1

Introduction to Process Planning

1.1 Introduction

Manufacturing process planning involves figuring out the best way to make a product or component, from choosing the right materials and methods to determining the most efficient sequence of steps. The main goal of manufacturing process planning is to optimize the production process, making it cost-effective while ensuring high-quality results. In small manufacturing companies, process planning is still conducted by manual methods that rely on experienced process planners who apply their knowledge in design and manufacturing to produce efficient and cost-effective process plans. More advanced manufacturing companies may utilize computer-aided process-planning (CAPP) systems to help in process-planning activities, saving money, and making more efficient process plans.

In this chapter, an overview of the manufacturing process-planning activities is presented, and the importance of these activities and the communication between design and manufacturing departments is highlighted to ensure competitive products in shorter lead times. The chapter briefly describes CAPP methods, whereas the manual methods are just schematically presented since this method is covered in detail throughout this book.

1.2 Process Planning Within Product Development Cycle

Process planning is the deliberate selection of the techniques needed to make a product affordable and competitive. Procedures, machine tools, and other equipment must be devised, chosen, and determined to transform raw materials into finished and assembled goods.

Process planning may be also considered as a bridge between product design and manufacturing, as illustrated in Figure 1.1. The initial steps of process planning coincide with the product design phase, involving decisions such as material selection and manufacturing methods such as casting, forging, or die casting. The formal endpoint for product design is marked by the release of all product data, usually in the form of three-dimensional (3D) models and engineering drawings, which specify the precise product details. At this juncture, process planning takes charge, outlining the comprehensive manufacturing plan for each component of the product.

Manufacturing Process Planning: A Practical Approach for Mechanical Engineering, First Edition.
José V. Abellán-Nebot, Carlos Vila Pastor, and Héctor R. Siller.

Companion website: www.wiley.com/go/Manufacturing_Process_Planning_1e

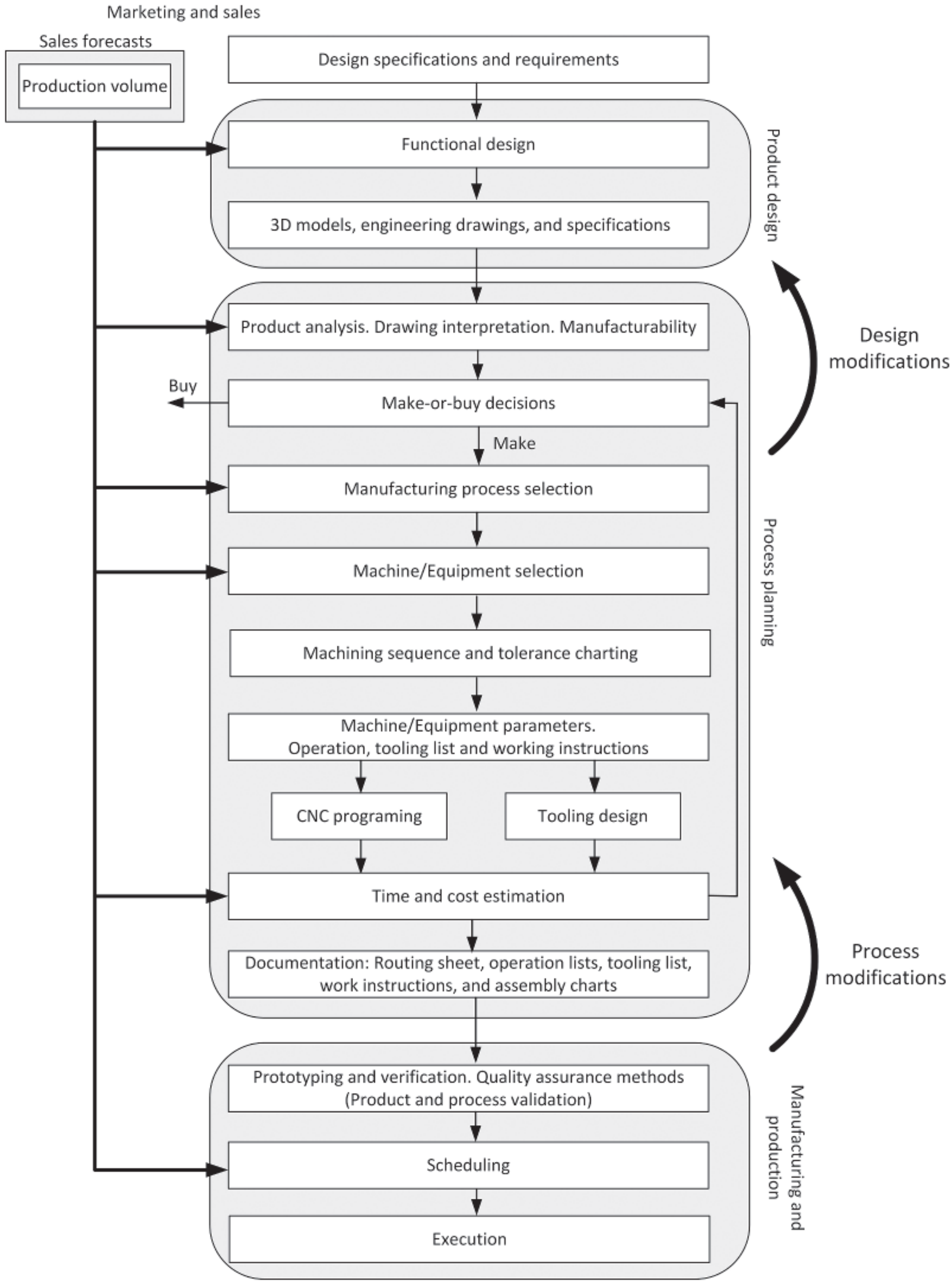

Figure 1.1 Traditional process planning deployment where machining operations are involved.

