Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Integrated Product Design and Concurrent Engineering

Companies both in manufacturing or service have to be restructured or re-organised in order to overcome challenges of the 21st century in which customers are not only to be satisfied, but also to be delighted. Global competition and escalating market efficiency are driving engineering businesses to adopt design philosophies which reduce product design cycle time. Figure 1.1 shows some notable changes in manufacturing industry, based on literature [1, 2]. The learning is that in this competitive environment, organization should use flexible, adaptive and responsive processes. For this, it has to use some enabling technologies and tools. One such design philosophy is "Concurrent Engineering". Concurrent Engineering (CE) is "the systematic approach to the simultaneous, integrated design of products and their related processes, such as manufacturing, testing and support" [2]. Conceptually, CE is intended to

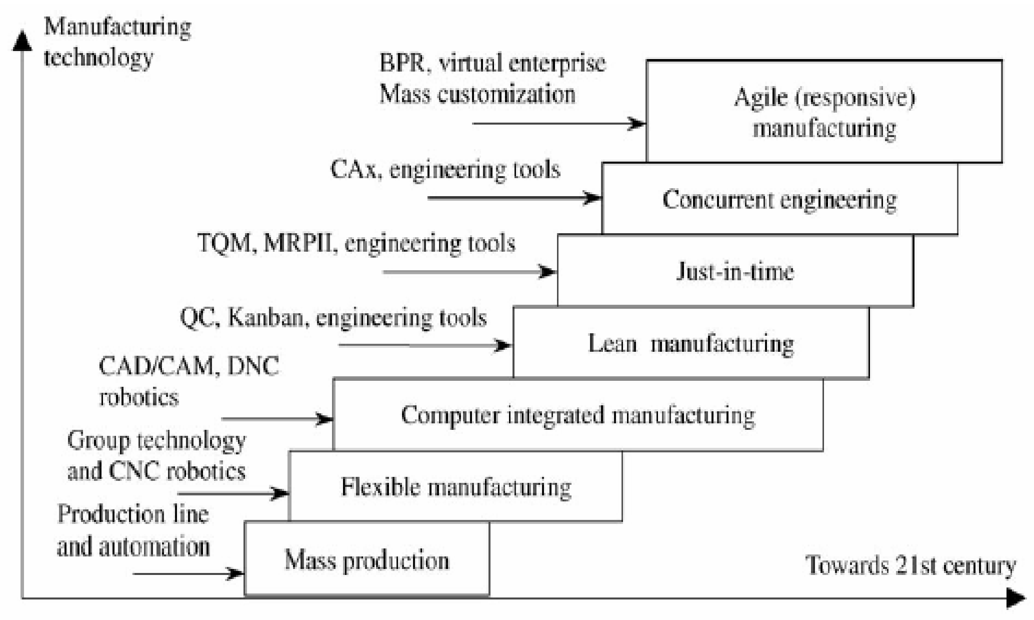


Figure 1.1 Development of Manufacturing Technology [1]

shorten the design cycle time by allowing engineering processes to run in parallel, rather than in series. This approach is intended to result in consideration of all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements. Put more simply, it is the concurrent design of products and their related processes, including manufacture and support [3].

A similar concept is that of Integrated Product Development (IPD), which is a philosophy that systematically builds teams across functional disciplines to integrate and concurrently apply the processes necessary to produce an effective and efficient product, that satisfies customer needs. This covers not just the design of the product, but also the prototyping of the product, product testing, design of the production process, design of instruction and support manuals, design of maintenance procedures, and the design of review and updating procedures.

The goal of both methodologies is to make significant reductions in design and development cycle time for new products. Reduction claimed reductions are of the order of 30 per cent to 70 per cent of total product development cycle time. Faster development, and a reduction in time-to-market, gives:

- competitive advantage over competitors who take longer to respond to market changes, customer needs, new technologies, or premium prices before competitors offer customers a choice.
- faster return on the development investment and therefore a lower financial risk.
- longer life cycle for the product.
- higher return on the total investment.

In addition to reductions in development cycle times, there are other benefits from such a rigorous and systematic approach to design and development. There are significantly fewer changes in specification of the components during the lifecycle of the product because the initial design work is both thorough and done with the manufacturing and support process in mind. Attention to effective design also results in higher quality and consistency of components and of the final product, i.e., quality is designed into the product, not inspected onto it. Attention to process design results in higher productivity of the manufacturing process.

The above discussion shows that concurrent engineering can have much far-reaching effects on a business and therefore it must be considered as a strategic initiative. Leading innovative companies have always treated product development as a strategic process because they have always recognised it as a key component of their competitive strategy. If they are real product innovators, it is in effect their key business strategy.

In a global marketplace, where competition is everywhere, cutting product development cycle times may be the difference between creating a market and missing a market. The concept of concurrent engineering is simple. However, it does require fundamental changes in ways of working. First it requires a fundamental shift in organisation structure and culture to break down the barriers (and they do exist) between R&D, design, and manufacturing. By the very nature of the process, these departments have to start working together bringing their particular expertise to the table simultaneously rather then sequentially. They must respect each other's expertise and attack issues and problems jointly. Most importantly, they must also address to design and manufacturing process from a customer standpoint.

The essence of CE is the integration of product design and process planning into one common activity. Concurrent design helps improve the quality of early design decisions and has a tremendous impact on life cycle cost of the product.

CE can be visualized as illustrated in Figure 1.2. In this, figure the designer is represented by the hub of the wheel. Designers coordinate the inputs and re-design suggestions from each of the domain experts (shown in the circumference). One can think of Concurrent Engineering (CE) as accomplishing this purpose using five interrelated elements:

1. Careful analysis and understanding of the fabrication and assembly processes. This allows the designers to predict the performance of the product and select production schemes from alternative processes.
2. Strategic product design conceived to support a specific strategy for making and selling the product. The product should be made to marketing specifications for market value, shelf life, and usability.
3. Rationalized manufacturing system design coordinated with product design.
4. Economic analysis of design and manufacturing alternatives to permit rational choices among design alternatives.
5. Product and system designs characterised by robustness. Robustness means resistance to unpredicted noise or errors in production and in use. In other words, the product's performance is as resistant as possible to variations in dimensions within the tolerance.

The goals of CE within these elements are:

- Avoiding component features that are unnecessarily expensive to produce, e.g., specification of surfaces smoother than necessary, wide variations in wall thickness of an injection-moulded component, too-small fillet radius in a forged component, or internal apertures too close to the bend line of a sheet metal component.
- Reducing costs of making, by the optimum choice of materials and processes e.g. can the component be cold-headed and finish-machined rather than machined from bar stock?

This approach encourages the designers to consider interactively all elements of the product's development process from the design through to the disposal (including customer requirements, product quality, manufacturing costs and production time) [4]. Despite wide acceptance of the CE approach, an implementation rate of around only 50% is reported [5]. The main barrier to implementation is the lack of tools and techniques available to assist in implementing the approach. This is the area chosen for work in this thesis.

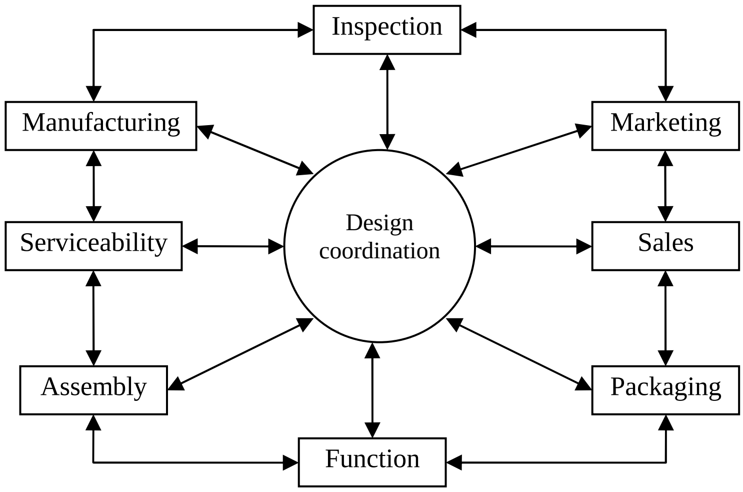


Figure 1.2 The Concept of Concurrent Engineering

Most of the CE research to date has focused on combining production considerations with product design issues [6, 7, 8, 9]. CE applications were reported to achieve a 30 to 60% reduction in time-to-market, 15 to 50% reduction in life cycle costs and a 55 to 95% reduction in engineering change requests. It is well established that over 70% of the total development cost of a product is frozen during the design phase, though this phase accounts for less than 7% of the total value [10].

Over the last two decades, a significant shift has taken place in the source of competitive advantage for manufacturing companies. Traditionally, firms made use of economies of scale to produce highly standardized products to satisfy massive and large homogeneous markets. Nowadays, to stay competitive, firms need the capability to produce a broad variety of high quality products, and must exhibit rapid responsiveness to dynamic and increasingly fragmented markets by introducing new products frequently at short lead times [11].

In complex products, changes in the design requirements to meet rising performance targets can result in the need for radical changes to component material properties, configuration and geometry. Consequently, new manufacturing technology processes need to be developed to achieve these geometries. Thus, a key feature in a new product introduced in this sector is the ability to integrate knowledge of manufacturing technology innovations into the design process in a timely and appropriate way. To mitigate risk it is necessary to make this knowledge available as early in the design process as possible [12].

Currently, most of the research focuses on job and batch production, whose objective is to produce customized parts while trying to maintain minimum manufacturing cost by use of standard cutters, fixtures and machine tools. An important step toward establishing manufacturing planning platforms for mass customization is the development of planning methodologies that provide easy access to information in the previous manufacturing plans. Due to the similarity / commonality among production systems or among specific customized products, the concept of reuse presents itself as a natural choice to facilitate increasingly efficient and cost effective product development. That is, a new manufacturing plan that reuses a previous plan at some level or to some extent will be less expensive to develop than a plan that is designed from scratch. By reusing prior plans, an engineer can save design time and cost by leveraging previously worked-out solutions. Figure 1.3 shows the roles and issues relating to manufacturing planning in the production cycle, which is composed of three stages: design, manufacturing planning and production.

