Chapter 6: Information Models used in the IPPPIS

Manufacturing domain knowledge in the various departments, systems and processes are to be systematically modeled to come out with the concurrent design of product and process in the machine tool manufacturing company. This chapter explains the systematic information modeling of the IPPPIS developed with its various components, namely, process planning model, manufacturing activity model, manufacturing resource model etc., by making use of different modeling techniques discussed in the previous chapter. Integration of these components in the IPPPIS will help organization to achieve the integrated product development. In the concluding part of this chapter details of the manufacturing cost and time estimation model and methods are given.

6.1 Information Exchange between Preliminary Design and Preliminary Process Planning

It is not sufficient only to transfer the design information to process planning. It has become essential to feed the process planning information back to design for assessing manufacturability, assemblability, processing time, and cost. Figure 6.1 shows a framework of preliminary design and preliminary process planning integration [36, 94].

Figure 6.2 illustrates the communication between preliminary design and preliminary process planning based on the integrated design object model and manufacturing process object model. Design information, such as form, structure, materials and other product properties to be shared by process planning based on the design object model. Likewise, manufacturing information on preliminary process planning, such as primary manufacturing processes, process sequences, process parameters, setup
Figure 6.1 Integration Framework of Preliminary Design and Preliminary Process Planning [36]

Figure 6.2 Communication Between Design and Process Planning based on Integrated Design and Manufacturing Process Object Model
specification, and cost/time needs to be made available for product design based on the manufacturing process model, to guide product designers to optimize design specifications. Therefore, an integrated information model that supports the two-way communication between preliminary design and preliminary process planning is important and necessary. The design information includes the requirements, function, behavior, and form/structure of artifacts.

6.1.1 The Early Effects of Design

By the time, a machine has been designed, only about 8 % of the total product budget has been spent [7]. However, by that point, the design has determined 80 % of the lifetime cost of the product (Figure 6.3). The design determines the manufacturability, which determines a significant part of the introduction and production cost (about the 80 % cost of the product). Once this cost is locked in, it is very hard for manufacturing to remove it. Cost reduction programs should start with product design since it has the most influence over the design’s overall cost.

![Figure 6.3 Cost Advantage of Early Decisions](image)

Figure 6.3 Cost Advantage of Early Decisions

168
6.1.2 CE in a Machine Tool Manufacturing Company

Figure 6.4 shows the CE network, in a machine tool manufacturing company producing a wide range of machines with processes and their interconnections. Similar networks in manufacturing are available with many literatures [95]. CE was developed for a project in this company to develop two new products. Production includes a wide range of machines like conventional turning, milling, drilling and grinding machines, CNC machines and machining centres. The project involved almost every activity typical to this industry, from research to customer requirement planning.

![Figure 6.4 Typical CE Network in a Machine Tool Manufacturing Company](image)

6.1.3 Process Planning Model (PPM)

Process plan modeling was used to describe the process plan strategy of a manufacturing process. A process plan model includes a hierarchically structured process plan: generic plan, macro plan, detailed plan, and micro plan. In
conceiving the PPM, the possibility of using different methods was taken into account, two of them being basic:

- the method through variants,
- the generative method.

The method through variants (VPP - Variant Process Planning) is conceptually based on the idea that similar parts are being manufactured in similar ways. Therefore, one of the main components of the PPM is that of part coding, which uses the principle of group technology. In a consistent database the variant, which is closest to the needed part, must be identified. Creating and modifying the typified process is the job of the engineer.