Process planning derives its input from 3D models or engineering drawings that detail what needs to be produced and in what quantity. These drawings are carefully scrutinized to determine the project's overall scope. For complex assembled products, considerable effort may be invested in breaking down the product into its constituent parts and subassemblies. Initial decisions regarding subassembly groupings, such as whether to manufacture certain parts or purchase them, as well as determining the general tooling requirements, may also be made. Subsequently, a detailed routing plan is developed for each part, requiring technical expertise in processes, machinery, and production economics. In essence, process planning translates the engineering drawing of a component into a group of manufacturing process steps, leading to the creation of a route sheet, which outlines the sequence of operations necessary for the component. The term "route sheet" is used because it also specifies the machines through which the part must pass to complete the sequence of operations (Kesavan 2009).

In the context of product design and manufacturing on a global scale, three key functions are involved: marketing and sales, design, and manufacturing. These functions traditionally follow a sequential process. Marketing assesses the contemporary market trends and requirements, creating new product concepts based on its findings. It also formulates specifications for the further enhancement of existing products, guided by market assessments. The design function utilizes these product concepts and specifications from marketing, providing a comprehensive overview of all parts and subassemblies required for the final product. This includes detailed 3D models, drawings, assembly plans, and bills of materials. The product requirements determined during the design phase are then assigned to the process-planning team. This information serves as the basis for creating detailed work instructions needed for production, defining, in case the part should be manufactured in-house, the manufacturing processes, the machine/equipment needed, tooling requirements, etc. These instructions are transferred to the manufacturing facility for production, as depicted in Figure 1.1.

Consequently, even though the design and manufacturing departments operate independently, the process-planning activity serves as a connection between them, following a sequential approach. This sequential approach, traditionally utilized in product design and manufacturing, assumes a lengthy lifespan for the product with a consistent demand over an extended period. However, in current competitive global markets, this assumption often does not hold true. As a result, manufacturing organizations have explored ways to reduce the time required for product design and manufacturing, commonly known as time to market. Some organizations have prioritized organizational changes with the intention of forcing all the stakeholders to be involved in the whole product development cycle and fostering cross-functional collaboration to expedite the design and manufacturing processes of their products. This method, based on the collaboration of cross-functional teams, is commonly known as concurrent engineering. However, it can be found with other terms such as simultaneous engineering or integrated product development.

Unlike a sequential approach, commonly referred to as "over-the-wall engineering" since no bidirectional communication exists to ensure product performance and manufacturability, concurrent engineering can be seen as a cooperative approach where members from all stages are in continuous communication to improve product design and facilitate the subsequent stages of production (Figure 1.2). Some activities that may be found under a concurrent engineering approach are listed in the following:

- Collaborate in the definition of product design specifications.
- Choose the best design and manufacturing techniques to employ.
- Propose modifications of geometrical specifications or relaxation of tolerances.
- Evaluate the design's manufacturability and modify it accordingly.
- Evaluate the assembly of the design to detect potential assembly issues and improvements.

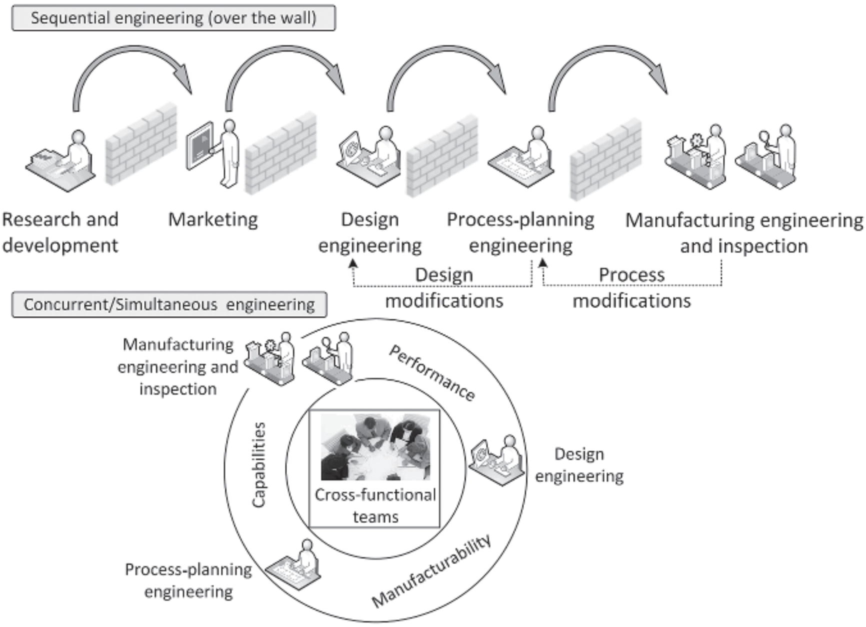

Figure 1.2 Sequential engineering versus concurrent engineering.

Besides reducing time to market, the main benefits of applying concurrent engineering are reducing cost and increasing product quality and productivity. However, managing concurrent engineering is challenging, and it requires the commitment of all stakeholders, and very often some of them are reticent to multidisciplinary collaboration.