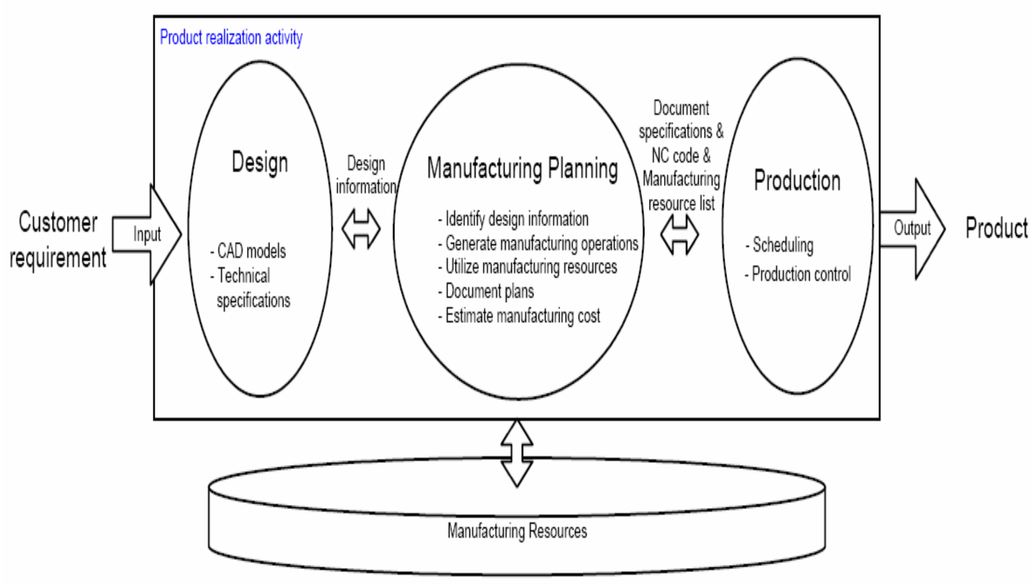


Figure 1.3 The Roles and Issues of Manufacturing Planning in the Production Cycle

The product data model is central to CE and can be defined as the sum of all the information needed to define a product, consisting of both geometric and non-geometric information. In order to make CE possible, a product data model needs to be made at the beginning of the design cycle. Geometric and limited non-geometric information are defined with Computer-Aided Design (CAD) tools. Geometry defined in CAD can then be exported to downstream engineering applications where additional non-geometric information, called attributes, are assigned and attached to the geometry before other engineering tasks are performed [13].

1.2 Manufacturing Information Modelling

To meet market challenges, manufacturers trying to improve their efficiency in areas of product development and resource utilization. In the manufacturing industry domain, the development and manufacture of products requires, a wide range of information to support the decision-making processes, during different stages of the product lifecycle (especially, in engineering design). A knowledge-intensive process is needed for many tasks, such as conceptual design, detailed design, engineering analysis, assembly design, process design, and performance evaluation. Each task is carried out using multiple areas of knowledge and experience. Engineering designers have to access and retrieve information from numerous design resources to make decisions. Research shows that engineering designers spend as much as 30% of their working time on searching and accessing information. Hence, to improve product development decisions and to obtain a competitive advantage, an industry should effectively organize, store, and retrieve such knowledge and experience [14].

Knowledge Management (KM) can be used to capture code, store and retrieve information. It has been used in manufacturing enterprises during the last decade in a variety of decision-making processes, and continues to be the focus of research interest. As the notion of KM matures, it is increasingly clear that KM is not just about technology. It cannot be realized simply through information systems. The challenge of managing knowledge in an organizational context lies in effectively harnessing multiple knowledge sources into coherent business intelligence, and embedding the intelligence into the organization’s memory (OM).

In many companies, product and process design are fragmented and difficult to manage and coordinate. CAD/CAE tools automate the design and development process but, in many cases, cause the rapid proliferation of designs without regard to the impact on the rest of the organization. These tools are integrated to varying degrees. Often these systems are used to create an item's geometry on paper to communicate with other functional areas of a company [15].

One survey indicated that the typical company re-creates an item's geometry five or more times in areas such as customer proposals or marketing specifications, conceptual design, detail design, finite element analysis, other engineering analysis, detail drafting, fabrication or assembly sketches, work cell device programming, tooling and fixture design, and training and service manuals. Each time part geometry or product design information are independently maintained in a separate system or independently created on paper, another source of redundant design information are created, which needs to be managed. Non-integrated systems also require additional effort to transfer data from one system to another. This allows errors to creep into the process and data can be miss-handled or lost. Delays are inherent in this process and extra effort is required to coordinate activities. Technology and information integration represent one dimension of overcoming these traditional problems. Integrated design and manufacturing automation systems and databases are the basis for the engineering blueprint of the future. This will allow manufacturers to “cost-effectively improve product and process design”, while facilitating the integration of design activities with the production process.

Product and process design will be greatly enhanced using integrated databases and information systems to maintain and optimize the use of design information. Product and process design information are treated as a corporate-wide resource. This information must be stored and maintained in a logical, consistent, non-redundant and usable manner. A shift is required to definition-oriented design information that can directly drive downstream processes with little or no human interpretation and planning.

Evolving standards such as the Standard for the Exchange of Product Model Data (STEP) will provide a more complete set of product data in a neutral format. This design information has to be distributed to workstations, controllers and other systems as per requirement. Changes to product and process design data to be managed in accordance with the company's data access and configuration management procedures. By focusing on maintaining product and process design information electronically, paper-based representations of this data are minimized. As paper drawings are avoided, there will be reduced manual handling and storage of documents, reduced time to access the most current design of a part, and prevention of errors from avoiding the use of outdated drawing information. Design and administrative activities can be streamlined. When design information is maintained electronically, design can be readily analyzed and improved, so that more mature and manufacturable designs are developed more quickly. Most importantly, this is the basis for definition-oriented designs.

1.2.1 Knowledge Management

The sharing of design and manufacturing knowledge across the product introduction process can be viewed as a knowledge management problem. Features are a popular method of exchanging design and manufacturing knowledge in CAD/CAM platforms to assist the decisions of designers [12]. A feature is defined as a collection of geometry to which some engineering significance can be assigned. Such representation enables knowledge pertaining to that feature to be structured and represented for different life cycle domains, such as design or manufacturing. However, the domain-specific nature of features limits their ability to be used in knowledge sharing, across different domains. Techniques such as multifeature view mapping, where features from one domain are translated into a second domain, have been developed to overcome this problem. However, this results in a number of different product models being stored. A further limitation is that the geometric nature of a feature requires the product design to have reached a stage of maturity (typically detail design) for the technique to be successfully deployed. This limits their use to later life cycle domains.

Therefore, in developing information systems to share manufacturing and design knowledge for re-use, the preferred approach is to create knowledge models to structure and represent knowledge and information to be shared, in the form of a product model and in cases of manufacturing knowledge, an additional process model. Often represented as class-based UML diagrams, these models enable different domains to be modeled and translated.

It is also reported in literature that, manufacturing constraints represented as rules and parameters are mainly related to the selected configuration and material of the component. The manufacturing options are compared by cost with no assessment of manufacturing capability. A knowledge management database has to be developed, to support manufacturing knowledge in design, using a feature-based product model and an integrated process model [16].

The development of such an information system requires, an effective integration of the key variables involved in manufacture planning and user-friendly interface. This research deals the development of such an information system, with a focus on the data model and the user interface design undermining its operation [17].

Knowledge management involves the identification and analysis of available and required knowledge, and subsequent planning and control of actions to develop knowledge assets to fulfill organizational objectives. Knowledge assets are the knowledge regarding markets, products, technologies and organizations, that a business owns or needs to own which enable its business processes to generate profits [18]. There are four kinds of knowledge management. They are: (1) creating knowledge repositories in which knowledge can be stored and retrieved easily; (2) improving knowledge access to facilitate its transfer between individuals; (3) enhancing a knowledge environment to conduct more effective knowledge creation, transfer and use; (4) managing knowledge as an asset and concern about how to increase the effective use of knowledge assets over time.

1.2.2 Concurrent Engineering

The systematic approach to the design process is indicative of the methodological approach adopted widely in Europe and the US [12]. The sequential nature of this process can be a problem in that the design may reach a stage of maturity before its manufacturability has been assessed. This can lengthen development times and lead to inefficient or unnecessarily costly manufacturing processes.

In an effort to help designers better assess the downstream life cycle impacts of their design choices, manufacturing companies and researchers have developed many design decision support tools referred to as Design for X (DFX) methodologies [19]. Concurrent engineering(CE) and associated techniques such as design for manufacture (DFM) aim to reduce the cost of the component and its developmental lead time by considering a proposed design solution in terms of ease of manufacture as early as is practicable. Such techniques have resulted often in substantial lead-time reductions and cost reductions. However, the DFM technique does not account for other design requirements, which may be required simultaneously during the embodiment stage. A further line of a DFM is that there is an assumption that all the manufacturing processes selected are capable and proven [20].

Successful implementations of CE techniques are usually been team-based, using methods such as IPTs (integrated product teams). Researchers have recognized the opportunity to develop Integrated Computer Technologies (ICTs) to support this team-based approach by providing quality of data. The challenge in developing such systems is ensuring that the information is structured in such a way as to make it communicable between systems [21].

1.3 Process Planning systems and Some New Approaches

Process planning translates design information into the, process steps and instructions, to effectively manufacture the products. Many computer-aided tools support design process. Computer-aided process planning (CAPP) has evolved to simplify and improve process planning, and to achieve effective use of manufacturing resources [15].

1.3.1 Process Planning

Process planning encompasses the activities and functions required to prepare a detailed set of plans and instructions to produce a part. This planning begins with engineering drawings, specifications, parts or material lists and a forecast of demand. The results of planning are:

- Routings, which specify operations, operation sequences, work centers, standards, toolings and fixtures. This routing becomes a major input to the manufacturing resource planning system to define operations for production control purposes and define required resources for capacity requirements planning purposes.
- Process plans, which typically provide more detailed systematic work instructions including: dimensions related to individual operations, machining parameters, set-up instructions, and quality assurance checkpoints.
- Fabrication and assembly drawings to support manufacture (as opposed to engineering drawings to define the part).

Manual process planning is based on a manufacturing engineer's experience and knowledge of production facilities, equipment, their capabilities, processes, and tooling. Process planning is very time-consuming and the results vary based on the person doing the planning.

1.3.2 Computer Aided Process Planning

Manufacturers have been pursuing an evolutionary path to improve and computerize process planning, which has gone through the following five stages:

Stage I - Manual classification; standardized process plans

Stage II - Computer maintained process plans

Stage III - Variant CAPP

Stage IV - Generative CAPP

Stage V - Dynamic, generative CAPP

Prior to CAPP, manufacturers attempted to overcome the problems of manual process planning by basic classification of parts into families and developing somewhat standardized process plans for part families (Stage I). When a new part is introduced, the process plan for that family is to be manually retrieved, marked-up, and retyped. While this improved productivity, it did not improve the quality of the planning of processes, and it did not easily take into account the differences between parts in a family or improvements in production processes.

Computer-aided process planning initially evolved as a means to electronically store a process plan once it was created, retrieve it, modify it for a new part and print the plan (Stage II). Other capabilities of this stage were table-driven cost and standard estimation systems.

