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CURRENT TREND IN COMPUTER AIDED PROCESS PLANNING

Authers:

Nafis Ahmad[1], Dr. A.F.M. Anwarul Haque[2], Dr. A. A. Hasin[3]

1. Lecturer, Department of Industrial & Production Engineering, BUET, Dhaka,
2. Professor, Department of Industrial & Production Engineering, BUET, Dhaka,
3. Associate Professor, Department of Industrial & Production Engineering, BUET, Dhaka.

Abstract: CAPP system plays a key role to integrate design and manufacturing or assembly systems properly considering available resources and design constraints. Many CAPP systems have so far been developed. Different researchers adopted different advanced techniques and approaches such as feature or solid model based design, object oriented programming, technological databases, and utilized advanced computing methods including expert system and artificial intelligence. Recently some research areas such as feature recognition or feature extraction from CAD file, application of AI techniques like Genetic Algorithms (GAs), Artificial Neural Network (ANN), Fuzzy logic are gaining more attention among the researchers. Feature recognition improves overall effectiveness of a manufacturing system by eliminating the human involvement between design and process planning. Due to the rapid development of computing technology, AI techniques have been found to be very suitable at different stages of process planning. Poor responses of the current static CAPP systems to the real time shop floor status and dynamic nature of the manufacturing environment made many researchers to develop dynamic CAPP systems. In this paper, a comprehensive overview of the current trend in research works on CAPP is presented, classifying those works into several categories according to their focus.

KEYWORDS : CAPP, CAD

1 INTRODUCTION

An efficient CAPP system has a key role to integrate the design and manufacturing or assembly systems properly considering available resources and design constraints. It has been found that 15% of the process planner's time is spent on technical decision making while remaining time is spent equally between gathering data, calculating and the preparation of documentation [39]. Investigation shows that an efficient CAPP systems could result in a total reduction of the manufacturing cost by up to 30% and time in the manufacturing cycle and the total engineering time could also be reduced by up to 50%[39].

Computer Aided Process Planning (CAPP) is a very old idea. Niebel presented the first idea of using the speed and consistency of computer to assist in the determination of process plans. Despite the early recognition of possibility of extracting operations and processing sequences from the part geometry as described in CAD, computer aided process planning has not been addressed broadly until 1970s. In 1976 two CAPP systems (CAPP and MIPLAN) were developed. Subsequently Wysk (1977) presented a generative system for detailed process selection titled APPAS [3]. Since then CAPP has begun to be widely addressed.

Process planning is first defined by Chang [6] as the function within the manufacturing facility that establishes which processes and parameters are to be used (as well as those machines capable of performing these processes) to convert a work piece to a finished part from its initial form to the final one predetermined in a engineering drawing. Process planning is that facet of manufacturing engineering which covers the translation of engineering design data into the most efficient method of part manufacturing [33]. The society of Manufacturing Engineers defines process planning as "the systematic determination of methods by which a product is to be manufactured, economically and competitively."

Task of process planning involves a series of steps. During manual process thinking, a process planner first reviews an engineering drawing to identify major removable features of the part. The planner then studies the design specifications and compares these specifications with his/her knowledge about the production. The planner can also take help of the available documents to ascertain the ability of producing the design part. Finally based on the shop floor capacity, the process planner may either decide to sub-contract the work or to make the part in-house, which results in the preparation of a list of manufacturing steps to manufacture the part. So process planning activities basically include the following: interpretation of product design data, selection of machining processes, selection of cutting tools, selection of machine tools, determination of setup requirements, sequencing of operations, determination of the production tolerances, determination of the cutting conditions, design of jigs and fixtures, calculation of process times, tool path planning & NC program generation, generation of process route sheets etc.

The manual process planning highly relies on the expertise of a process planner. Though the CAPP uses almost the same steps taken in manual process planning, it requires very short time compared to manual process planning. CAPP optimizes the process planning by using different optimization techniques. Due to the rapid diminishing of experienced process planner in current industry, required shorter product life cycle, the importance of CAD/CAM, the research on CAPP has gained more attention than ever before and has received the highest priority in the recent years.

2 BASIC PROCESS PLANNING SYSTEMS

Since the first CAPP system was developed in the early 1960's, there has been a proliferation of development that leads to various CAPP systems, from research and industrial prototypes to company and commercial packages, being tailored to different planning problems and offering a wealth of different solutions. At present, there are two general approaches to computer aided process planning variant and generative; each one is associated with specific planning techniques. These two approaches are discussed in brief.