Regarding product and production costs, it is important to note that approximately 70% of the total cost of a product is determined during the design phase (Ullman 1992). However, some studies reduce this impact to 47% on average (Ulrich and Pearson 1993). This cost allocation is primarily influenced by material selection and the associated manufacturing methods. The remaining 30% is attributed to decisions made regarding the manufacturing process, such as the utilization of production equipment and tooling. Additionally, it is widely recognized that any modifications made to the product during later stages have a greater impact on production costs compared to earlier stages, and the time required to implement such changes is longer. Figure 1.3 shows the impact of product design on product cost and production cost in common manufacturing companies.

Due to these reasons, concurrent engineering should be considered a widespread practice within manufacturing companies to minimize lead times and decrease the overall costs associated with the final product.

1.3 Process-Planning Levels of Detail and Activities

As stated earlier, process planning seeks to completely define the manufacturing processes, tools, process parameters, inspection methods, etc., required to manufacture a product according to the 3D models and technical drawings from the design office. Process planning can be conducted at different levels of detail defining four different types of process planning (ElMaraghy and Nassehi 2014): generic planning, macroplanning, detailed planning, and microplanning.

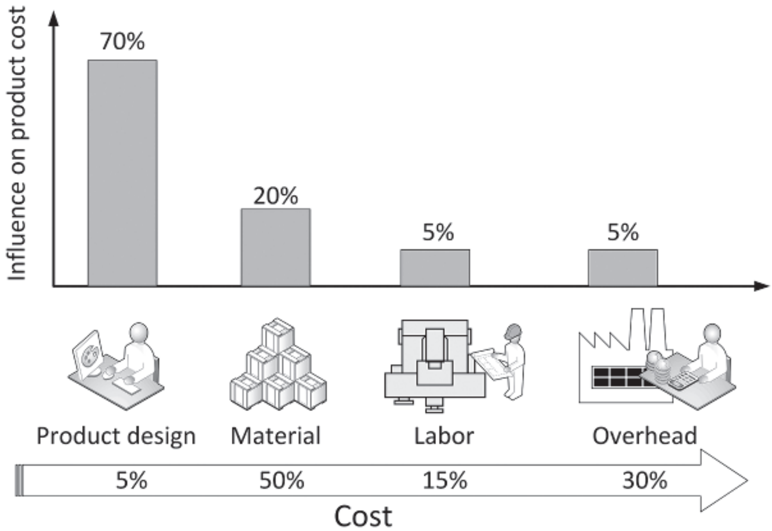

Figure 1.3 Impact of product design on product cost and production cost in common manufacturing companies. *Source:* Adapted from Munro and Associates (1989).

Generic planning refers to rough process planning where only manufacturing process selection is conducted according to material, production volume, process capabilities, and cost. Macroplanning details the equipment selection related to manufacturing, assembly, and inspection, and defines the routing sheets, a document that shows the route of each part with the stations and equipment involved at each step. Detailed planning refers to specific information at each station about the sequence of operations, tooling, fixtures, etc. Finally, microplanning describes process and operation parameters, NC programs, inspection procedures (conformity zones, sampling strategy, etc.), working instructions, calculation of overall times and costs, etc., which ends with the documentation of operation sheets. Although a first analysis for a new product development starts with generic planning, a final microplanning will be required before production.

Many different process-planning activities are required depending on the level of detail needed. For a complete process planning before production, the following activities are commonly conducted:

1.3.1 Interpretation of Product Design Data and Manufacturability

The initial stage in developing a process plan for any component involves referring to the product design data, mainly in the form of 3D models and engineering drawings. Interpreting the product data involves analyzing the part's geometry, dimensions, and correlated dimensional and geometric tolerances, as well as surface finish conditions and material specifications. Production information about lead time and production volume is also gathered.

A key analysis to be conducted at this step is a manufacturability analysis. Process planners should evaluate and propose design modifications that may reduce manufacturing costs and time. Practices related to design for manufacturing (DFM) and design for assembly (DFA) are applied for this purpose, and modification or relaxation of geometrical specifications and tolerances are also studied and shared with the design team.

1.3.2 Bill of Materials Analysis and Make-or-Buy Decision

Given the final 3D models and technical drawings, all components of the product are analyzed to decide which parts are going to be purchased from the market and which ones are going to be manufactured in-house. Typically, if the part can be produced in-house, a cost comparison between making versus buying is done. Assumptions are often required regarding factors such as expected capacity, demand patterns, waste, inventory levels, and fluctuations in material availability and affordability. After the make-or-purchase decisions are made, the bill of materials for the product is defined, including the make-or-buy nature.

1.3.3 Manufacturing Process Evaluation and Selection

After analyzing the technical drawings and deciding which parts are being manufactured in-house, process planners can start to evaluate which manufacturing processes are more appropriate for producing the parts.

At this stage, the part material highly determines the manufacturing process selection. Thus, the process planner may engage in meaningful discussions with design engineers to reconsider the material selection. For example, some alloys are well-suitable for casting or machining processes but are less adequate for forming processes. Note that these discussions are typically conducted at the design stage when cross-functional teams work together.

Manufacturing process selection requires identifying both primary processes (e.g., casting, forging, rolling, extrusion, drawing, and bending) and secondary processes (e.g., machining, surface finishing, and joining/assembly processes) that are required for reaching part specifications under the constraints of production volume and production rate identified. For example, every manufacturing process and equipment possesses inherent capabilities when it comes to achieving a certain surface quality. Therefore, any process or machinery that cannot meet the specified surface quality requirements would either be eliminated beforehand in the selection process, or additional finishing operations would need to be incorporated.