![Diagram](image)

**Figure 6.5 The Scheme of the Work Structure in a PPM**

The first activity carried out is coding, classifying and grouping the parts into families, which represents the preparation state followed by the production state. This refers to the usage of the PPM during actual production. The database, which was created during the preparation state, undergoes a process of continuous improvement with new part types, which are to be machined. Their regrouping is to be made based on the group technology by modifying and adapting the configuration of the new part type as and when needed. The main role is that of the database and that of the knowledge base, which must be updated and improved constantly. In
6.1.4 The Realisation of the Process Planning Model (PPM)

Figure 6.6 shows the composition of the objects for the model realised for the PPM. The classes of an application are organised as a graph, and is shown in Table 6.1. Contrary to a relational model, the object-oriented model allows not only the description of the static aspect of an application, regarding data and structure, but also the description of the dynamic aspect, regarding the object behavior and communication [96].
an object is to be accessed or modified only through the multitude of tasks (methods) which define the object.

### Table 6.1 Classes of an Application for an Object

<table>
<thead>
<tr>
<th>Object - machining process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class – milling</td>
</tr>
<tr>
<td>attributes</td>
</tr>
<tr>
<td>operation number &lt;integer&gt;</td>
</tr>
<tr>
<td>speed &lt;float&gt;</td>
</tr>
<tr>
<td>feed &lt;float&gt;</td>
</tr>
<tr>
<td>rotation &lt;float&gt;</td>
</tr>
<tr>
<td>methods</td>
</tr>
<tr>
<td>operation_creation()</td>
</tr>
<tr>
<td>parameter_calculation()</td>
</tr>
<tr>
<td>parameter_modification()</td>
</tr>
<tr>
<td>parameter_optimization()</td>
</tr>
</tbody>
</table>

**Object MT (Machine-Tool)**

- gauge dimensions
- useful work way
- rotational range
- feed range
- cutting tool change
- technical conditions

**Figure 6.7 Defining the Machine Tool Object**
Through the tasks of the machine-tool object, it is possible to call the components (Figure 6.8). Similarly, for the components of the object-machining task (MT), the program-specific functions are called (Figure 6.9).

From the object’s structure there can be seen the information’s structure, as well as the tasks’ implementation as shown in Figure 6.10. The advantages of OOP could be achieved mainly because of the discipline associated with the encapsulation and inheritance (characteristics that allow the development of new classes by describing the differences to the already existing ones).

**Figure 6.10 Information Structure Object**
6.2 Feature Information Modeling for Part Families

It is difficult to distinguish between simple features and combined features on an absolute basis. However, from the topological view, it is safe to say that simple features are the lowest level of feature and combined feature can be broken down into two or more simple features. From the functional view, the function of simple features differs when used in different parts. Combined features have their pre-defined composition of simple features and provide fixed functions in a specific part family. In this research, surfaces are treated as simple features. The basic surfaces are flat surface, internal cylinder surface, and internal cone surface. The combined features are the combination of these simple surfaces. The definition of combined features follows the rules:

1. The geometry of a combined feature must link together or have particular topological relationships.
2. A combined feature acts as a unit to provide a specified function in part families.
3. A combined feature has one or a list of particular manufacturing processes in the manufacture of a part family.

6.2.1 Combined Feature Information Structure

In order to represent the combined features, the detailed information of combined features should be studied first and organized into a hierarchical structure:

- **An identifier**: or an ID, which is needed to uniquely represent a feature.
- **Feature type**: Feature type is the most critical information that describes the greatest information content of a combined feature.
- **Surface information**: Surfaces are considered the atomic primary features and are mathematically represented by operational data sets. The O-O modeling techniques can be applied for necessary reasoning.
In each combined feature, there is a main surface (MS), which determines feature’s parameters, position, and orientation. Auxiliary surfaces (AS) are those surfaces that are attached to main surfaces. The relationships between the main surface and auxiliary surfaces should be described as well.

- **Manufacturing process information:** The feature information can be further linked to the cutter and the local toolpath used to machine this feature.

- **Feature functions:** The feature’s functions indicate its particular functionality in a part family. Sometimes, the change of feature parameters may influence the whole part’s function. For example, in the caliper family, the change of the diameters of piston bores will change the fluid pressure that the caliper can provide to the brake pads. Corresponding parameters of combined features in the caliper family may change accordingly, which causes the manufacturing plans of the whole parts to change greatly. Therefore, the critical feature’s function should be identified and represented in feature model.