This initial computer-aided approach evolved into what is now known as "variant" CAPP. However, variant CAPP is based on a Group Technology (GT) coding and classification approach to identify a larger number of part attributes or parameters. These attributes allow the system to select a baseline process plan for the part family and accomplish about ninety percent of the planning work. The planner will add the remaining ten percent of the process modifying or fine-tuning the process plan. The baseline process plans stored in the computer were manually entered using a super planner concept that is, developing standardized plans based on the accumulated experience and knowledge of multiple planners and manufacturing engineers (Stage III).

The next stage of evolution is toward generative CAPP (Stage IV). In this stage, process planning decision rules are built into the system. These decision rules will operate based on a part's group technology or features technology coding to produce a process plan that will require minimal manual interaction and modification (e.g., entry of dimensions).

While CAPP systems are moving more and more towards being generative, a pure generative system that can produce a complete process plan from part classification and other design data is the goal for the future. This type of purely generative system (in Stage V) will involve the use of artificial intelligence type capabilities, to produce process plans as well as to be fully integrated in a CIM environment. A further step in this stage is dynamic generative CAPP, which would consider plant and machine capacities, tooling availability, work center and equipment loads, and equipment status (e.g., maintenance downtime) in developing process plans.

The process plan developed with a CAPP system at Stage V would vary over time depending on the resources and workload in the factory. For example, if a primary work center for an operation(s) were overloaded, the generative planning process would evaluate work involving that work center, to be released alternate processes and the related routings. The decision rules would result in process plans that would reduce the overloading on the primary work center by using an alternate routing that would have the least cost impact. Since finite scheduling systems are still in their infancy, this additional dimension to production scheduling is still a long way off.

Dynamic, generative CAPP also implies the need for online display of the process plan on a workorder-oriented basis to insure that the appropriate process plan is provided to the shop floor. Tight integration with a manufacturing resource planning system is needed to track shop floor status, load data, and assess alternate routings vis-a-vis the schedule. Finally, this stage of CAPP would directly feed shop floor equipment controllers or display assembly drawings online in conjunction with process plans in a less automated environment.

1.3.3 Some of the New Approaches in Process Planning

In many companies, product and process design are fragmented and difficult to manage and coordinate. CAD/CAE tools automate the design and development process but, in many cases, cause the rapid proliferation of designs without regard to the impact on the rest of the organization. While these tools are integrated to varying degrees, often these systems are used to create an item's geometry on paper to communicate with other functional areas of a company [15].

As mentioned earlier a company recreates an item geometry many times in different departments. This allows errors to creep into the process and data is mis-handled or lost. Delays are inherent in this process and extra effort is required to coordinate activities. Technology and information integration represent one dimension of overcoming these traditional problems. Integrated design and manufacturing automation systems and databases are the basis for the engineering blueprint of the future. This will allow manufacturers to cost-effectively improve product and process design, while facilitating the integration of design activities with the production process.

Product and process design will be greatly enhanced with integrated databases and information systems to maintain and optimize use of design information. Product and process design information must be treated more as a corporate-wide resource. This information must be stored and maintained in a logical, consistent, non-redundant and usable manner.

The automation of manufacturing planning activities presents many challenges, since it involves a multitude of conflicting criteria and competing objectives and also requires a great deal of expertise and knowledge, both of which are not easy to model and codify. For example, minimizing product costs and keeping on a tight delivery time schedule is always a dilemma, and it is hard to fulfill these two objectives simultaneously. Hence, some research in production planning support systems focus on isolated portions of planning activities, especially on the improvement of manufacturing process performance such as: selection of cutters and optimal machining parameters; and the generation of optimal cutting toolpaths, etc. However, several questions in CAMP remain unanswered and many issues must still be resolved. Some of the new approaches in these areas such as feature based process planning, solid model based process planning, static and dynamic process planning are discussed in Chapter 3.

1.4 The Work in the Thesis

Using present design approaches and tools, there is incomplete knowledge of the required manufacturing steps to produce the part, and inadequate consideration of the variety of other downstream influences that shape time to market, market acceptance, and product longevity. In the part design stage many important constraints relative to the product and its process of manufacture often neglected. These flaws lead to a multitude of costly and time-consuming design reworks or difficult process modifications as unanticipated problems must be rectified.

The work in this thesis was to develop an Integrated Product and Process Planning Information System (IPPPIS) for a machine tool manufacturing firm. For this, analysis of the fundamental elements necessary for modeling manufacturing and process planning framework used in machine tool manufacturing was done. Then a model for collaborative design has been developed for a machine tool manufacturing firm. The workability of this approach was tested using a prototype of the system developed. Case study is presented to demonstrate the feasibility of the approach and brings out the benefits.

1.5 Organization of the Thesis

Chapter 2: This chapter is devoted to discussion on research issues, research objectives, and research methodology after conducting a literature survey on information systems, database application for decision-making.

Chapter 3: This chapter is used to present a discussion on CE, design for manufacturing, process planning systems, databases and GT classification in the context of a machine tool manufacturing company.

Chapter 4: Concepts used for developing a classification and coding system in the context of a machine tool manufacturing company are discussed in this chapter.

Chapter 5: Process design, process planning and information modeling using object-oriented system analysis approach in the IPPPIS are detailed in this chapter.

Chapter 6: Information modeling of the process, manufacturing activity, manufacturing resource, manufacturing cost and time, manufacturing plan is detailed in this chapter.

Chapter 7: A case study dealing with product and process design of small parts for a machine tool company is presented in this chapter.

Chapter 8: In this last chapter conclusion, limitations of this work and scope for future work are presented.

Chapter 3: Concurrent Engineering and Information System for Product Development

Product and process technology is rapidly evolving to overcome the challenges of global competition. Customers are placing more emphasis on quality and reliability, at the same time looking for more good value. Time to market or speed to market is becoming a key paradigm of world-class manufacturing. To respond to this dynamic and challenging environment, manufacturers are implementing concurrent engineering concepts to reduce design cycle time and increase product value. While design for manufacturability (DFM) is core part of concurrent engineering, its concepts are based on the entire product life cycle from concept development through use and disposal.

Different approaches for concurrent design of product and process is explained in the first part of this chapter. Cost and time impact of DFM concepts and different process planning approaches are detailed in the later part of this chapter. CE system for product and process design is presented with the need for an object-oriented database management system to represent this information. Finally, data base application and Group Technolog (GT) in the context of data mining and decision support systems are explained in the last part of this chapter.

3.1 Concurrent Engineering

Concurrent engineering is based on the concept of integration of design of products, manufacturing and support process. It is different from the traditional way of assessing manufacturability of the product after it has been designed, and then making appropriate changes to the product to enhance its producibility. This approach increase the design cycle time, increases the product development cost, and may not result in the optimum way to produce the product. Instead, manufacturability has to be considered and built into from the very start of product development and design. A framework for concurrent engineering is presented in Figure 3.1.

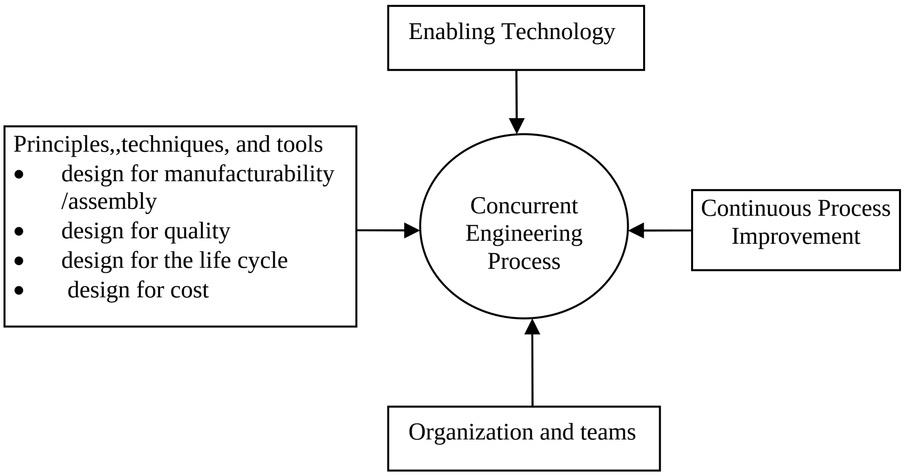


Figure 3.1 A Framework for Concurrent Engineering

3.1.1. Definition of CE

"Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. Typically, concurrent engineering involves the formation of cross-functional teams, which allows engineers and managers of different disciplines to work together simultaneously in developing product and process design [74]. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements".

3.1.2 Goals of CE

- Greater competitiveness
- Improved profitability
- Rise sales and profits from new products
- Reduce new product time-to market

- Reduce human and capital costs
- Maintain or increase product quality
- Leverage knowledge and experience
- Close integration between departments and promotion of team spirit

3.1.3 Scope of CE

- Implement process changes within 1-2 years
- Involve people with stakes in new products
- Focus on business process improvements

3.2 Systems Engineering Based Approach for Product and Process Concurrent Design

Design of the product and the process have to be integrated to assure optimum process is used for manufacturing of the product. This additional consideration is also needed to ensure integration of the design of the product [74].

3.2.1 Product Upstream Design

The product upstream design process is based on the requirement modeling process. The specification file constitutes the starting point or base for the design process (Figure 3.2, left part). The first step of the process relates to the users need capture. It is an important step because there are lot of technical information, from the functional class (e.g. "dimensioning of the product") and non-functional class (e.g." the cost") to be captured. Moreover, the knowledge of project manager is used to ensure that these need are realistic and to refine them if necessary [76].

The third step is verification/validation of the technical requirements. On the one hand, verification deals with evaluating each technical requirement to ensure that it would have the quality representation of the user's need. On the other hand, it has to be ensured that there is no contradiction among the expressed requirements. Validation is based on the stakeholder needs, which led to requirement description. The task here is to ensure that each stakeholder needs have been taken into consideration.

The technical requirements verification / validation failure results in return to the requirements analysis step. At the end of this step, product design process is achieved and the product design file is transferred to the manufacturing process upstream design, which will analyse it. This process responds either by a continuation development acceptance or by a modification request. The second situation is associated with a technology modification request or with a non-conformity problem. This implies a new capture of the users needs.