Therefore, after analyzing the technical drawings, materials, and production requirements, a list of potential processes can be compiled. Those candidates that can be applied to fulfill part and production requirements are then compared in terms of cost to ultimately identify the best manufacturing processes. At this step, early cost estimation tools are applied to assist in the final manufacturing process selection. After the selection of appropriate manufacturing processes, the raw material size for producing the part, including its size and any specific requirements such as heat treatment, are also defined.

1.3.4 Selection of Machines and Equipment

The next stage, once the process planner has decided which manufacturing methods to use, is to choose the right equipment, taking availability, process capability, production range, and cost into account. Factors such as the size and weight of the components being produced, the physical dimensions of the machinery, tooling availability, setup and production costs, and any limitations in terms of power and force are relevant aspects of the final equipment selection.

1.3.5 Machining Sequence and Tolerance Charting

After selecting manufacturing processes, machines, and equipment, the process sequence is defined. When secondary machining operations are needed, the machining sequence should be analyzed in detail to avoid excessive manufacturing tolerance accumulation that may produce parts out of specifications. Machining sequence diagrams and tolerance charts facilitate the definition of proper machining sequences to ensure part specifications.

1.3.6 Selection of Operation and Process Parameters

After selecting the machines and the sequence of operations to be conducted, it becomes necessary to define specific parameters for each operation on each machine. When dealing with casting or plastic deformation machinery, temperatures, cycle time, speeds, etc., are critical parameters. In the case of machining equipment, cutting tools should be selected depending on the geometry to be machined, the material of the workpiece, and the quality and capability requirements. Additionally, cutting parameters should be defined together with cutting strategies and cutting tool paths. Machining handbooks and cutting data recommendations from tool manufacturers are used for this purpose. It is possible to calculate the amount of nonvalue-added time (such as handling and setup) and operation time needed for each operation based on the process parameters. This facilitates the compilation of the total time needed for the job for a later cost estimation.

1.3.7 Tooling Design

Tools, dies/molds, and workholding systems are also defined for each processing step, and if specific fixtures are needed, a fixture design activity is conducted. For instance, in casting, patterns and molds must be designed. In the case of machining operations, the process planner analyzes the workpiece and the final part to determine the appropriate workholding devices. If a fixture or jig is required for a specific operation and the location and clamping conditions have been identified, this information is typically passed on to a specialized fixturing developer. Based on these requirements, the fixturing specialist generates detailed drawings and a general arrangement drawing of the workholding device to be designed and fabricated. In many cases, this may involve modifying an existing design or utilizing standardized components (Scallan 2003).

1.3.8 Time and Cost Estimation

Estimating cycle times and related expenses for the process plan is another responsibility of the process planners. This involves forecasting manufacturing costs and lead times associated with creating a component or product based on historical data or standard data from handbooks. Unlike early cost estimates at the manufacturing process selection step, a more detailed estimation is conducted now since data about the specific equipment used, the process and operation parameters, and inspection procedures have already been defined. At this step, an accurate manufacturing cost estimation is crucial for determining the unit cost and assessing the product's success. This estimation may result in changes in batch size considerations or whether to produce or purchase a particular product or component that was not clearly identified at the first steps of process planning.

1.3.9 Documentation and Communication

Documents are created and shared with the design and manufacturing departments as a part of the different preceding activities conducted. Basically, process-planning documentation presents the methods, sequence of tasks, parameters, time, and workforce required for manufacturing a product and they should clearly identify the version of the document, date, and the person in charge.

At the generic and macroplanning level, assembly charts, operation charts, and routing sheets are defined. The assembly and operation process charts graphically show the sequence of operations (assembly, manufacturing, or inspection operations) that are necessary to produce a product and it shows the equipment and time required at each operation. In a similar vein, routing sheets provide a tabular overview of the raw materials' journey through the manufacturing process. A list of the production tools and equipment that will be used is usually included. Routing sheets are typically used to accompany materials as they move around the production shop floor, giving operators pertinent information at every turn.

At detailed and microplanning levels, operation lists, tooling lists, work instruction sheets, and inspection sheets are defined. The operation list shows a detailed plan for every operation defined in the routing sheet, including information about operation and process parameters such as feeds and speeds in case of machine tools, setup procedures, and operation times. The tooling list serves the purpose of providing a comprehensive specification for all necessary tooling across various operations. For specific activities, work instruction sheets may be provided to offer supplementary information that is not covered in the operation or process sheets, providing additional details for the tasks at hand. Finally, inspection sheets and quality reports present comprehensive instructions and procedures for examining and measuring crucial quality attributes. If there is a need to collect and record specific quality data for statistical process control (SPC) analysis, an inspection or quality report is required.

1.3.10 Selection of Quality Assurance Methods

Process planners should determine the quality assurance methods at the product and process validation stage and at the production stage in collaboration with quality engineers. Inspection stages or in-process inspection measurements, sampling plans, the instruments required, and the conformity zones are defined for all critical product specifications. It is crucial to achieve a compromise between guaranteeing product quality and avoiding excessive inspection tasks, which would extend the processing time and increase the total manufacturing cost (Scallan 2003).