Figure 6.11 shows the combined feature information structure.
6.2.2 ORM of Combined Features

Based on the combined feature’s information structure discussed in section 6.2.1, the ORM of combined features is established, as shown in Figure 6.12. A combined feature has its own manufacturing feature type that is composed of a main surface, auxiliary surfaces and surface relationship objects. Three surface types are involved in this ORM. They are flat surface, cylinder surface and cone surface. The form tolerance, position, orientation tolerance and runout tolerance are treated as object in this ORM. Tolerance classification of the combined feature used in the ORM is given in Table 4.15 of chapter 4, Section 4.2.7.
Figure 6.12 ORM of Combined Features

6.3 Process Modeling for Manufacturing Strategies of Features

The knowledge used in IPPPIS is represented either by cases (cased-based reasoning) or by sets of manufacturing rules (rule-based reasoning). Cased-based CAPP can retrieve previous experiences stored in IPPPIS, modify the old solution for new parts, and abstract and store the newly generated solutions in IPPPIS.

6.3.1 Decision-Making Technologies

The process plan generated is based on existing experience. While rule-based IPPPIS generates process plans from scratch by the use of
manufacturing rules that come from manufacturing companies. There are several advantages for case-based systems over rule-based systems, including the following:

- Case-based systems have the ability to become more efficient by abstracting and storing previous solutions and reusing these solutions to solve similar problems in the future. A rule-based system will always generate solutions from scratch, duplicating previous solution efforts.
- Case-based systems have the ability to learn from their mistakes, once a solution is corrected and stored as a case. A rule-based system will repeat mistakes until its rule base is updated with new rules.

However, rule-based systems do have an advantage over case-based systems such as easy maintainability. When manufacturing resources change in a company or the CAPP systems are applied in another company, it is hard to update corresponding cases in a case-based system. If the system is a rule-based system, only corresponding rules are needed to be updated [74].

6.3.2 Information Content in the IPPPIS

Four functional modules carry out the tasks of IPPPIS sequentially. The part information-modeling module abstracts features from part CAD models and represents part information by FTGs, which are composed of features and the relationships between features. In the meantime, the features manufacturing strategies are associated with features based on the BOP of part families, which is called feature-level decision-making. Setup planning is carried out based on either the BOP or tolerance and manufacturing resource capability analysis, in which manufacturing knowledge for mass customization is incorporated.
Setup planning is also called part level decision-making. Conceptual fixture design and manufacturing plan generation are mainly derived from the BOP of part families. Both of them incorporate the machine-level decision-making strategies.

Corresponding to the above functional modules of the IPPPIS for mass customization, the information involved in the IPPPIS is organised into three categories, which are shown in Figure 6.13:

1. Manufacturing data and knowledge bases store the manufacturing data and knowledge applied in mass customization;
2. BOP represents the company-specific ‘best of practice ‘ (BOP) of part families;
3. The blackboards store the information generated by the functional modules of the IPPPIS.
In the IPPPIS, information in each category is divided into three levels: the feature-level, the part setup planning level and the machine-level. Information in the same level serves for the same function module.

6.3.2.1. Manufacturing Data and Knowledge Bases

In the CAMP, the following information are considered and stored in the manufacturing data and knowledge bases:

* **Combined Features**

  Combined features were defined based on particular part families. The parts in the same part family may have the same type of combined features and feature relationships so that the part families BOP was used as the reference to generate new plans.

* **Features Manufacturing Strategies**

  Combined features are associated with pre-defined manufacturing strategies, in which customized combination of cutters, tool paths, and machine tool motion requirements were specified for particular part families. The designs of cutters and tool paths were based on experience and they are stored in templates. Therefore, when the same combined feature was encountered, the existing experience was reused.