2.1 Variant Process Planning (VPP)

It follows the principle that similar parts require similar plans. Therefore, the process requires a human operator to classify a part, input part information, retrieve a similar process plan from a database (which contains the previous process plans), and edit the plan to produce a new variation of the pre-existing process plan. Planning for a new part involves retrieving of an existing plan and modification. In some variant systems parts are grouped into a number of part families, characterized by similarities in manufacturing methods and thus related to group technology.

In comparison to manual process planning, the variant approach is highly advantageous in increasing the information management capabilities. Consequently, complicated activities and decisions require less time and labor. Also procedures can be standardized by incorporating a planner's manufacturing knowledge and structuring it to a company specific needs. Therefore, variant systems can organize and store completed plans and manufacturing knowledge from which process plans can be quickly evaluated.

However, there are difficulties in maintaining consistency in editing practices and adequately inability to accommodate various combinations of geometry, size, precision, material, quality and shop loading. The biggest disadvantage is that the quality of process plan still depends on the knowledge background of a process planner.

2.2 Generative Process Planning (GPP)

Generates process plans utilizes decision logic, formulae, manufacturing rules, geometry based data to determine the processes required to convert the raw materials into finished parts.

It develops new plan for each part based on input about the part's features and attributes. Due to the complexity of this approach a generative CAPP system is more difficult to design and implement than a system based on the variant approach. But a generative CAPP system does not require the aid of a human planner, and can produce plans not belonging to an existing part family. It stores the rules of manufacturing and the equipment capabilities in a computer system. The generative approach is complex and a generative system is difficult to develop.

In comparison, the variant systems are better developed and mature than generative systems; they are suitable for planning processes in mass or large production volumes. For planning discrete processes of manufacturing products of great diversity, generative systems are much more suitable than variant systems. However true generative systems are still to come although the earlier optimistic speculation made by researchers. Most CAPP systems in use now are either variant systems or semi-generative systems (with some planning functions developed with variant approach, others with generative approach).

Proper combination of the two approaches can make an efficient CAPP system. First the system will check whether the process planning is possible for a new part by variant approach. If variant system is unable to identify the part to be of a previous group or family it will use generative technique for process planning. So both the variant and generative process planning approaches need further development in parallel.

3 SOME NEW APPROACHES

In the last two decades huge research work is performed in different research areas in CAPP. These work can be categorized by the types of part involved in these works, like prismatic part [16, 22], cylindrical parts [19, 39], sheet metal [1], foundry [2] and assembly systems [5, 4, 37]. Besides this broad classification, research works can also be categorized on the basis of geometric modeling techniques. Some new ideas are presented here briefly.

Feature-based and Solid Model based Process Planning

Solid Model-based process planning uses solid modeling package to design a 3D part. In feature-based process planning systems a part is designed with design oriented manufacturing feature or a feature extraction/feature recognition system is used to identify part feature and their attributes from the CAD file.

Nasser, El-Gayar and others [28] presented a prototype **solid model based automated process planning system** for integrating CAD and CAM system. In this system a three-dimensional (3D) finished part is built by using a solid modeling package. The primitive (Cylinder, cone, block, wedge, sphere and torus) is used to define the removal volume. This system consists of three major sections: CAD interface, production knowledge, and process planning. The CAD interface includes the finished part drawing. The finished part is built by using the AutoCAD Advanced Modeling Extension (AME) module in a PC. With the AME module, the user can create complex 3D parts and assemblies by using Boolean operations to combine simple shapes. The production knowledge is placed before the process planning procedure, where it accommodates the essential knowledge. It contains information about the machine tools, tools, materials in stock, cutting parameters, and so forth. The process plan is then generated based on recognized solid primitives and production rules

In the **prototype Feature Based Automated Process Planning** (FBAPP) system features are recognized from the removable volume point of view rather than from the design part point of view. The entire process in FBAPP is naturally closer to the thinking of a human process planner. A **feature based** approach for cylindrical surface machining process is developed by Yong et. al[19]. The process involves the following steps: (1) Recognizing form features from the part geometry, (2) converting the form feature into machining volumes (negative features) suitable for turning and milling machining (3) combine them into alternative machining volumes (4) associating machining process classes to each machining volume, and (5) generate precedence relations between these volumes. Then the output is used by a process planning system where process sequence sequences are determined and the assignment to multiple spindles and turrets is made.