1.4 Technical Data Required for Process Planning

Process planning requires dealing with reliable information about product design, manufacturing capabilities, equipment capacities, manufacturing process parameters, etc. In general, the following sources of information should be available during process planning (Adithan 2007):

- Process plans of selected universal parts or other process plans from previous products that could serve as a good starting point.
- Product data and engineering drawings pertaining to each product component. For example, component drawings, product specifications, requirements, and a bill of materials outlining the quantity of each component used in the product.
- Design data handbooks (charts of limits, fits and tolerances, material properties, etc.).
- Manufacturing process capabilities and material–process compatibility matrices for process selection.
- Machinery data handbooks (tables of process parameters for different manufacturing conditions and different work materials).
- Cutting data from vendors of machining tools and inserts.
- Specifications of machines available on the shop floor (e.g., for machine tools: travel, spindle and motor power ratings, working dimensions, etc.).

- Machine hourly rate for all equipment available in the shop.
- Tables of standard costs related to manufacturing processes, materials, operators, etc.
- Tables of defining inspection sampling plans.

1.5 Process-Planning Methods

Process planning can be classified into two primary methods: manual process planning and computer assisted planning (CAPP). Expert engineers carry out manual process planning, taking their time to study and develop a workable plan based on the shop floor's existing tools and equipment. CAPP approaches can be grouped into variant CAPP or generative CAPP, and both seek to reduce or avoid relying on expert process planners, saving time and cost along process-planning activities. While manual process planning is most suitable for small shops that cannot afford the cost and implementation of CAPP systems, large companies with a wide variety of product geometries to be manufactured in-house can take advantage of using these computer-aided tools.

1.5.1 Manual Planning Methods

In manual process planning, all the activities shown in Figure 1.1 are conducted by experienced process planners. The most relevant tasks are listed in the following:

1) The process planner chooses the best manufacturing processes for producing the component by looking at the technical drawing, applying their manufacturing experience, and being aware of the available resources. They also choose the size and shape of the material to be utilized, frequently based on designs that have already been created for related elements.
2) The process planner determines the manufacturing parameters for each operation conducted at each manufacturing process. For machine tools operations, it is determined the tools, feeds, and speeds for a particular workpiece material. To ascertain the scheduled times for each handling and machining step involved, they also refer to manuals and standard data. The setup time and time per unit quantity for each activity are then determined using these time estimates.
3) All the relevant information from step 1 is documented in the routing sheet. This sheet provides a comprehensive list of all the operations. For each operation, an operations list is defined by specifying all the details mentioned in step 2.

The manual process-planning method is usually based on preset workflows for workpiece types that are often manufactured on the shop floor. After analyzing the drawing and identifying the required production processes, the process planner can choose and appropriately modify the corresponding preset sequence of activities.

1.5.2 Computer-Aided Process Planning

Process planning is still mostly a knowledge-intensive manual operation carried out by skilled engineers, but there have been numerous attempts to use computer tools to automate process-planning tasks. The primary application of CAPP systems is found in machining processes, where the most crucial tasks that significantly influence production cost, total time, and manufacturability are setup planning and sequencing of operations.

The CAPP systems let process planners generate manufacturing process plans with the aid of advanced computer software. CAPP systems are known to be more efficient than manual approaches and their main advantages are as follows:

- Automation and efficiency. Manufacturing plan generation time and effort can be greatly decreased by using CAPP technologies to automate process-planning operations. Moreover, the process planner's expertise and experience are less important to the process-planning process.
- Optimization and cost reduction. The software can perform optimization algorithms to identify process plans that minimize production time, reduce costs, or optimize other specified objectives. It considers various factors (e.g., time, cost, or quality) and constraints to find the best possible solution.
- Flexibility and adaptability. The software can easily adapt the process plans to changes in product designs or manufacturing requirements. It can quickly generate new process plans based on updated inputs, allowing manufacturers to respond to changes efficiently.

There are two principal approaches when dealing with CAPP systems: the variant approach and the generative approach.

1.5.2.1 Variant Approach

In CAPP systems, the variant approach, also known as the retrieval method, refers to CAPP systems that obtain a standard plan from a database and adapt it to fit a specific part. Typically, a coding system and a group technology (GT) classification are used to organize the parts based on their geometrical and manufacturing characteristics. This coding scheme uses a string of alphanumeric characters to stand for particular attributes shared by all parts or products in the part family.

The Opitz coding system (13 digits), MICLASS (12 digits), KK3 system (21 digits), and DCLASS (8 digits) are examples of typical GT coding systems. One of the most widely used GT coding schemes in manufacturing companies is the Opitz system, which consists of 13 numbers categorized into three groups. First to fifth digit codes are named form codes, and they are used to describe the geometrical attributes of the part. The sixth to ninth digit codes are supplementary codes that provide relevant information to manufacturing such as raw material shape, material, etc. The latter group of digits, tenth to thirteenth digits, are secondary codes that give information about production processes and production sequences. Figures 1.4 and 1.5 show the possible values and the corresponding explanation for the form and supplementary codes. As it can be observed, increasing the value of the digit in the form codes means a more complex part. If a component has several features in the same code digit, the value of the feature with higher complexity is chosen. For the secondary codes, they can be defined specifically according to the company's needs. An example of using the Opitz coding system is shown in Figure 1.6.