* **Manufacturing Resource Capabilities**

  Manufacturing resources include cutters, machine tools, and fixtures. Some of them are standard tools and can be brought from the market. The others were designed specifically for particular processes used in manufacturing plans. The capabilities of available manufacturing resources should be described and stored in a format that the CAMP can interpret and manipulate.

* **Manufacturing Knowledge Extracted from BOP**

  Manufacturing rules and knowledge were extracted from BOP and applied in the automated reasoning mechanism such as automated determination of feature manufacturing strategy, automated setup
planning and automated manufacturing plan generation. In this research, three levels of manufacturing knowledge were identified:

- **Universal:** General knowledge without regard to a particular shop
- **Shop level:** Additional process details based on the particular manufacturing systems in a shop
- **Part-level:** Full information based on particular part families production in a specific machine shop

All this information is embedded in the BOP. It needs to be identified and stored in the CAMP so that when BOP is missing, CAMP can use the above knowledge to generate feasible manufacturing plans.

### 6.3.2.2. Best-Of-Practice (BOP) for Part Families

BOP for part families are the most important reference enabling engineers to design a new manufacturing plan. The specific decision-making strategies of part families were embedded in the BOP, which include strategies about how to deal with the information association between part design, part manufacturing and the utilization of manufacturing resource capabilities. Therefore, the decision-making strategies in the BOP were identified first and then the BOP was described in a format that is accurate, complete and unambiguous. This is used by the CAMP system. In this research, information in BOP has been divided into three levels: feature level, part setup planning level and machine-level. The detailed format of BOP is discussed in Chapter 7.

### 6.3.2.3. Blackboards used in CAMP

Blackboards were used to store the shared information generated by the modules of the CAMP. It is in the blackboards that computers are dealing with, and the manufacturing information that is represented by information models. There are four blackboards in CAMP that store features, features’ manufacturing strategies, part setup planning and manufacturing plan information.
An OSA approach is used in this research to analyze and represent the information in the blackboards, focusing primarily on the information associativities of part design, part manufacturing and manufacturing resource capabilities, used in part production. The objective of using the OSA approach is to facilitate the use of part families BOP to help engineers rapidly design new manufacturing plans.

6.3.3 Process Information Structure

The process information structure is composed of cutters, cutting motions, and economic process accuracy, as shown in Figure 6.14. Economic process accuracy describes the process capability of surface finish and tolerance limitation. Each feature may have several alternative manufacturing processes.

![Figure 6.14 Information Structure of the Process Model](image)

Using the process model, it is expected that a user can add new cutting tool descriptions and corresponding tool path descriptions to the process model easily. This challenge is handled in two ways. First, establish extensible
cutter and tool path representations so that users may easily add their own customized cutter and tool path descriptions. Second, validation to ensure that customized cutting tools and tool paths such as the tool path simulation are valid in practice.

6.4 Manufacturing Plan Generation

Task of manufacturing plan generation with its various components, like machine tool selection, conceptual fixture design and part layout design, global process sequence and tool path generation, cycle time calculation is described in chapter 4. Machine tool information modeling, planning strategies, which is also part of manufacturing plan generation, is described here.

6.4.1 Machine Tool Information Modeling

In mass customization, plenty of vendors provide a variety of machine tools with similar functions. How to use machine tool specifications to make the right choice becomes a critical problem in reduce manufacturing costs. From the discussion of manufacturing resource capabilities, it can be seen that machine tools make a significant contribution to these capabilities. The information of machine tools is summarised, and an O-O machine tool information model, as shown in Figure 6.15 is built.
6.4.2. Planning Strategies

Planning strategies describe the creation and manipulation of process plans for the manufacture of a product to a given specification, and
enterprise/factory configuration [39]. This knowledge was used to estimate how long it takes to manufacture a product and will describe:

1. Hierarchies of processes and sub-processes, e.g., drilling and machining are all subprocesses of machining.
2. How processes are to be sequenced? e.g., casting precedes machining, and setting must occur before a work piece can be milled.
3. How to calculate the duration of a process. This is often a function of a processing rate and a geometric feature of a product.