For machining various types of pockets efficiently, it is necessary to decompose bulky features of sculpture pockets into thin features. Joo , Cho, and Yun[16] designed a **feature based process planning for sculptured pocket machining**. First the bulky feature of sculptured shape of pocket is segmented into several thin layers and the temporal precedence of the segmented features is constructed; then variable cutting condition is applied to each smaller feature. They found that, if the sculpture shape of pocket is segmented horizontally and vertically and apply variable cutting condition to each feature machining becomes easier.

Interactive and feature blackboard based CAPP is a new approach that complies with the traditional process planning [41]. Human process planner gets familiar with the system very quickly. Plans can be manually edited or completed by knowledge base systems. The architecture of Black board system can be seen as a number of people sitting in front of a blackboard. These people are independent specialists, working together to solve a problem, using the blackboard for developing the solution. Problem solving begins when the problem and initial data are written on the blackboard, looking for an opportunity to apply their expertise to develop the solution. When a specialist finds sufficient information to make a contribution, he records the information on the blackboard, solves a part of the problem and makes new information available for other experts. This process continues until the problem has been solved.

Currently many researches are conducted for the application of object-oriented approach to different research problems [34,40]. **Object oriented process planning** is a logical means for representing the real world components within a manufacturing system. The developer identifies a set of system objects from the problem domain and expresses the operation of the system as an interaction between these objects. The behavior of an object is defined by what an object is capable of doing. The use of Object Oriented Design or Object Oriented Programming for developing of a process planning system provides the tool for addressing the complexity of process planning and the capability to incrementally and functionality as the system matures, thereby permitting the developer creating a complete manufacturing planning system. Object oriented systems are more flexible in terms of making changes and handling the evolution of the system over time. This technique is an efficient means for the representation of the planning knowledge and a means of organizing and encapsulating the functionality of the system with the data it manipulates. This modularity results in a design that can be extended to include additional functionality and address other processes. The design also expands on traditional piece part planning by extending the part model to support planning for end products composed of multiple parts and subassemblies.

4 STATIC AND DYNAMIC PROCESS PLANNING

Different researchers distinguish dynamic process planning from static one in different ways. Usher and Fernandez [35] proposed that the static process plan is concerned with the generation of alternative plans that are generic in that they do not take into account the specifics with respect to the operational status of the shop floor resources. This planning involves the selection of, assignment, and sequencing of the processes and machines that could potentially be used if available. The dynamic planning takes place when a job is released for production to the shop floor. At this time, the macro level plans are retrieved and planning is completed taking into consideration of the availability of the shop floor resources and the objectives specified by the scheduler.

In dynamic process planning system the part design can be evaluated and redesigned based on the manufacturability analysis and the manufacturing processes can be selected efficiently and flexibly exploiting product information provided by part representations. The result of the dynamic process planning is a set of ranked near-optimal alternative plans. Dynamic process planning can deal with both variant and generative process design issues. It can perform manufacturability evaluation and generate the modification or refinement suggestions in different stages of part design. The main feature of this model is the functional integration and information integration [9]. Functional integration means that all functional modules such as part design module, process design module, and manufacturability evaluation module must mutually support each other. Interaction among them should be performed efficiently. Information integration means the system should provide direct access to all necessary information to each functional module during any stage of product or process design. For example, while conducting a product design, the manufacturing resource capability information should be provided to the product design engineer, and during the process design, the design part feature information should be made available to the process design engineer in a similar manner. Second, other functional modules can share information, which originally belongs to a certain module, such as part feature information created by part feature modeling module.

Larsen and Alting [23] express the idea in a different way. They categorized process planning systems into **non-linear, closed-loop** and **distributed process planning** systems. In **non-linear process planning systems**, which generate and rank all possible alternatives, plans for a part prior to production independent of the resource status on the shop floor; then at the time of production, the scheduler works it way through the alternatives until one is found which meet the current constraints of production. **Closed-loop process planning** generates a plan for a job in real-time at the time of production based on the feedback from the shop floor with respect to the status of the resources at that time and **distributed process planning** involves performing planning and scheduling in parallel [42].