The variant process planning has two operational stages, a preparatory stage and a production stage (Chryssolouris 2013). The preparatory stage involves the following tasks (Figure 1.7):

1) Part classification. The first step is to apply GT to classify parts into groups based on their similarities in terms of shape, size, function, and manufacturing requirements.
2) Group formation. Once parts are classified into families and their process plans have been added to the system, the next step is to form groups based on the similarity of manufacturing processes required to produce those parts. Parts within the same family often share similar machining operations, tooling requirements, and production methods. By forming groups, CAPP can leverage the similarities to design standardized process plans for each group.

Code	Digit 1	Digit 1: Part Class	Digit 2	Digit 2	Digit 2: External shape, external shape elements	Digit 3	Digit 3: Internal shape, internal shape elements	Digit 4: Plane-Surface Machining	Digit 5	Digit 5: Auxiliary holes and Gear teeth
0	Rotational parts	L/D ≤ 0.5			Smooth, no shape elements		No hole, no breakthrough	No Surface machining	No gear Teeth	No auxiliary hole
1	Rotational parts	0.5 < L/D < 3	Stepped to one end		No Shape elements	Smooth or stepped to one end	No Shape elements	Surface Plane and/or curved in one direction, external	No gear Teeth	Axial, not on pitch circle diameter
2	Rotational parts	L/D ≥ 3	Stepped to one end	or smooth	Thread	Smooth or stepped to one end	Thread	External Plane Surface related by Graduation around a circle	No gear Teeth	Axial, on pitch circle diameter
3	Rotational parts	With deviation L/D < 2	Stepped to one end	or smooth	Functional Groove	Smooth or stepped to one end	Functional Groove	External Groove and/or slot	No gear Teeth	Radial, not on pitch circle diameter
4	Rotational parts	With deviation L/D > 2	Stepped to both ends		No Shape elements	Stepped to both ends	No Shape elements	External Spline (polygon)	No gear Teeth	Axial and/or radial and/or other direction
5	Rotational parts	Special	Stepped to both ends		Thread	Stepped to both ends	Thread	Internal Plane/Surface and/or slot, external spline	No gear Teeth	Axial and/or radial on PCD and/or other direction
6	Non-rotational parts	A/B ≤ 3 A/C ≥ 4	Stepped to both ends		Functional Groove	Stepped to both ends	Functional Groove	Internal Plane/Surface and/or slot	With gear Teeth	Spur Gear teeth
7	Non-rotational parts	A/B > 3			Functional cone		Functional cone	Internal Spline (polygon)	With gear Teeth	Bevel Gear Teeth
8	Non-rotational parts	A/B ≤ 3 A/C < 4			Operating thread		Operating thread	Internal and External polygon, groove and/or slot	With gear Teeth	Other Gear Teeth
9	Non-rotational parts	Special			All others		All others	All others		All others

Figure 1.4 Explanation of the form codes (digits 1–5) in the Opitz coding system. *Source:* Opitz (1970)/with permission of Elsevier.

Digit 6		Digit 7		Digit 8		Digit 9	
Dimension D (rotational part) or part length A (nonrotational) (mm)		Material		Initial form		Accuracy in coded digits	
0	≤20	0	Cast iron	0	Round bar, black	0	No accuracy higher than IT7
1	>20 ≤50	1	Modullar cast iron Malleable cast iron	1	Round bar, bright drawn	1	2
2	>50 ≤100	2	Mild steel (not heat treated)	2	Bar: triangular, square, and hexagonal	2	3
3	>100 ≤160	3	Hard steel	3	Tubing	3	4
4	>160 ≤250	4	Mild and hard steel (heat treated)	4	Angle, U-, T-, and similar sections	4	5
5	>250 ≤400	5	Alloy steel	5	Sheet	5	2 and 3
6	>400 ≤600	6	Alloy steel heat treated	6	Plate and slab	6	2 and 4
7	>600 ≤1,000	7	Nonferrous metal	7	Cast and forge component	7	2 and 5
8	>1,000 ≤2,000	8	Light alloy	8	Welded assembly	8	3 and 4
9	>2,000	9	Other materials	9	Premachined components	9	2, 3, 4 and 5

Figure 1.5 Explanation of the supplementary codes in the Opitz coding system. Digit 9 identifies which form codes (digits 1–5) require higher accuracy than IT7. *Source:* Opitz (1970)/with permission of Elsevier.