Certain levels of planning knowledge will also be relevant to different levels of facility representation. For example, a model of an individual machine tool can describe constraints on the processes under its control (e.g., setting is required before milling), but cannot assume knowledge of other facilities. A constraint on “casting preceding machining” must for example be described by a factory or enterprise level model, which makes assumptions about the availability of foundries and machine tools. This allows the machine tool model (on its own) to be reused in environments using forges and other fabrication technologies.

6.5 Manufacturing Activity Model

Figure 6.16 shows the class diagram for a manufacturing activity. Such an activity is a generic manufacturing operation performed on a workpiece. The manufacturing activity class has a recursive definition, which generates a hierarchical structure. The levels in the hierarchy can be, for example, workstation, operation, step and feature. The manufacturing activity indicates the level.
Figure 6.16  Manufacturing Activity Class Diagram
If we take the example of reading the relationship in this diagram, manufacturing activity, manufacturing resource association states that a manufacturing activity can have zero to many manufacturing resource. The resource class stores attributes related to a facilities use of resources. A machine shop will for example use machine tools, drill-bits, lubricating oils and work pieces. Attributes may therefore include: the minimum and maximum sizes of work-pieces; the availability of tools, bits and lubricating oils; the number of machine tools and drill-bits used for individual drilling processes; and the rate at which lubricating oils are consumed. The process class stores attributes related to processes, e.g., milling rates and tolerances achieved. Process constraints may also be described, e.g., the maximum input surface tolerance for a finish milling process.

Both the resource and process classes are considered as information classes rather than knowledge representations. This is because they provide no information relating to how the information stored by the class is used. Knowledge of how to interpret resource and process settings is however stored in the strategy class. Indeed, the separation of strategies from resource and process information is one of the significant contributions of the manufacturing capability model. Strategies describe how a facility applies resources and processes to make products, and was considered as a knowledge representation. The role of the strategy class is demonstrated by the following example. A constraint stating that a “grinding process can only be applied to a surface if its tolerance is already less than 500μm” cannot be readily applied to different machine tools with different processing capabilities. This is because the “500μm” attribute is directly referenced by the constraint. Making indirect reference to the 500μm value however, allows the rule to be more generally applied: e.g., the “grinding process can only be applied when the surface tolerance is within the machine tool’s grinding-capability”. If the grinding capability is stored
separately from the strategy (i.e., in a separate process class) then the same strategy can be reused for multiple machine tools. This principle has been described within agent systems, as the separation of declarative data from procedural knowledge. Similar concept is explained in many literatures [97, 98].

Similarly manufacturing activity is associated with manufacturing parameters, handling, load unload, setup, processing idling etc.. Manufacturing activity has subclasses with details on work piece, manufacturing parameters, priority rules etc..

The result of the manufacturing activity is the artifact to be made. ArtifactToBeMade has the manufacturing processes, which include a set of manufacturing activities. Manufacturing consists of many subManufacturingActivities that are defined recursively. The intermediate process represented by workpiece, which is a type of artifact class. Additionally, manufacturing activity will have the following attributes: manufacturing part quantity, manufacturing resource, estimated cost/time, branch and joint. Branch and joint are considered together to form the structure of concurrent and parallel activities.

The ManufacturingActivity class has the following subclasses: Setup, Handling, Processing, LoadUnload, and Idling activity. This model supports integrated manufacturing activity, sequence, alternative activity, parallel activity, concurrent activity, resource, manufacturing time, and cost.

6.6 Manufacturing Resource Model

Manufacturing resources include machine tools, cutting tools, and fixtures. Currently, supplier-based manufacturing is widely adopted so that planners have considerable choices of manufacturing resources to finish manufacturing plans. How to evaluate a candidate manufacturing resource’s capabilities has become one of the critical factors in reducing manufacturing
costs in mass customization. Several O-O manufacturing resource models were established to express the relationships between manufacturing resource capabilities and feature attributes.