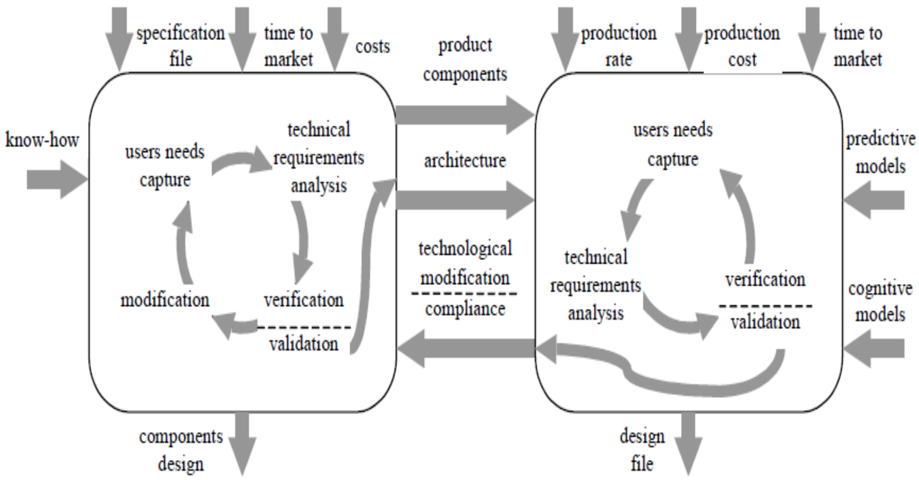


Figure 3.2 Product (on left) and (on right) Process Upstream Co-design [76]

3.2.2 Process Upstream Design

This design process is based on the inputs from the requirement modeling process (Figure 3.2, right part). The product design process, starts with the stakeholder needs capture. In addition to the stakeholder needs, this step has to take into account the information transmitted by the product design process, by the way of the product design file. This set of needs is analysed and refined and is passed on to the next step.

In the requirements analysis also ensures feasibility of the needs. This activity is relies on the experience feedback. A set of system technical requirements is then made available.

The verification/validation step can lead to conclusion that some technical requirements do not satisfy the initial needs. In that case, a new iteration is carried out within the design process, as an internal feedback. When these iterations end, the result of this step is transferred to product design process. The outcomes are, the product associated to the design file proposed is feasible, or it is feasible with some compromise of realisation, or it is not feasible. The product design process will work till the product is realisable and it is possible to continue the development of the process design. The virtual prototyping step can be then started. The objective of this is to obtain the best knowledge of the manufacturing process, before its actual realisation.

3.2.3 Product and Process Co-design

Concurrent design consists of binding the two design processes as suggested in Figure 3.2. The product design process is a "major" part of the design movement, which provides a design file expressing a set of technical requirements that the process design task would have to take into consideration. The process design task considers the following:

1. The product design file containing the description of a feasible product, which is then passed to the next level.
2. If product detailed in the design file is not feasible, and then the upstream design processes will have to be reactivated for fixing new technical requirements.
3. If the product is feasible with some minor modifications, the product

design team checks the acceptability of these modifications for meeting the stakeholder needs and give a new product design file with more precise design information.

3.3 Understanding the Advantages- Industry Experience

Table 3.1 shows the effect of concurrent engineering on percentage (%) product development Cycle-Time reduction by industry, based on 25 researches studied reported in Paul D. Collins and Alan Leong [77].

Table 3.1 Effect of Concurrent Engineering on Percent (%) Product Development Cycle-Time Reduction by Industry [77]

Industry	% Time Range	Reduction Median
Agriculture	54	54
Aerospace	38-43	40
Automotive	25-7 5	50
Chemical	44	44
Computer	59-71	65
Consumer Goods	20-56	47
Electromechanical	24-79	52
Electronics	40-67	50
Heavy Machinery	60-63	61
Medical Devices	42-50	46
Telecommunications	33-67	50
• Cycle- time reduction averages about 50% • Robust effects among firms in many industry groups		

CE has led to dramatic benefits for a large number of companies from various industries. Some of the findings are presented here as a pointer towards the potential benefits of this best practice [74]. World-class companies have achieved remarkable performance using concurrent engineering. Table 3.2 gives some of the benefits obtained from concurrent engineering.

Table 3.2 Benefits Obtained from Concurrent Engineering [74]

Benefits and Metrics	**Results**
Decreased lead time	
Development time	30-70%
Time to market	20-90%
Improved quality	
Engineering changes	65-90% fewer
Scrap and rework	up to 75% less
Overall quality	200-600% higher
Reduced Cost	
Productivity	20-110% higher
Return on assets	20-120% higher
Manufacturing costs	up to 40% lower

Boeing's Ballistic System Division achieved the following improvements.

- 16% to 46% in cost reduction in manufacturing
- Engineering changes reduced from 15-20 to 1-2 drafts per drawing
- Materials shortage reduced from 12% to 1%
- Inspection costs cut by a factor of 3
- NCR , Ohio, USA used CE to develop a new cash register and achieved the following benefits;
- reduction in parts and assembly line;
- 65% fewer suppliers;
- 100% fewer screws or fasteners;
- 100% fewer assembly tools;
- 44% improvement in manufacturing costs;
- a trouble-free product introduction.

A study at Rolls Royce revealed that design determined 80% of the final production cost of 2000 components. According to General Motors executives, 70% of the cost of manufacturing truck transmissions is determined in the design stage. Ford Motor Company has estimated that among the four manufacturing elements of design, material, labor, and overhead, 70% of all production savings stem from improvements in design.

A study revealed that product design is responsible for only 5% of a product's cost; it can however determine 75% or more of all manufacturing costs and 80% of a product's quality and performance. Another study shows that 70% of the life cycle cost of a product is determined at the design stage [Figure 3.3]. The life cycle cost here refers to cost of materials, manufacture, use, repair, and disposal of a product [78, 79].

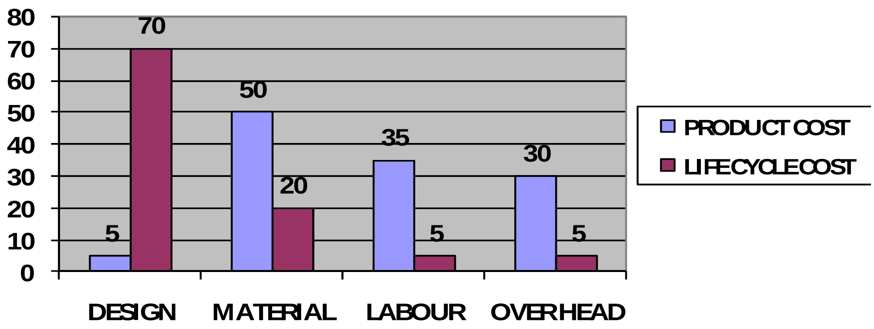


Figure 3.3 Product Cost Vs Life Cycle Cost

3.4 Traditional Versus Concurrent Design

Competition in the marketplace forces machine tool manufacturing firms to continuously-generate new (and more attractive) product designs while maintaining high quality, low costs and short lead-times [7]. Traditionally, decisions on these issues were taken in a serial pattern. First, a product design was selected from a set of feasible designs, driven primarily by marketing objectives and engineering constraints. The chosen design was then transferred to the production planning function that developed an appropriate manufacturing plan. Such plans were guided primarily by operational objectives (e.g., cost minimization, capacity utilization, load balancing, etc.). Finally, the product design and the production plan decisions became constraints for the logistics function that determined the supply sources. This serial pattern is known to generate solutions that suffer from two major deficiencies [45].

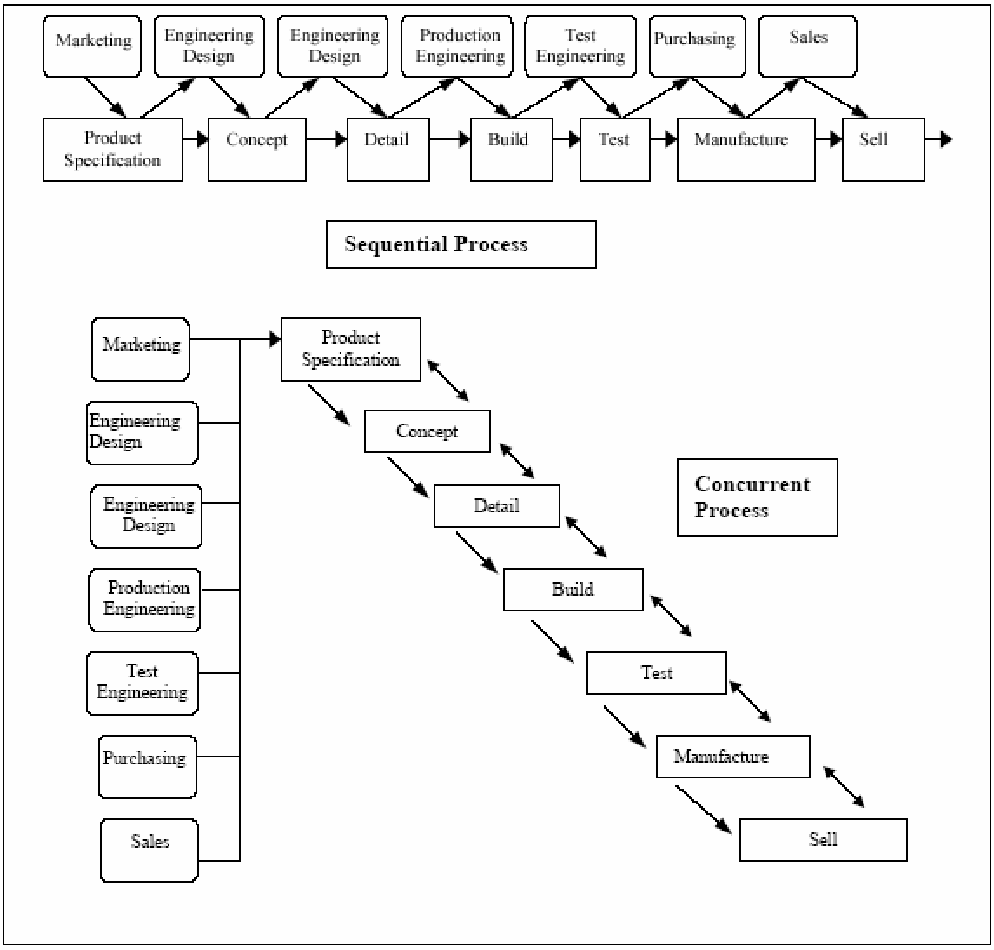


Figure 3.4 Sequential and Concurrent Development of New Product[5]

First, it is slow because parallel processing opportunities are often missed. Second, it leads to sub-optimal solutions, because each stage can make, at best, sequential locally optimal choices. Concurrent engineering (CE) is a paradigm aimed at eliminating such flaws. CE dictates that product and process decisions are made in parallel as much as possible, that production considerations to be incorporated into the early stages of product design. CE concept leads to a fundamental tradeoff. On one hand, it reduces the need for re-design and re-work (thus reducing development time) and increases the chances for smoother production (thus helping to minimize cost and improve quality). Figure 3.4 shows process in sequential and concurrent development in a machine tool manufacturing company [5, 8].