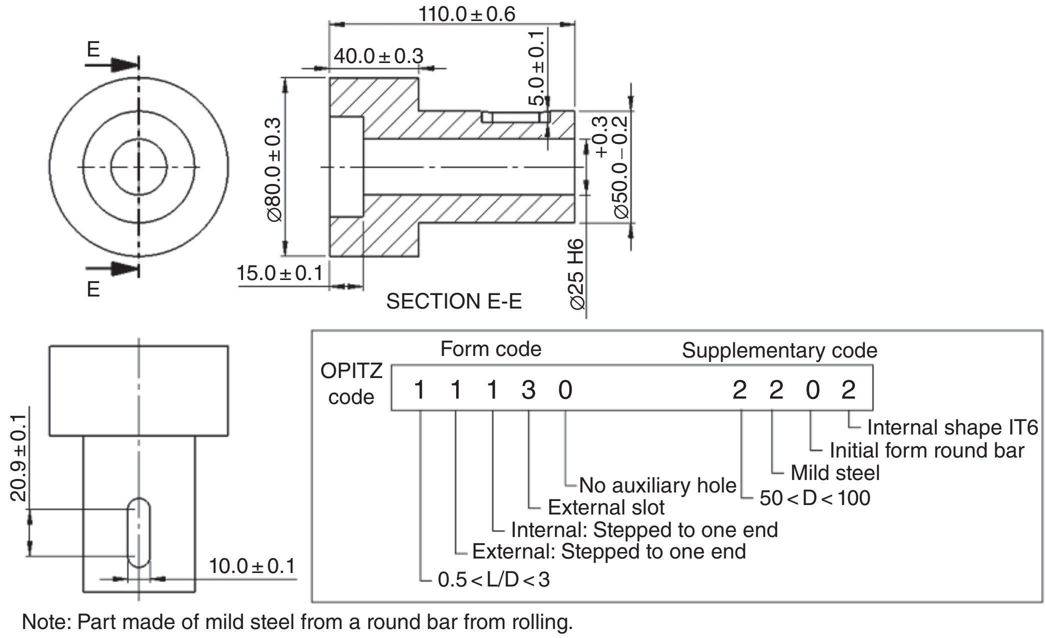

Figure 1.6 Example of application of the Opitz coding system.

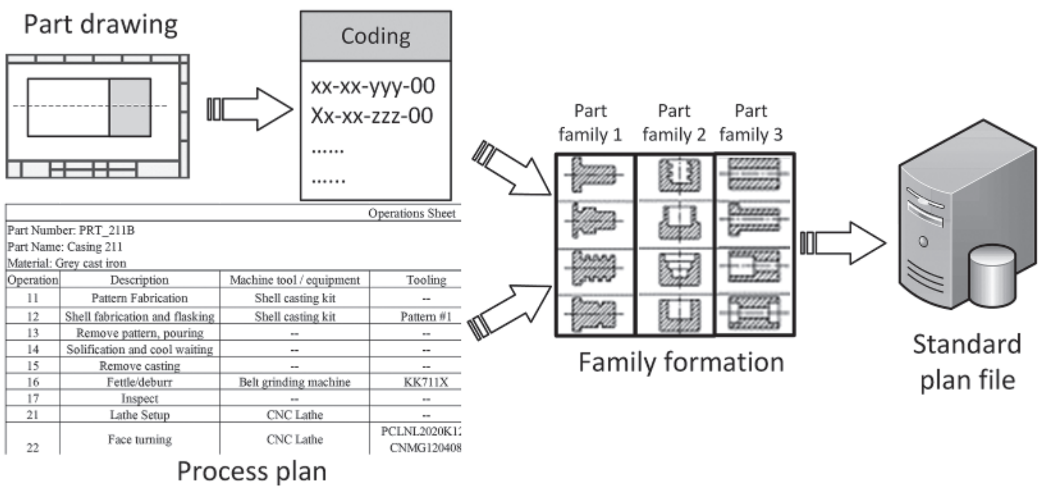

Figure 1.7 Preparatory stage of CAPP variant approach. *Source:* Adapted from Chryssolouris (2013).

3) Creation of process-planning templates. For each part group, process-planning templates or standard process plans are created based on previous process plans. These templates define the sequence of manufacturing operations, tooling requirements, machining parameters, inspection points, and any other relevant information needed to produce the parts in that group. The templates serve as a guide for generating specific process plans for individual parts within the group.

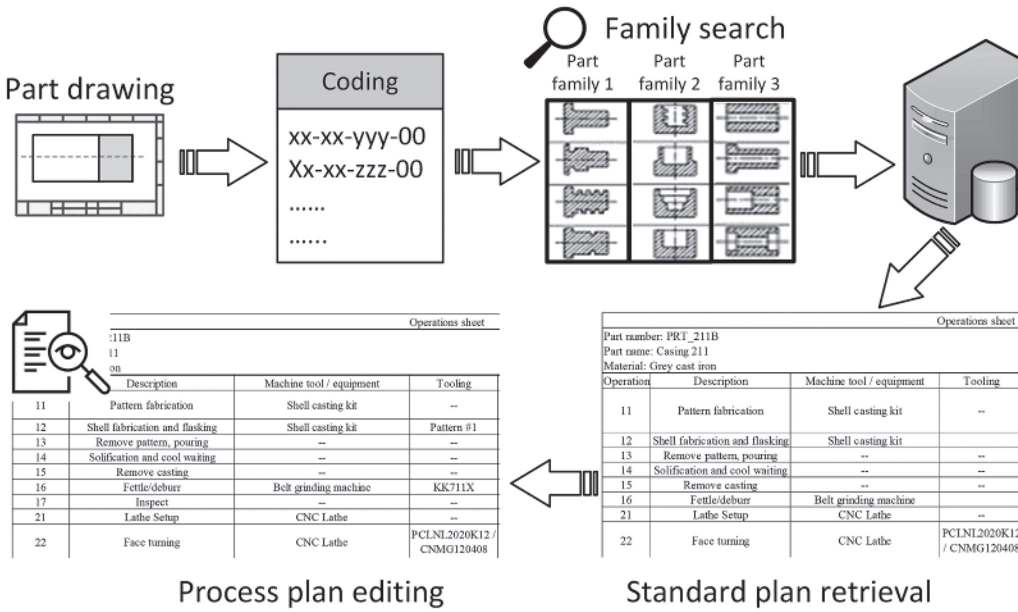

Figure 1.8 Production stage of CAPP variant approach. *Source:* Adapted from Chryssolouris (2013).

The second stage is named the production stage and it involves coding and classifying new components so the CAPP system identifies the part's family and selects the corresponding process-planning template. The system then customizes the template to the specific requirements of the individual part, considering any unique features or tolerances. This customization results in a variant process plan that is specific to the particular part while still benefiting from the standardized processes of its group (Figure 1.8).