5 LINKS BETWEEN CAD AND CAPP

Creating link between CAD and CAPP is one of the most difficult tasks in concurrent design and manufacturing. Without proper interface between CAD and CAPP it is impossible to generate a process plan, which will need least amount of time and cost. Feature recognition or feature extraction is the key to achieve this objective. In mechanical assembly or machining processes a feature is, usually, defined as a set of constituent faces. The geometric information related to a feature is obviously subset of object. In addition to the geometric information, some non-geometric information associated with a feature is also essential for process planning. Feature extraction is categorized into three classes.

- Graph/pattern matching,
- Knowledge based system and
- Geometric decomposition.

In **graph/pattern** matching search technique is used to find the primitives like faces and edges in a part design. From these primitives the graph of the geometric shapes is created. Then the graph is used to identify the features of the part. In the **knowledge based** feature extraction technique expert system rules and techniques are used to extract features from the 3D solid model using the internal boundary representation of the designed part [21]. **Geometric decomposition** includes cell decomposition, convex hull and constructive solid geometry tree rearrangement.

Yong [19] shows how decomposition technique can be used for feature recognition. In his work central Form Feature Decomposition (FFD) is obtained from its boundary geometry by applying convex decomposition, called Alternate Sum of Volumes with Partitioning (ASVP) which uses convex hull and set difference operations. This feature recognition method has important advantages to support automated process planning. Foremostly, interacting features are properly recognized. In addition, outside-in hierarchical relations, face dependency, and accessibility information of features are obtained. The extremality-based, outside-in, geometric hierarchy of the boundary faces of a part is intrinsically important for both material removal oriented part manufacturing process and additive processes such as deposition and assembly operations.

Kakino [25] was the first to develop a part description method on the basis of fundamental concept of converting the drawing information into computer-oriented information for the data structure. The part shape was described by using algebraic construction rules and operation rules in set theory performed on the volumetric element formed by the revolving or parallel movement of the reference surface. Based on Kakino's work Jakubowski used a syntactic manner to describe 2D profile information on 2D machined parts. He applied extended context-free grammars to describe machined parts families and gave a detailed explanation of techniques for parser construction. Chof [25] also outlined the use of syntactic pattern recognition in identifying elementary machine surfaces for process planning in machining centers.

6 AI TECHNIQUES IN CAPP

In the past, traditional computer programs have been used to solve formalized problems, where the statement and principles are well understood. The ill formalized and less-understood problems have led to development of Artificial Intelligence (AI), particularly form of knowledge based systems (KSB) or Expert System (ES). Knowledge based systems developed from the field of artificial intelligence, which in turn is a branch of computer science. AI is developed to attempt to simulate human intelligence in a computer. AI attempts to adapt, learn, invent, and accumulate the combined wisdom of a profession. Currently some AI techniques such as Genetic Algorithms (GAs), Artificial Neural Network (ANN), Fuzzy Logic are widely used for CAPP system [12,36] but Expert System (ES), which is an AI tool, has been used in CAPP system for a long time.

Many ES based CAPP systems have so far been developed and researcher still trying to solve many CAPP problems by ES [8,10,20,39]. Younis et. al [39] discussed how to develop a Expert System for CAPP. They explained the expert system for only rotational components using metal cutting operations, and generative process planning is chosen over variant process planning. The process-planning domain is analyzed in terms of the problem specifications and knowledge characteristics. The expert system is divided into the following main components

a) Knowledge base,
b) Knowledge acquisition mechanism,

c) A recognition/inference mechanism &
d) A user interface mechanism

Expert systems differ from databases in that their knowledge is not simply readable as data, but can also used for solutions of different types of problems. Knowledge is thus distinguished from data in that it is integrated with instructions for its use. For this the division of the knowledge into as many fragments as possible makes a knowledge base more modular. Manufacturing knowledge [41] in a CAPP system is

- The design related manufacturing knowledge- is employed for instance by the CAD expert module, which allows to extract/add process planning information from/to the part design.
- The part process manufacturing knowledge associates the data content of the part model to the process model; it embodies the process selection expert module, which determines the different manufacturing steps to be undertaken on a certain part or feature and the sequencing relationships between those manufacturing steps.
- The resource process manufacturing knowledge associates the data content of the available resources to the process model; it embodies for instance the machine selection expert, which determines the candidate machine tools for the operation on a certain workpiece.
- The resource part manufacturing knowledge relates the part data with the resource data (e.g. selection of a tool/machine is influenced by the dimension of the part)
- Process plan generation knowledge encloses the knowledge that brings all other knowledge sources together.