3.5 DFM and Concurrent Engineering

Generally, concurrent engineering (and DFM) is accomplished through a iterative "spiral" design process (shown in Figure 3.5) in which marketing experts, designers, manufacturing engineers, and other personnel jump back and forth between identification of customer needs, design of the product, and assessment of manufacturing issues [34,37].

Barriers to effective DFM and concurrent engineering occur when the people performing marketing, design, and manufacturing cannot communicate or share knowledge. For example, when designers lack detailed knowledge of the current manufacturing practices and the manufacturing engineers are not available to provide this assessment, the designers may not be able to do sufficient manufacturing assessments of their designs. The result may be commitment to a design that is unnecessarily expensive to manufacture.

Before the industrial revolution, the salesperson, designer, and craftsperson were often the same person. This person had a detailed understanding of the customer's needs: how the design would meet those needs, and how it would be made. Concurrent engineering naturally occurred within that person's head. However, as industries have grown in size and complexity, marketing, design, and manufacturing departments have evolved into separate departments, each with their own specialized knowledge. While this makes the streamlined creation of complex products possible, it has also increased the knowledge and communication barriers between these areas. The goal behind many DFX tools is to supply designers with manufacturing, quality, environmental impact, or other product life cycle knowledge that is otherwise inaccessible. Various ways in which these methods may be applied in any or all of the life cycle stages shown in Figure 3.5 [37].

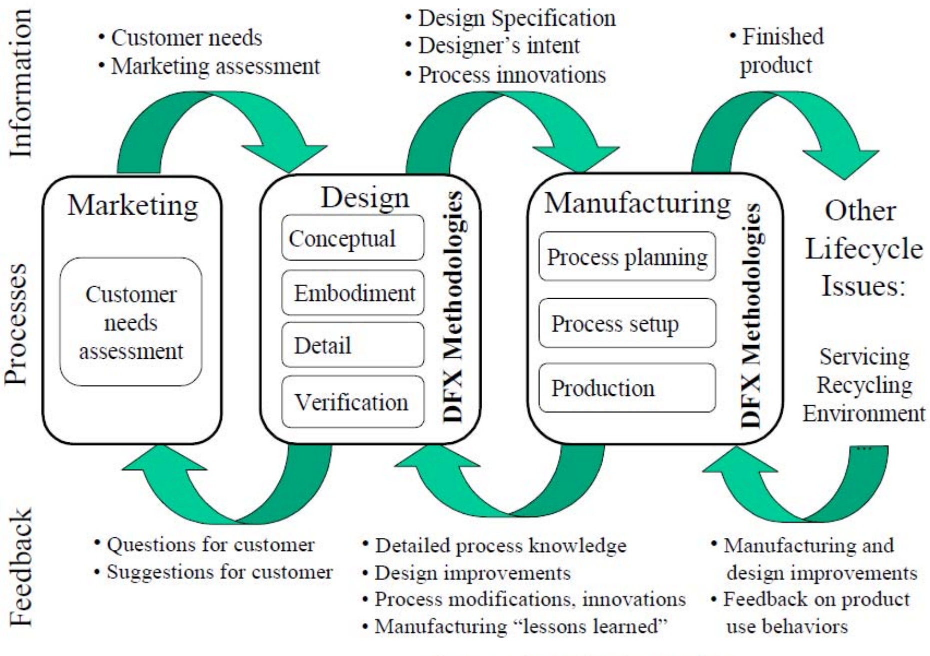


Figure 3.5 The Design for X cycle [37]

3.6 Design for Manufacturability

Design for manufacturability is a proven design methodology that works for any size company. Early considerations of manufacturing issues shorten product development time, minimize development cost and ensure a smooth transition into production and reduced time to market [37, 75].

Quality can be designed in with optimal part selection and proper integration of parts, for minimum interaction problem. Considering the cumulative effect of part quality on product quality, designers are encouraged to carefully specify part quality.

Many costs are reduced, since product can be quickly assembled from fewer parts. Thus, products are easier to build and assemble, in less time, with better quality. Parts are designed for ease of fabrication and commonality with other designs. DFM encourage standardization of parts, maximum use of purchased parts, modular design and standard design features. Designers will save time and money by not having to "reinvent the wheel". The result is a broader product line that is responsive to customer needs.

Companies that have applied DFM have realized substantial benefits. Cost and time to market are often cut in half, with significant improvement in quality, reliability, serviceability, product line breadth, delivery, customer acceptance and general competitive posture.

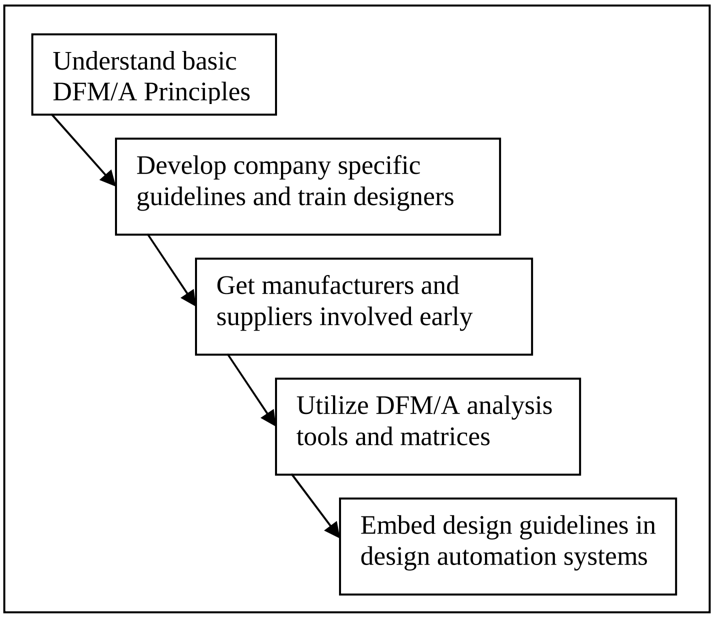


Figure 3.6 Stages of Design for Manufacturability

A key concept of concurrent engineering is the design of a producible product that can be cost effectively manufactured within the enterprise's production process. The application of design for manufacturability/ assemblies (DFM/A) principles and tools facilitates the development of producible product. Producibility needs to be designed into the product from the very beginning through early manufacturing involvement and application of DFM principles, rather than modifying product design prior to release to production, to correct deficiencies that result in an un-producible design. In other words, the design of the product needs to be integrated with the design of the manufacturing process. There is a series of evolutionary stages that an organization will typically take to incorporate DFM/ A concepts [37, 75]. These stages are shown in Figure 3.6.

3.6.1 Benefits of DFM

DFM can increase profits both by increasing revenue and by lowering costs. The principle of considering all goals and constraints early can produce a better product, in addition to a more manufacturable one. Further, the product will enter the market place earlier, because an inherently simpler product is designed right the first time, without the introduction of any problem, delays and change orders. Having a better product that enters the market sooner can have a substantial effect on sales. Sales and market share projections can quantify this potential.

The other source of increased profits is cost reduction. It should be emphasized that any cost saving go straight to the bottom line as profit.

1. Assembly cost saving.
2. Part fabrication cost saving.
3. Work-in-process Inventory saving
4. Market flexibility and delivery
5. Finished goods inventory saving.
6. Material overhead savings
7. Machinery utilization savings
8. Floor space savings
9. Quality cost savings
10. Development cost savings
11. Product sooner to market.
12. Superior product design

3.6.2 The Early Effects of Design

By the time a product has been designed, only about 8 % of the total product budget has been spent. However, by that point, the design has determined 80% of the lifetime cost of the product. (See Figure 3.7). The design determines the manufacturability, and that determines a significant part of the introduction and production cost, of 80 % 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, because it has the most influence over the design’s overall cost.

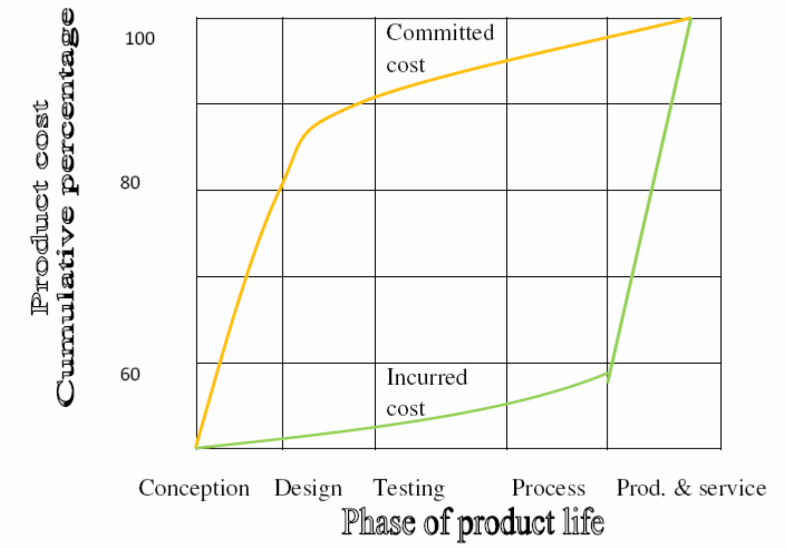


Figure 3.7 Product Cost Vs Time

3.6.3 DFM Versus Design Time

Designers may also be tempted to think that considering all these constraints will delay the completion of the design. However, it really takes no more time (may be even less time), because thinking about all the constraints at once will steer the designer more quickly to the optimal design.

Table 3.3 Cost of Engineering Changes [75]

Time of design Change	Cost $
During Design	1,000
During Design Testing	10,000
During Process Planning	100,000
During Test Production	1,000,000
During Final Production	10,000,000

The net result of not considering manufacturability early is a design, which will not easily incorporate DFM principles later. In order to make such a design manufacturable, it may be necessary to make changes in the design. The cost of changes rises drastically as the product progresses towards production. Table 3.3 shows how the cost for each change escalates during the development of major electronic product [75]. A very expensive and time-consuming way to implement DFM is through engineering change orders (ECO's). Thus, spending a little time early on DFM saves a lot of time later by avoiding changes and redesigns.

3.7 Understanding Manufacturing

Designers should know the process that will be used to build what they design. No one would be impressed with recipes created by someone who never cooked. Similarly, designer should be familiar with all the processes they are specifying. This is the only way they can choose the right process, specify the right tolerance, utilize existing factory process, minimize setup changes, and assure smooth product introduction. All of these will minimize costs.

3.7.1 Process Capability

Process capability is the repeatability and consistency of a manufacturing process, relative to the customer requirements in terms of specification limits of a product parameter. This measure is used to objectively measure the degree to which your process is meeting or is not meeting the requirements [15, 80]. Capability indices have been developed to graphically portray that measure. Capability indices let you place the distribution of your process in relation to the product specification limits. Capability indices are to be used to determine whether the process, given its natural variation, is capable of meeting established specifications. It is also a measure of the manufacturability of the product with the given processes. Capability indices can be used to compare the product/process matches and identify the poorest match (lowest capability). The poorest matches then can be targeted on a priority basis for improvement.