The primary benefits of a CAPP based on the variant approach are that the process planner has control over the final process plan and that they are comparatively easier to use and comprehend than those based on the generative approach. They may be a very useful tool for helping to organize and support process-planning efforts. Variant CAPP systems, however, are limited to planning components that are very similar to those that have already been planned. Process planners still need to examine and modify the standard plan for the component.

1.5.2.2 Generative Approach

The foundation of this CAPP approach is starting from scratch with each component and developing a new process plan. Because of this, this system does not make use of items that have been already manufactured; instead, it combines product and process data to construct a process plan automatically for a new component. These plans are produced by computer software using formulas, algorithms, decision logic, and geometric analysis. CAPP systems use automatic feature identification algorithms to classify features and propose the best manufacturing operations. For instance, in the machining process planning different setups and machining sequences may be defined according to the features identified, their tool access directions, and the datum surfaces available. In accordance with machining practices, the CAPP system defines machining sequencing based on knowledge-focused reasoning rules and heuristics.

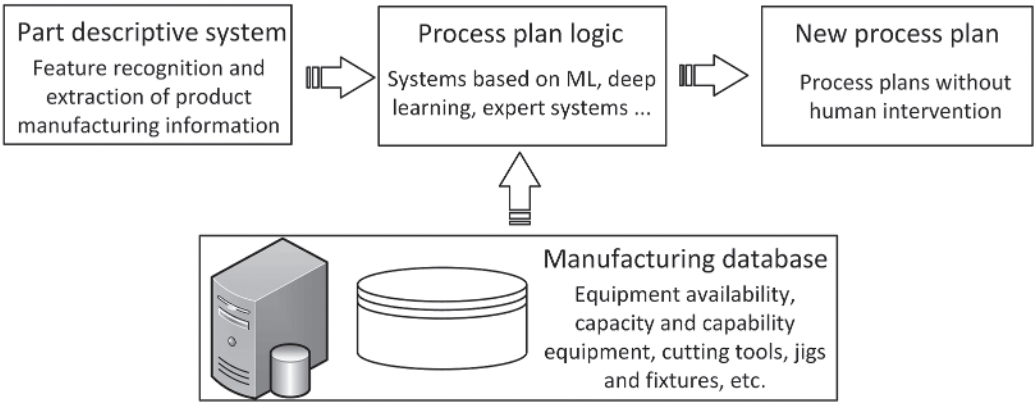

Figure 1.9 CAPP generative approach.

The major components that define a generative CAPP software are shown in Figure 1.9 and are defined as (Scallan 2003):

- A part-based system that defines the material and geometry, including geometric and dimensional tolerances and surface quality specifications. This system interprets the product manufacturing information (PMI) annotations from CAD models and conducts feature recognition processes to completely describe each component of the product.
- A database of information on the manufacturing machinery accessible and their capacities and capabilities.
- A subsystem that detects and sequences the operations and the required process parameters based on the part description and available equipment. This is the core of the generative CAPP system, and it relies on advanced algorithms based on expert systems or other techniques.
- A report generator to create the process plan.

Generative process planning often incorporates knowledge and rules from domain experts, which are encoded into the software. This CAPP approach applies advanced computer methods to automate and optimize the process-planning tasks. Theoretically, human intervention is not necessary for generative CAPP solutions. However, this is rarely the case because most systems need some kind of assistance. In fact, most CAPP works are not easily scalable to other processes, according to recent surveys, and no completely generative CAPP systems have been implemented yet (Al-wswasi et al. 2018).

The specific computer methods used in generative CAPP software solutions can vary and it depends on the complexity of the manufacturing processes, available data, desired optimization objectives, and the specific requirements of the industry. Some of these advanced computer methods are discussed as follows:

- Expert systems. Expert systems utilize rule-based reasoning to capture the knowledge and expertise of human process-planning experts. These systems encode domain-specific rules, best practices, and heuristics into an inference engine, which can generate process plans based on input parameters and constraints.
- Machine learning (ML). ML algorithms are commonly used in generative CAPP to analyze historical process-planning data and learn patterns, relationships, and rules from the data. This learned knowledge can then be used to generate new process plans based on similar input data.

- Deep learning approaches. Neural networks, particularly deep learning architectures, can be used in generative CAPP to analyze and interpret complex data, such as product designs or manufacturing parameters. Neural networks can learn from large datasets and generate process plans based on the learned patterns and relationships. They can be employed for tasks such as feature recognition, process optimization, or decision-making in generative CAPP.
- Constraint programming. Constraint programming is a technique that models and solves problems by defining constraints and finding solutions that satisfy those constraints. In generative CAPP, constraint programming can define and enforce various manufacturing constraints, such as material availability, tooling constraints, machine capabilities, and process sequencing requirements. It helps generate feasible process plans under different types of constraints.

Questions and Exercises

1 What is process planning?

2 What is the meaning of "concurrent engineering" and why is important in process planning?

3 Explain the impact of product design on production cost and the final product cost.

4 Enumerate the process-planning activities commonly carried out in the manufacturing industry.

5 Describe the different levels of process planning according to the details of the process planning.

6 What is the difference between the routing sheet and the operation list sheet?

7 Which are the most common process-planning methods? Describe them briefly.

8 Explain the main CAPP methods in industry.

9 Explain the main advantages of applying CAPP methods in industry.

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