The **inference engine** accesses the knowledge base and retrieves the rules to be executed from it. It can start from a given data, the actions of the rules whose preconditions are fulfilled by the database are performed. This procedure is repeated until no more rules are applicable. Inference engine can start with a goal; only those rules whose action parts include the goal are checked. If some parameter of preconditions is unknown, they are requested from the user or derived from other rules.

Kryssanov and et. al. [20] discussed a formal method for building CAPP expert system. They considered the usage of logical models for development of a CAPPES building technology. Coppini and Da Costa [10] present a technique to represent the qualitative information provide by mathematical model (e.g. Taylor's equation) and informal knowledge used by experimented practices involved in the selection of machining parameters. This technique is based on production rules associated with constraints. Example of constrains are time, tool life; chip-form disposal; machine power and so on.

Recently **Artificial Neural Network (ANN)** is gaining attention among the researchers. Neural networks are a class of computing systems, which utilize a high parallel architecture. Problem solving tasks, such as process planning, may be considered as pattern classification tasks, which can be efficiently solved by neural network. [36]. The process planner learns mapping between input patterns, consisting of features and attributes of a part, and output patterns, consisting of sequencing of machining operations to apply to these parts. Thus, neural network offers a promising solution for automating of process planning knowledge.

The network consisting of large numbers of simple processing units, which communicate in parallel through weighted connections. Figure 2.1 demonstrates 3-layer perceptron architecture. The first layer is the input layer, whose units take on activations equal to corresponding network input values. The second layer is referred to as a hidden layer, because its outputs are used internally and not considered as output of the network. The final layer is the output layer.

A neural network can be used for the automatic acquisition of process planning knowledge. This approach overcomes the time complexity associated with earlier attempts using machine-learning techniques. The neural network approach uses a single methodology for generating useful inferences, rather than using explicit generalization rules. Because the network only generates inferences as needed for a problem, there is no need to generate and store all possible inference ahead of time. Further research is necessary to automatically recognize the machining features directly from the CAD models.

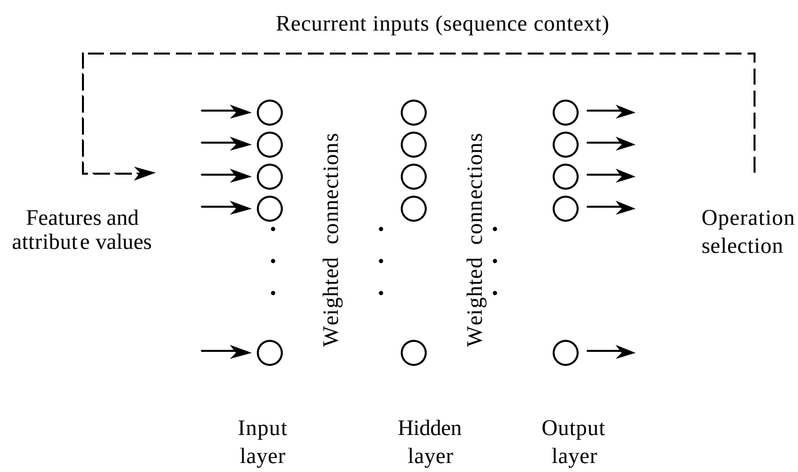

Figure 1: A neural network

7 OPTIMIZATION TECHNIQUES IN CAPP

Optimization of process planning is one of the foremost targets of Manufacturing Systems, since it is believed that only those industries capable of making effective productions would withstand international competition in this millennium. Numbers of research works are performed for generating optimum process plan. The optimum process plan may be on the basis of time or cost or on the basis of some weighted combination of these two. Tool selection, machine selection, process selection and tool path selection, process parameter selection are the most important areas for optimization in process planning.

The **branch-and-bound** technique can be used for solving combinatorial optimization problems for process planning. The combinatorial optimization problems are problems of choosing the best combination out of all possible combinations. Kyoung, Cho, Jun, [12] used branch and bound method for selecting the optimal tool, which minimizes the machine time by using the range of feasible tools and the **breadth-first** search. They applied the technique for pocket machining. They concentrated their work on optimization of selecting tool combinations.