The Figure 3.8 shows a series of sample distributions that fall inside of and outside of the specification limit [80]. This is an example of an unstable, and not capable process. The right side of the diagram shows all of the distributions falling within the specification limits. This is an example of a capable process.

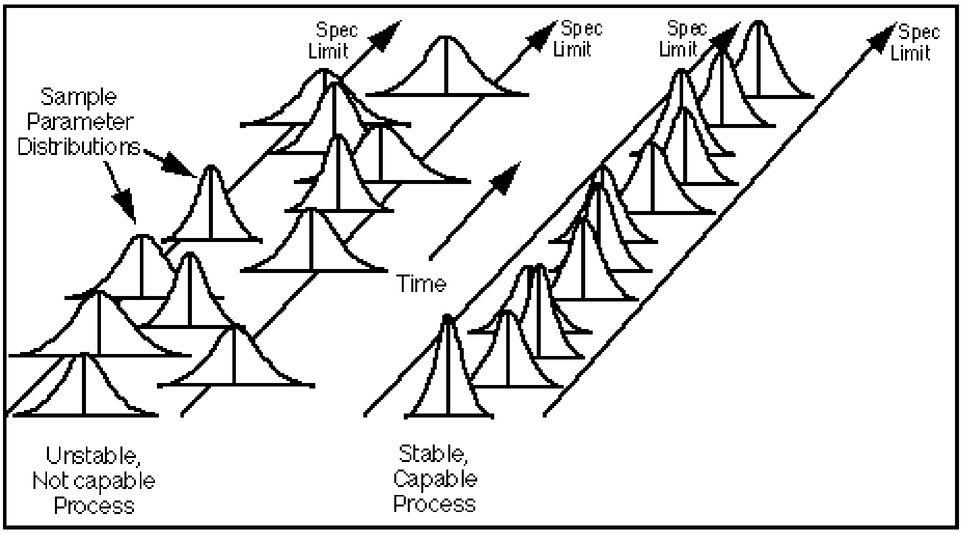


Figure 3.8 Sample Distributions that Fall Inside of and Outside of the Specification Limit [80]

3.7.2 Quality Function Deployment

Quality function deployment is a structured approach to defining customer requirement and translating them into specific steps to produce products to meet those requirements. The "voice of the customer" is the term used to describe these stated and unstated requirements. The voice of the customer is captured in a variety of ways: direct discussion, surveys, customer specifications, observation, guarantee data, filed reports etc.. This understanding of the customer requirements is then summarized in a product planning matrix or house of quality". These matrices are used to translate higher level "what" into lower level "hows" as shown in Figure 3.9 [15].

While the QFD matrices are a good communication tool at each step in the process, the matrices are the means and not the end of this methodology. The real value is in the approach to QFD. QFD is oriented towards organizing a group of people representing various functional organizations that are involved in product development, marketing, design engineering, quality assurance, manufacturing/manufacturing engineering, finance, product support etc.

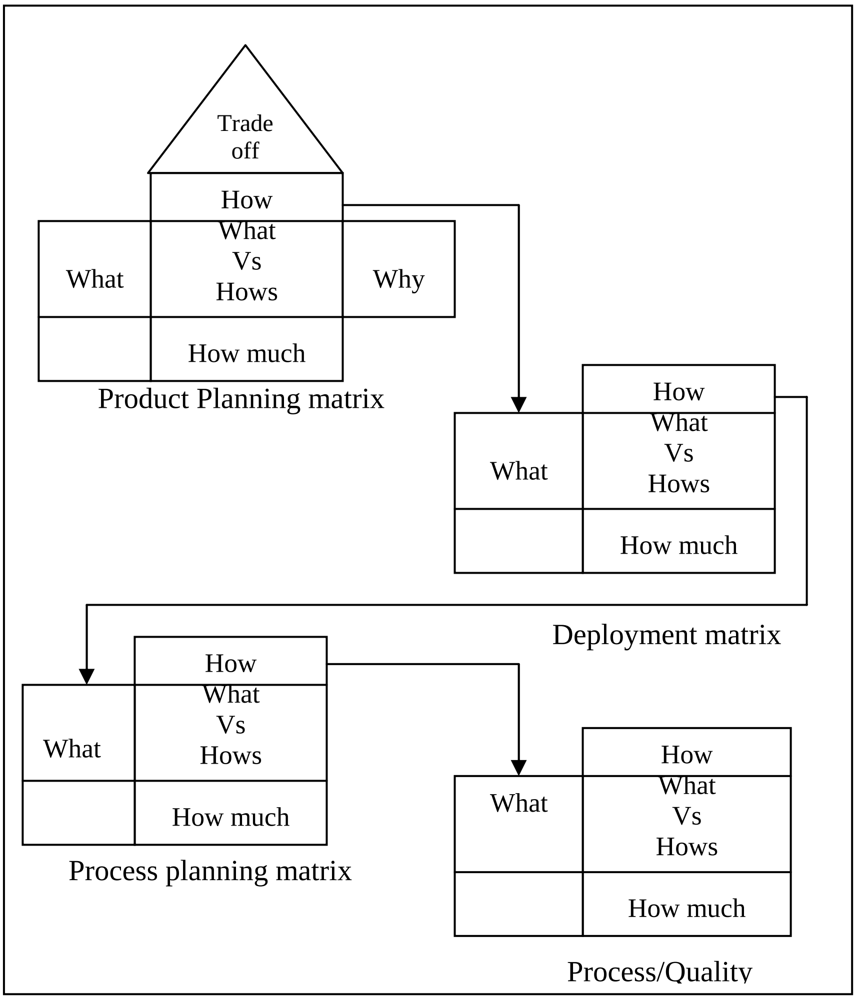


Figure 3.9 Quality Function Deployment (QFD) [15]

Active involvement of these departments can lead to balanced consideration of the requirements or "what" at each stage of this translation process and provide a mechanism to communicate hidden knowledge – knowledge that is known by one individual or department but may not otherwise be communicated through the organization. As a result, QFD is an effective communication and quality-planning tool.

One of the common issues with many companies is that they have not understood what QFD really is or what it can do for them. If one explores the common issues companies face with new product development, one can better understand how QFD can fit into the development process to address the following issues:

1. Current and future customer needs are not adequately understood.
2. The competitive situation is not understood nor adequately considered.
3. Inadequate attention is paid to developing a product strategy and value proposition.
4. Product requirements and specifications are not carefully balanced against needs and implications.
5. Insufficient attention is given to developing collaboration and teamwork.
6. In the rush to develop a new product, inadequate attention is given to developing and evaluating concept alternatives.
7. Critical characteristics, process requirements and quality controls are not effectively linked.

3.7.3 Design for Cost

Product costs are a major consideration in the development of most products. Marketing will generally intend that a new product be targeted for a particular price point, or the product will be proposed to a customer for development based on a quoted product cost. This projected product cost may also include an allocation of the estimated cost (budget) for the development effort. These target costs are provided to the design team as part of the product specification. Techniques such as quality function deployment may also include target costs as part of the product-planning matrix. Cost targets are essential information to help a product development team understand what it needs to accomplish, that is, design to cost.

With a larger, more complicated product/system that may involve multiple product development team, these target cost need to be allocated to different modules, subsystems, or sub-assemblies to provide a tangible target for each team. A tracking system is needed to monitor the achievement of these cost targets. In addition, a product cost model is needed to develop these cost estimates at a relatively early stage in the design and to asses the cost implications of various design alternatives.

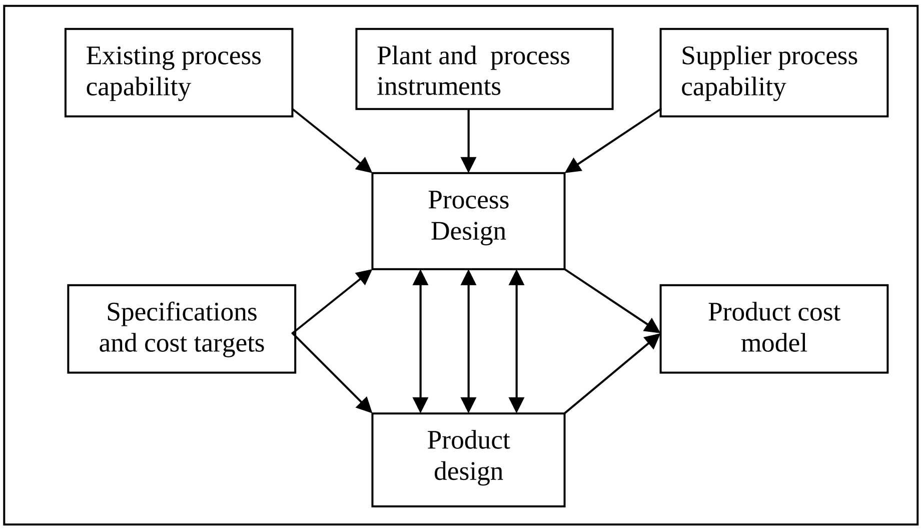


Figure 3.10 Product Cost Model

Figure 3.10 shows the relationship of a product cost model to product and process design activities. A product cost model is based on set of process capabilities that an organization uses. These can be existing process capabilities, or future process capabilities created by investment in new production equipment. Early cost estimates, can be developed using DFM software and cost estimating systems for various manufacturing operations such as machining, and casting. These tools need to be extended to consider other product-cost elements such as tooling, test equipment, and production equipment decisions. Cost modeling software is available to consider the impact of various indirect costs and different process approaches to product costs.

If an effective product cost model is put in place, it will allow the product development team to integrate and summaries the results of many detailed design decisions, and evaluate the effects of different product and process design alternatives. The result will be a projection of product cost, which can be compared to cost target and used to monitor the achievement of design-to-cost objectives.

3.8 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 [81]. Figure 3.11 gives a four-dimensional framework for CAPP [53].