6.6.1 Integration of Manufacturing Resource Capabilities in the IPPPIS

As previously indicated, the tasks carried out by the IPPPIS were designed in three levels of planning: the feature-level, the part setup planning level and the machine-level. Therefore, the consideration of manufacturing resources was also divided into three steps, in which the effect and contribution of machine tools, fixtures and cutters are properly identified and utilised, resulting in the achievement of optimal manufacturing cost. A summary of the three levels is presented in Table 6.2.

**Table 6.2 Three Levels of Manufacturing Resource Capabilities in the IPPPIS**

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feature manufacturing strategy determination</td>
<td>Selection of combination cutters and toolpath for individual features</td>
</tr>
<tr>
<td>2</td>
<td>Setup planning</td>
<td>Determination of machine tools and fixture’s capabilities</td>
</tr>
<tr>
<td>3</td>
<td>Manufacturing plan generation</td>
<td>Determination of machine tools and fixtures used in the manufacturing system</td>
</tr>
</tbody>
</table>

**Level 1: Determine Cutters and Toolpath to Manufacture Individual Features**

At this level, a feature’s form, dimension, and precision attributes were taken into consideration and manufacturing resource’s shape, dimension and precision capabilities are incorporated. Based on a feature-level BOP, some candidate feature’s manufacturing strategies were selected along with the cutters, toolpath, and the requirement to the machine tool’s motions.
**Level 2: Design the Setup Plans within the Consideration of Flexible Machine tool Capabilities**

A feature’s position and orientation attribute was achieved in this level. Therefore, position and orientation capability of manufacturing resources was considered in this level, based on the available machine tools and fixtures.

**Level 3: Determine the Part Layout on Fixtures and try to Utilize Machine tool Capability Completely to Achieve Minimum Cycle Time**

Since several parts may be machined on one fixture in the IPPPIS, a feature’s position and orientation attribute was reconsidered in this level, as should the corresponding machine tool’s moving range and worktable dimensions in order to accommodate feature’s position and orientation. The three-level integration of manufacturing resource capabilities in the CAMP are shown in Figure 6.17. By using this integration of manufacturing resource capabilities during the manufacturing planning activity, engineers can easily identify the critical factors within manufacturing resources that

![Figure 6.17 Integration of Manufacturing Resource Capability in the IPPPIS](image-url)
affect manufacturing costs and time frame of manufacturing plans. This will help to make a quick decision on the choice of machine tools, fixtures and cutters for specific manufacturing plans.

During the manufacturing planning activities in the IPPPIS, the optimal utilization of flexible manufacturing resources including cutters, machine tools and fixtures, will increase production throughput and decrease manufacturing costs. Hence, the information content of manufacturing resource capabilities were properly identified and represented in the IPPPIS so that engineers can manipulate them to make the accurate choices. Three resource capabilities: shape, dimension and precision, position and orientation capabilities are discussed in this chapter. The architecture to enable the integration of manufacturing resource capabilities to the IPPPIS is also proposed.

6.6.2 Manufacturing Resource Capabilities

Parts are composed of features, which are associated with sequences of manufacturing processes. For ordinary processes, the regular manufacturing resources are machine tools, fixtures and cutters. The interrelation of these resources constitutes three capabilities: feature shape capability, feature dimension and precision capability, and feature position and orientation capability. In this research, the capabilities are modeled in three classes: shape capability class, dimension and precision capability class, and position and orientation capability class. These classes represent the commonality of the manufacturing resource objects. Because the planning was carried out on feature-by-feature basis, manufacturing resource capabilities were mapped into part design specifications, including feature form, feature precision, and feature position and orientation, as shown in Figure 6.18.
6.6.2.1 Shape Capability