Different researchers used different techniques to optimize process parameters but all of those techniques have their own limitations. **Direct search** methods include function evaluation and comparisons only. **Gradient search** methods need values of function and its derivatives, and their computerizations are also problematic. They are more difficult than the direct search methods, but they can yield more accurate for some computational efforts.

Derivative-based mathematical optimizations are not manageable for optimizing functions of discrete variables. **Dynamic programming** that may be applied to problems whose solution involves a multistage decision process, can handle both continuous and discrete variables. Contrary to many other optimization methods it can yield a global optimum solution. However if the optimization problem involves a large number of independent parameters with a wide range of values (as in the case of optimization of cutting parameters), the use of dynamic programming is limited. As the numbers of variables and constraints increases, the optimum has a tendency to grow flatter with less probability that the realizable optimum will be a mathematical optimum, and hence computational effort increases considerably.

Geometric programming is a useful method that can be used for solving nonlinear problems subject to nonlinear constraints, especially if the objective function to be optimized is a polynomial with fractional and negative exponents, while the constraints may be incorporated in the solution techniques. It is more powerful than other mathematical optimization techniques when the problem is restricted by one or two constraints. However if the degree of difficulty increases, the formulated problem might be more complicated than the original problem. Geometric programming can only handle continuous variables.

The solution to the optimization problems, which includes real value variables, can be obtained using numerous methods. However, each method has its own profit and hindrances. There is no efficient all-purpose optimization method available for nonlinear programming problems. The computational time and cost involved in the determination of optimal parameters commonly depends on the complexity or simplicity of the model. Some models can produce accurate solutions by making rigorous computation, which is not economic in terms of computation time and cost. Sometimes the solution from these models may not be optimal. Some other models may develop solutions far from the optimum in a fast manner. Therefore a compromise between the high accuracy of a rigorous solution and low accuracy of an oversimplified solution should be made.

Genetic Algorithms (GAs) are robust search algorithms that are based on the mechanics of natural selection and natural genetics. They combine the idea of "survival of the fittest" with some of the mechanics of genetics to form a highly effective search algorithm. Genetic algorithms belong to a class of stochastic optimization techniques known as evolutionary algorithms. Among the three major types of evolutionary algorithms (genetic algorithms, evolutionary programming, and evolution strategies) genetic algorithms are the mostly widely used. GAs are most often used for optimization of various systems, especially complex problems such as those involving manufacturing systems analysis.

Dereli, T. and Filiz, H.I [12] explained the application of GA for determination of optimal sequence of machining operations based on either minimum tool change or minimum tool traveling distance or safety. Combination of these criteria also might be used. They also explained how the optimum position of tools on the automatic tool changer or turret magazine of a CNC machine tool is obtained by using GA.

8. CONCLUTION

Many CAPP systems have so far been developed and commercialized. New systems adopt many advanced techniques and approaches such as feature-based modeling, object oriented programming, effective graphical user interfaces, technological databases and utilize advanced computing methods including expert system and artificial intelligence. But the implementation of CAPP systems in industry lags behind the rate of development of new systems and introduction of new ideas in the field. Though tremendous effort has been made in developing CAPP systems, the effectiveness of these systems is not fully satisfactory. CAPP as the main element in the integration of design and production has not kept pace with the development of CAD and CAM. This situation has made process planning a bottleneck in the manufacturing process. In spite of the benefit promised by the various developed CAPP systems, their adaptation by industry is painfully slow. Today, when companies use CAPP systems, it is mostly done in isolation from the product design as well as the production planning and control activities. Design of a part is generally done in the CAD environment. So it is necessary to create link between CAD and CAPP where a two-way interaction will exist between design and process planning. It is no longer sufficient to ensure an effective flow of information from design to process planning to provide the data and knowledge necessary for creating an effective process plan. It is also becoming increasingly essential to feedback information from process planning to assist the designer at an early stage in assigning various design features not only from functional point of view but also regarding manufacturability because a large percentage of product cost is committed once its features, materials, tolerance and surface quality parameters have been selected at the design stage. Dynamic process planning which is one of the key areas for research and development, will integrate design and manufacturing and reduce the total product development time by facilitating two-way interaction between design and process planning.

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