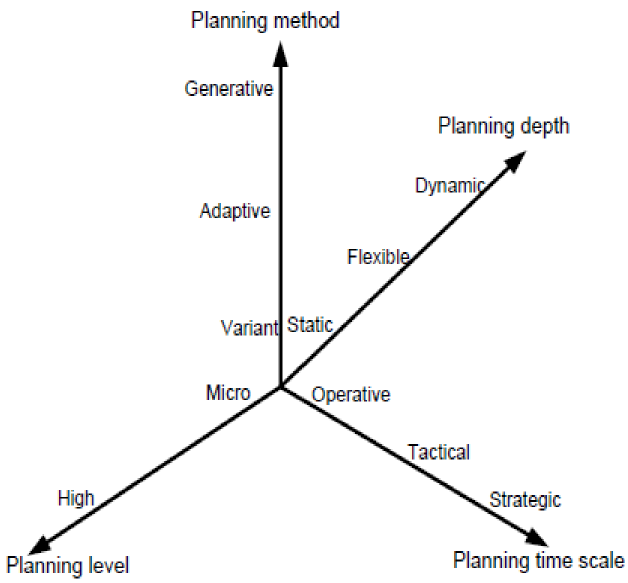


Figure 3.11 Four-Dimensional Frameworks for CAPP [53]

Planning level: Planning may be performed either on a high level, which focuses on the overall selection of rough production strategies, or on a low level that increasingly concentrate on particular processes, such as the determination of cutting parameters, process sequences, cutters, machine tools, and other manufacturing resources.

Planning time scale: The planning time scale can range from short-term planning of a certain production to long-term development of the entire production facilities. Short-term planning is more concerned with manufacturing operations at the shop-floor level, for example, processes, process sequences, and manufacturing resource utilization. Medium-scale planning is based on cost, quality, and process capability, while long-term planning is carried out at the company level to control the total production activities of a manufacturing company. The material planning, production technology, machine cell layout, and production system capability are considered here.

Planning methods: Variant and generative approaches are two basic approaches of the decision-making strategies. Some systems use hybrid decision-making strategies, which utilize both variant and generative approaches.

Planning depth: The generated plans can be treated as fixed or variable according the shop-floor scheduling systems. If a system uses static planning, the plans cannot be modified after being generated. For flexible planning, rough plans without actual manufacturing resources are created off-line. The shop-floor schedulers carry out the final detailed on-line planning and the choice of manufacturing resources. Dynamic planning can change results during the manufacture of parts according to the dynamic state of manufacturing systems.

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.

3.8.1 Variant Process Planning (VPP)

The variant approach, which marks the beginning of CAPP systems, is basically a computerized database-retrieval approach. It is based on group technology, classifying and coding parts for the purpose of segregating these parts into family groups [48]. Standard process plans are stored for each part family. The plans for new parts are derived by the modification of the standard process plans of part families. It follows the principle that similar parts require similar plans. Therefore, the process requires a human operator to classify part, input part information, retrieves 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.

3.8.2 Generative Process Planning (GPP)

The generative approach is used to automatically generated plans based on the analysis of part geometry, material and other factors that may influence the manufacturing decisions [48]. The need for a part description suitable for automated process planning led to the use of CAD models, mostly with a user's interaction for selecting the features of interest and providing data for planning. The use of knowledge-based systems and artificial intelligence techniques were the next major development in the direction of generative process planning. A good combination of algorithmic procedures and heuristics are essential for obtaining a good process plan.

3.9 Some New Approaches

In the last two decades, a lot of research work has been done in different research areas in CAPP. These works can be categorized based on the types of part involved, such as prismatic part, cylindrical parts, sheet metal, foundry and assembly systems [59]. Besides this broad classification, research works can also be categorized based on geometric modelling techniques. Some new ideas are briefly presented here.

3.9.1 Feature-Based and Solid Model Based Process Planning

Solid Model-based process planning uses solid modelling 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.

In the ***prototype Feature Based Automated Process Planning*** (FBAPP) system features are recognized from the removable volume point of view rather than from the part design point of view. The entire process in FBAPP is naturally closer to the thinking of a human process planner.

Interactive and feature blackboard based CAPP is a new approach that complies with the traditional process planning. Human process planner gets familiar with the system very quickly [82]. Plans can be edited manually or completed using 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 contribute, 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.

3.9.2 Object Oriented Process Planning

A lot of research work is done for the application of object-oriented approach to different problems [59, 60]. Object oriented process planning is a logical way for representing 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 behaviour 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 a process planning system provides a tool for addressing the complexity of process planning and the capability to incrementally augment functionality, and as the system matures, the developers can further create a complete manufacturing planning system. Object oriented systems are more flexible in terms of making changes and handling 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.

3.10 A New Wave of Database Applications

One important growth area for database applications is decision support including data warehousing and data mining. Data mining is the process of discovering hidden patterns and relationships in data by using advanced statistical analysis and modeling techniques. Data mining uses discovery-based approaches in which pattern-matching and other algorithms are employed to determine the key relationships in the data. Methods used for data mining include discovering association rules, clustering and classification. Another area of interest is Time Series Analysis. Time series analysis performs data analysis for time-related data in databases and data warehouses. The types of analysis include similarity analysis, periodicity analysis, sequential pattern analysis, and trend and deviation analysis.

3.10.1 Data Models

Before the first DBMS was developed, programs accessed data from flat files. These did not allow representation of logical data relationships or enforcement of data integrity. Data modeling has developed over successive generations since the 1960s to provide applications with more powerful data storage features. In this section, we will look at the differences between data models, concentrating on the relational model and the object model and explain the suitability of object oriented database model for our work.

Generally speaking, data models have evolved in three generations. The early generation data models tend to refuse to completely go-away. After all, companies often have made significant investments in databases, or have critical data dependent on them. Even some first-generation products are still in use and supported by their vendors [22, 66].

3.10.1.1 First Generation

The emergence of computer systems in the 1960s led to the development of the hierarchical and network data models, which are usually referred to as the first-generation data models [83].

3.10.1.2 Second Generation: The Relational Model

The relational model has been the most widely used and commercially successful way of modeling data. Its characteristics are very different from the earlier models. To begin, data entities are represented by simple tabular structures, known as relations. Primary keys and foreign keys define entity relationships and data integrity. The design of a relational database is based on the idea of normalization, the process of removing redundant data from your tables in order to improve storage efficiency, data integrity, and scalability.

3.10.1.3 Third Generation: "Post-Relational" Models

The third-generation models, first proposed in the 1980s, were a response to the problems that often arise when marrying an object-oriented system to a relational database. They are sometimes described as "post-relational," although it is more realistic to consider them as co-existing with the relational model and providing additional options for developers. Unlike the second generation, where the relational model was universally adopted, with some proprietary variations, the object-oriented third generation has evolved in two distinct directions, namely, object *data model* and *object-relational model* [83].

3.10.2 Information Modeling Using Object-Oriented Database Management Systems

Object-oriented model is becoming more and increasingly popular because it can represent complicated connections as well as represent data and data processing in a consistent way [83]. Process integration was the driving force that inspired the development of object-oriented database systems. A primary characteristic of objected-oriented applications is the ability to efficiently manage very complex information.

An object-oriented database management system (OODBMS) provides a storage place for objects in a multi-user client/server environment. Object-oriented model is becoming increasingly popular because it can totally represent complicated connections as well as represent data and data processing in a consistent way [66, 83]. Figure 3.12 gives the details of the database models transition. Figure 3.13 gives the difference in data storage in RDBMS and ODBMS.

An integrated knowledge- based information system has been implemented using the object-oriented database management system that supports Structured Query Language (SQL) in the IPPPIS. The information about an artifact design, processes, resources, time, and cost structure is stored in the database. The preliminary process planning system starts with reading the artifact information from the artifact database, including artifact name, main shape, shape complexity, symmetry, secondary positive features, secondary negative features, material, maximum size, weight, tolerance, surface condition and production volume. Then, the selection of primary manufacturing processes follows. This system automatically selects candidate primary manufacturing processes based on manufacturing knowledge. Next is the selection of: manufacturing resource (machine, die, mold, and tool for machining); estimating manufacturing time and cost; and then selection of the best primary manufacturing processes according to estimated manufacturing cost.

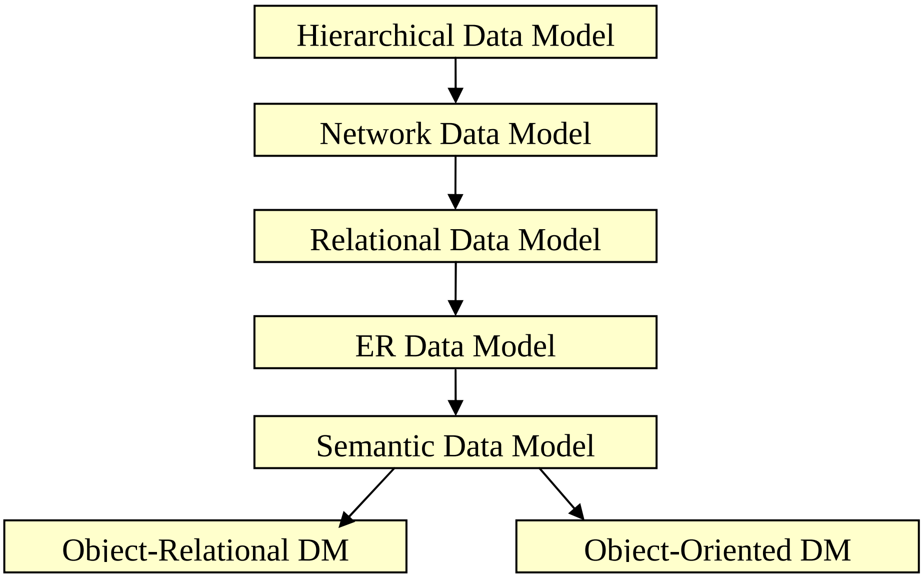


Figure 3.12 Database models transition.

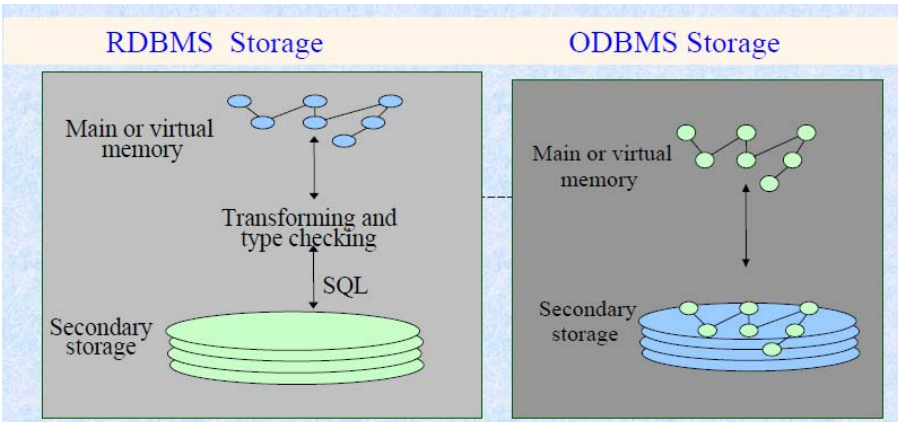


Figure 3.13 Data Storage in RDBMS and ODBMS

3.11 Need for Object-Oriented Database Management Systems

Process integration was the driving force that inspired the development of object-oriented database systems. A primary characteristic of objected-oriented applications is the ability to efficiently manage very complex information. With applications becoming more complex and users becoming more demanding, this type of database is becoming more necessary. One of the areas, which are impacting for the need of efficient and flexible object-oriented database systems, is in the systems for Computer Aided Design (CAD), Computer Aided Software Engineering (CASE). These applications require databases that can handle very complex data that can develop smoothly and can provide the high-performance required by interactive systems. With these requirements in mind it is not surprising that the CAD, CASE, Computer Aided Manufacturing (CAM) areas are specifically being targeted by object-oriented database vendors. Factory and office automation are other areas where object-oriented database technology is also very valuable. Object-oriented database systems can provide solutions for intricate problems and put them within the reach of users. Object oriented database provides a unifying paradigm for the development of database from data model.