One purpose of manufacturing planning is to generate detailed NC codes for a desired part shape and feature forms. It involves three elements: the primary motion and feed motion that are provided by the machine tools, and the working edge of the cutters. Sometimes the primary motion acts on parts and the feed motion acts on cutters, such as a typical lathe or a boring mill. In other cases, the primary motion acts on cutters and the feed motion acts on parts. The interactive relationships among a machine tool’s primary motion, feed motion, and cutters’ working edge express the capability of generating part shape and feature forms, as shown in Figure 6.19(a). In this research, non-rotational parts were always mounted on fixtures, and fixtures were installed on the worktables of machine tools. Therefore, in the manufacturing of non-rotational parts, the primary motion always acts on the cutters. The feed motions may act on either the non-rotational parts or the cutters. Figure 6.19(b) shows three cases of machine tool motions in the machining of non-rotational parts. Among them, the feed motion acts on the cutters in the drilling process, while also acting on the part in the milling process. The shape capability class is shown in Figure 6.20.
6.6.2.2 Dimension and Precision Capability

Dimension and precision are the second important aspect of part specifications. Since no manufacturing resources can produce precise geometry, shape deviation, dimension deviation and surface roughness always exist. Every combination of machine tool, fixture and cutter will assure a certain range of; dimension, dimension tolerance, surface finish, form tolerance, position and orientation tolerance. In Zhang’s research, they were classified this into three subclasses: dimension capability, precision capability, and surface finish capability. It is pointed out that dimension and precision modeling is a very complicated domain.

Figure 6.19  Feature Form and Shape Generating Processes
There are many intricate and unpredictable reasons that cause different kinds of deviations. Therefore, the experience in part families BOP becomes quite precious and it was used as a reference to ensure the dimension precision in part manufacturing.

1. Dimension Capability

Dimension capability is the means to measure the maximum and minimum dimensional range of a workpiece and its features. It is primarily derived from the working space of machine tools, cutters, and fixtures. For example, the dimension capability of a horizontal machine tool is the diameters of its round workbench, which at the same time constrain the fixture’s dimensions. A machine tool’s dimension capability was defined as the attribute of a machine tool class, as shown in Figure 6.20. Cutters were classified into two types: scattered dimensional series (i.e., drill, reamer, etc.), and free dimensional cutters (i.e., milling cutters). The dimensional limitation of a feature inferred from its cutters. The Cutter dimension capability is defined as the constraint used to drive the cutter templates to generate cutters.
2. Precision Capability

Precision capability was designed to allow manufacturing planning systems to select appropriate manufacturing resources, in order to satisfy precision requirements in features and feature relationships. The source that causes precision errors has been discussed in Zhang’s research [57]. In this research, the part families BOP is the most important reference for selecting machine tools, fixtures and cutters that have the same precision specifications as those in the BOP.

3. Surface Finish Capability

Surface finish depends on machining methods, cutting condition, cutting tool material, and workpiece material. It is assumed in this research that the manufacturing methods from part families BOP will ensure the surface finish requirement.

6.6.3 Manufacturing Resource Model

Figure 6.21 gives the details of manufacturing resource class diagram. A manufacturing resource is a physical machine or labor skill that was used in manufacturing artifacts. The manufacturing resource class has two subclasses: labor skill and manufacturing equipment. Labor skill represents labor rate and skill description. The manufacturing equipment subclass represents a piece of equipment (a physical entity). There are four subclasses: machine, die, mold and tool for machining. If necessary, other equipment classes may be added to the manufacturing equipment class. A piece of equipment has a set of parameters that describe the equipment. A machine can be a machining center, casting machine, forging machine, electrical discharge machine, and so on. A machine has a set of parameters, such as dimension scope and tolerance scope. A tool represents a tool used in the machining process, such as a cutter, extender, holder and gauge. Each tool has a set of tool parameters. The tool class has four subclasses: cutting tool, fixture tool, gauging tool, and accessory tool.
If we reading the relationship in this Figure 6.21, there can be many manufacturing resources like, labour skill, manufacturing equipment etc.. Manufacturing equipment can have further subclasses like machine, mould,
die, tool for machining etc. There can be one-to-many relationship between machine and machine parameters. A machine must have at least machine parameters, but the manufacturing equipments might have a machine parameter that has to be used. Tool for machining can have subclasses like tool parameters, cutting tools, fixtures etc..

