plan is required for another member of the family, the plan for the representative component is recalled and reviewed by an experienced planner. He carries out any modifications that may be required to make the plan suitable for the new component. If the representative component was properly selected, the modifications to the plan should be minimal thus making it possible for a new process plan to be generated with ease.

The main criticism to be made of variant process planning systems is that they do not fundamentally solve the problem. Essentially what they do is to speed up the process.
but by relying on a process planner to develop a plan for a representative component and reviewing this for specific applications, it locks in the difficulties and problems associated with manual systems as outlined above. The systems do not really generate new process plans. It is for this reason that the generative approach to process planning was developed. Variant type process planning systems are still dominant in industry however because they are easy to implement, they can handle a wide variety of parts and conceptually they are very similar to what has been done in the past and therefore are easily accepted.

**Generative Process Planning**

The generative approach to process planning is aimed at creating a new process plan by completely automatic means. This requires as input some form of geometric description of the component to be made. By applying some established logical rules to the input data, the processes required to produce the machined component are then generated automatically. The most popular approach involves the use of artificial intelligence (AI) techniques. These systems are generally based on simple elementary surfaces which can be recognized by some form of algorithm which then selects a suitable machining process to generate the surface.

Generative process planning is still in its early stages of development. The main obstacle to its development is that for any given type of surface, there is generally a multiplicity of operations which can generate the surface. Determining which one is optimal is influenced by such factors as production volume, required dimensional and surface accuracies, what other operations have to be carried out on the component, which machines are to be used, etc. This is a complex decision problem and that is why artificial intelligence is the most appropriate approach.

Although still in development, it is now recognized that generative process planning has considerable long term potential. Its analysis is based on the geometrical definition of the component and is therefore a prime candidate for use in an integrated CAD/CAM system, with geometry data from the CAD system being accessed by the process planning function for generation of manufacturing instructions for example in the form of NC data.

**INTEGRATION ISSUES**

In developing an integrated computer-aided design and manufacturing system (CAD/CAM), it is important to appreciate that even the best design can become useless unless it is properly manufactured. The design data must therefore be converted into proper manufacturing instructions which can then be executed to produce the desired component. The function responsible for converting design data into manufacturing instructions is process planning. This is therefore an essential element of an integrated CAD/CAM system [5].

Historically, the two disciplines of CAD and CAM have evolved separately with each applying computers to solve its most pressing problems in a disjointed manner. Thus functions like design, process planning, part programming and shop control have each applied computers to their particular field. Certainly each function benefits from computer assistance, however, the total benefit to the manufacturing enterprise will be increased if there is proper communication between the various functions. Some information is often common between functions and in other cases the output from one function is used to drive other functions. Without integration, data such as geometry would have to be re-entered, reverified and reformatted for each application. In situations such as that, errors and loss of data during transcription would be hard if not impossible to avoid [6].

The key to integrating the CAD and CAM functions is the flow of information between the various functions. A widely advocated approach is the use of a common database in which all the information relating to a firm and its products would be stored. In such a system, a wide range of information would be stored in the database. Each function
accessing the database would only make use of a subset of the available information. One of the major problems with this approach is the design of a suitable format for all this information. But perhaps the most important issue in this case is how to maintain the integrity of the data used. This requires that if any function alters data that is used by other functions, then there must be a way of communicating this change not only back to the database, but also to all the other functions that are using that information [7]. It is also necessary to ensure that there is no redundancy of data and at the same time any conflicts in data must be resolved.

Kamvar has proposed an interesting technique for the recognition and interpretation of graphical data from the database of a CAD system [8]. The approach involves use of a special program which analyses the CAD drawing files of a part and automatically generates a 23 digit code for the part. The generated code is a detailed description of the part and this can be used in other functions like manufacturing. In fact it is possible to link this with CAM-I's CAPP program to generate a process plan. This has been implemented for rotational parts but it seems much less likely to work with the more complicated prismatic parts.

THE ROLE OF PROCESS PLANNING

A lot of research in both industry and academic research institutions has been undertaken to provide some automatic means of linking the design process (CAD) to the manufacturing process (CAM). The result has been a variety of CAD systems which include NC part program generation capabilities. In fact this has become practically standard in state of the art CAD/CAM systems. Generally such systems take advantage of all interactive graphic capabilities of the CAD system to generate toolpath information from a mathematical model defining the object to be machined. Mullen has reported on a typical system which generates NC part programs in the APT language [9]. The weakness of such systems is that they require some form of interactive technique to establish the detailed machining requirements such as cutting conditions, the proper sequence of operations, capabilities of available machines etc. This is the very kind of information that is routinely generated by CAPP systems and therefore it would be ideal if they could be integrated with the CAD function and thus form a bridge between CAD and CAM.

As indicated above, the generative approach to process planning holds most potential as a vehicle for integrating CAD and CAM. A number of process planning systems have been proposed in the literature examples of which include APPAS, ICAPP, TIPPS, CAPP, SIPP, STOPP*. Current research in process planning is paying particular attention to the use of expert systems in process planning for the purpose of determining machining processes.

Once the suitable machining processes have been determined, it is necessary to convert these into explicit manufacturing instructions and this is where process planning plays a critical role in linking CAD and CAM. TIPPS is an example of a process planning system which achieves integration between design and manufacture for hole making operations [10]. In this case, the process planning system accesses the part description from a CAD database. A boundary internal model of the engineering part drawing is displayed on a graphics terminal and using an interactive procedure, surfaces requiring machining can be marked. A backward planning scheme searches a process knowledge database to find a sequence of manufacturing process which can achieve the design specification. However, this technique is only limited to hole making operations.

* Reference 1 includes an extensive survey of various approaches to computer-aided process planning and a number of systems are detailed.
Research at Delta CAE Ltd. has established initial links between various drafting, process planning and part programming packages (DOGS, CAPES and GNC, respectively). By taking advantage of the specific capabilities of the CAD system, design information required for process planning can be written out into a transfer file. The process planning system can then conceptually access this transfer file and read off the data required for process planning and hence generate the required process plans. An interface program can then access the generated process plans and transmit appropriate data from here into the part programming package. This offers the opportunity of an integrated design, planning and manufacturing system [11].

Integration of systems using transfer files and interface programs can be tedious and a system which offers direct integration between design process planning and manufacturing is required instead. An initial attempt at such a system aiming at total integration between CAD, CAPP and CAM is described fully in reference [5]. Within the same program, process plans for the manufacture of a variety of prismatic parts can be generated. An option within the program enables the automatic generation of part programs in addition to the process plans, using the manufacturing data given on the process plans. Further research with this system is concentrating on integrating the process planning package with a CAD system so that the geometry information for the part can be accessed directly. This could then be used to generate process plans and geometry descriptions required in part programming. The concept is illustrated in Figure 1 which also shows the potential for further integration with other production functions such as quality control and MRP II. Such a system would constitute a fully integrated manufacturing system.

CONCLUSION

The development of integrated computer aided design and manufacturing systems is a long term goal of critical importance to today's industry. Because of its function of converting design data into manufacturing instructions, process planning is an essential ingredient of an integrated manufacturing system. As process planning systems are developed, considerations for their integration into CAD/CAM must be born in mind. Research in this direction shows promise and the integration of design and manufacturing through process planning is an achievable goal.
REFERENCES


Figure 1: ELEMENTS OF AN INTEGRATED MANUFACTURING SYSTEM