6.7 Manufacturing Cost and Time

Cycle time is the critical factor in choosing the optimal manufacturing plan. Estimation of cycle time is indispensable for manufacturing plan. Manufacturing time depends on the feature to be machined. A framework for estimating the manufacturing cost and time is developed. The details of the framework given below:

6.7.1 The Feature-Based Cost Analysis Process

Figure 6.22 shows the flowchart of the feature-based machining cost analysis process. The process can be described as follows:

Step 1: Build the paint model in terms of a feature-based approach. That is, the part model is constructed by using the form features stored in the feature library.

Step 2: Specify the surface roughness of each feature of the part model. The above two steps are carried out by the designers. The developed system will carry out the following steps:

Step 3: Retrieve the feature related information from the CAD database. These data include the feature type, the values of the parameters used to define each feature and the B-Rep data for each feature.

Step 4: Based on the retrieved data, examine the manufacturability of each feature. These include the following tasks:

4.1. For each retrieved feature type, obtain its manufacturing process from the feature manufacturing process library,

4.2. For each process, acquire a group of suitable machines from the machine specifications file.
4.3. For those appropriate machines, select one, which provides a surface finish range to meet the required surface roughness of the specific feature.

**Step 5:** Estimate the required machining cost for each feature. This can be roughly computed based on the following process:

5.1 For each operation of the examined feature, compute the required machining time.

5.2 Compute the required machining cost for each operation.

5.3 Estimate the required machining cost for each feature.

![Flowchart of the Cost Analysis Process](image_url)

**Figure 6.22 Flowchart of the Cost Analysis Process**
6.7.2 Cost Estimation Methodology

Figure 6.23 gives the detailed architecture of the cost estimation system and implementing the same in an integrated product-process-design environment. The model is driven by a database of material and process dependent cost factors, minimizing user inputs. The goal is to enable design engineers to estimate costs accurately, even with limited knowledge of process.

![Cost Estimation System Diagram](image)

**Figure 6.23 Cost Estimation Systems – Overall Architecture**

It is always of interest for engineers to find the most economical solution. Basically, process economics means determining the cost efficiency of processes. For the IPPPIS, it is necessary to go through a very detailed economic analysis before selecting a specific processing method. However,
it is not practical to conduct a very detailed study in the manufacturing planning stage. Hence, some rough estimation was used to select the best solution. Cycle time calculation is known as the most effective determinant for mass customization.

6.8 Conclusion

This chapter has presented systematic information modeling method for a machine tool factory, with the details on various domain specific knowledge being structured and integrated within the IPPPIS. Different methods and tools discussed in the previous chapters have been used for the modeling the various components, explained in this chapter. Information exchange between design and process planning in the early stage of design will help the manufacturing companies to optimize the process design. Using techniques, such as, feature information modeling, process modeling of the feature, information exchange between product and process is done. Information content, such as manufacturing data, knowledge base and BOP’s are part of the IPPPIS. How this information was used for plan generation is described in this chapter. Information model such as, manufacturing activity model, manufacturing resource model, process planning model etc., were described in detail.

Integration of information models in the IPPPIS to come out with an integrated system for part design and process planning with optimized cost and time has been successfully demonstrated. The next chapter is devoted to the system implementation case study in a machine tool factory, to demonstrate the benefits that can have from the concurrent engineering based IPPPIS. How the IPPPIS benefited the machine tool manufacturing organisation where it was implemented to become lean and agile, will be also explained in the next chapter.