Object-oriented databases can store more types of data and access this data much faster than relational databases. Another big advantage of an object-oriented database over a relational database is that you can save unstructured data, such as video clips, audio clips, photographs, and documents, more efficiently. The object-oriented database often returns results more quickly than the same query within a relational database. Perhaps the most significant characteristic of object-oriented database technology is that it combines object-oriented programming with database technology to provide an integrated application development system [60].

The difference between the traditional approach and the object-oriented approach is shown in Figure 3.14. The object-oriented models were achieved in accordance to the requirements of integration in a complex information system and to the functions of traditional databases' administration systems.

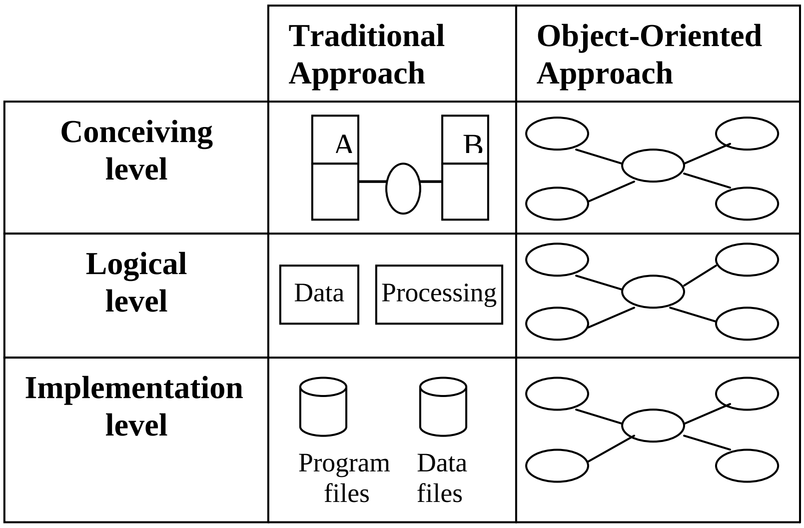


Figure 3.14 Difference Between the Traditional Approach and the Object Oriented Approach

The main concept used is the object. It is described by a complex network which constitute the object's attributes and methods (similar to group technology), Figure 3.15. The CAPP module's database contains:

- graphical data related to the parts, which have the shape and dimensions as basic types of the object-oriented models;
- alphanumeric data, which contain technological information;
- methods base, which comprises optimisation and calculation algorithms.

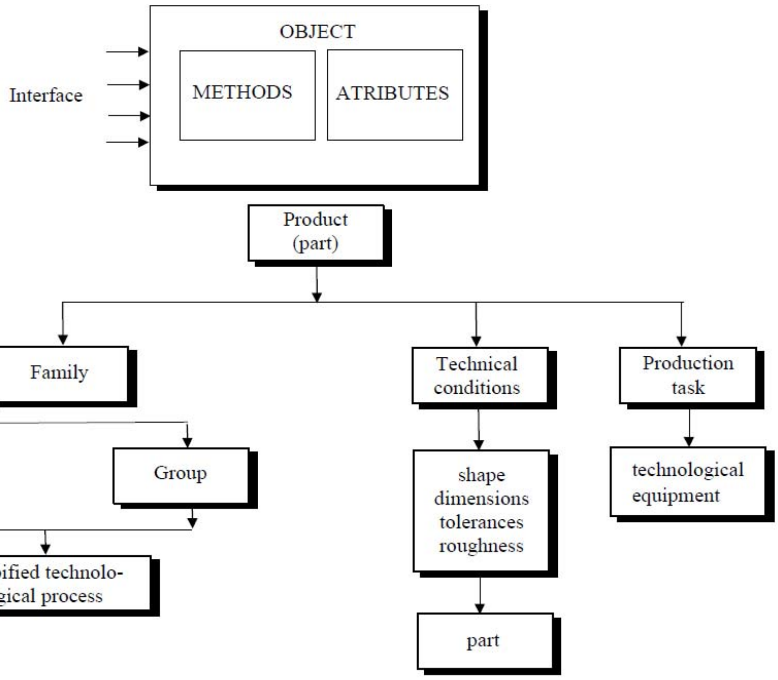


Figure 3.15 Object's Attributes and Methods

3.12 Data Mining and the IPPPIS

The need for automated analysis and discovery tools for extracting useful knowledge from huge amounts of raw data suggests that Knowledge Discovery in Databases (KDD) and data mining methodologies may become extremely important tools in realizing the above objectives. Data mining is primarily used in retail business. Applications to design and manufacturing are still underutilized and infrequently used on a large scale. Data Mining is often defined as the process of extracting valid, previously unknown, comprehensible information from large databases in order to improve and optimize business decisions. Some researchers use the term KDD to denote the entire process of turning low-level data into high-level knowledge [70].

Data mining techniques are at the core of the data mining process and can have different goals depending on the intended outcome of the overall data mining process [60]. Most data mining goals fall under the following main categories:

* *Data Processing* * *Verification* * *Regression*
* *Classification* * *Clustering* * *Association*
* *Sequential Pattern Analysis* * *Model Visualization* * *Deviation Analysis*

Although data mining algorithms are at the core of the data mining process, they constitute just one-step that usually takes about 15% to 25% of the overall effort in the overall data mining process. A collaborative effort of domain expert(s) (e.g., designer, production manager), data expert(s) (e.g., IT professionals) and data mining expert(s) is essential for the success of the data mining integration within design and manufacturing environments. A successful implementation of the data mining process often includes the following important stages. The first step involves understanding the application domain to which the data mining is applied and the goals and tasks of the data mining process; e.g., understanding the factors that might affect the yield of a Silicon wafer in the semiconductor industry. The second step includes selecting, integrating, and checking the target data set that may be stored in various databases and computer-aided systems (such as CAD, CAM, MRP or ERP).

3.12.1 Data Mining in Product Design and Development

The integration of data mining to design and manufacturing to be based on goals and capabilities of data mining as well as goals and weaknesses of current design and manufacturing environments. To broaden the understanding of how data mining can overcome a variety of problems in design and manufacturing a wide range of activities within manufacturing companies are considered.

During the product design and development, process data mining can be used in order to determine relationships among “internal” factors at each stage and “external” factors at consecutive and previous stages. Following are some examples of how data mining can be utilised.

- Data mining can be used to extract patterns from customer needs, to learn interrelationships between customer needs and design specifications, and to group products based on functional similarity for the purpose of benchmarking, modular design, and mass customization.
- At the concept design stage, data mining can support concept selection by: dynamic indexing and retrieval of design information in knowledge bases (e.g., patents and benchmarking products); clustering of design cases for design reuse, extracting design knowledge for supporting knowledge based systems; extracting guidelines and rules for design-for-X (manufacturability, assembly, economics, environment); and exploring interactively conceptual designs by visualizing relationships in large product development databases.
- During system-level design, data mining can aid in extracting the relationships between product architecture, product portfolio, and customer needs data.
- At the detailed design stage, data mining can support material selection and cost evaluation systems.
- During product development planning, data mining can be beneficial to activities, such as: the prediction of product development time and cost; effectiveness of cross-functional teams; and exploration of trade-offs between overlapping activities and coordination costs. Data mining can be used for identifying dependencies among design tasks, which can be used to develop an effective product development plan.

3.12.2 SQL and Data Mining

The large amount of data, which was generated and collected during daily operations and which contain hundreds of attributes, needs to be simultaneously considered in order to accurately model the system's behavior. It is the abundance of data, however, that has impeded the ability to extract useful knowledge. Moreover, the large amount of data in many design and manufacturing databases make it impractical to manually analyse valuable decision-making information. This complexity calls for new techniques and tools that can intelligently and (semi)automatically turn low-level data into high-level and useful knowledge [70].

Data access uses a high-level nonprocedural language (SQL). This makes relational databases better for ad- hoc querying. If the data you require is in the database, you will almost certainly be able to write a SQL query that retrieves it, though it may involve joining many tables to get the data [83]. An application will not be written in SQL itself. That is because SQL is a declarative language, not a programming language. It is not computationally complete, so you cannot write a full program with it. Its job is to express queries and perform some manipulation of the data in the database. As a result, either SQL is used at an interactive prompt or appears as strings embedded within another language. Of course, many relational database systems have the ability to use stored procedures, which are program modules that exist within the DBMS. Even though these are within the DBMS, they still need to combine SQL with another language, such as Oracle’s PL/SQL [84].

3.13 Group Technology and Classification Systems

Group technology principles may be applied to any conceivable entity ranging from manufactured parts and capital equipment to decision processes and human characteristics [85]. GT aims to take advantage of similarities that exist among items, and to increase effectiveness by:

1. allowing similar, recurring activities to be conducted together (e .g . part family scheduling);
2. standardizing similar activities to control activity proliferation and better utilize resources (e.g. control over new designs) ;

3. supporting convenient information retrieval so that historical information is accessible and usable (e.g., retrieval and modification of an old process plan to suit a newly designed part released to manufacturing)

A ***part family*** is a collection of similar parts that share specific design and/or manufacturing characteristics, identified for a well-defined purpose. All parts in a family may require similar treatment and handling methods, and efficiencies are achieved by processing the parts together. Manufacturing efficiencies are gained from reduced set-up times, part family scheduling, improved process control, standardized process plans, standardized instructions, group layouts, higher quality, and in general, increased learning. Product design advantages are gained when design engineers retrieve existing drawings to support new products and when features are standardized to prevent part proliferation [38].

Three structures used in classification and coding schemes are given below.

- Hierarchical structure: known as a mono-code, in which the interpretation of each successive symbol depends on the value of the preceding symbols
- Chain-type structure: known as a polycode, in which the interpretation of each symbol in the sequence is always the same; it does not depend on the value of preceding symbols
- Mixed-mode structure: which is a hybrid of the two previous codes.

Two parts that is identical in shape and size but quite different in manufacturing [Figure 3.16]:

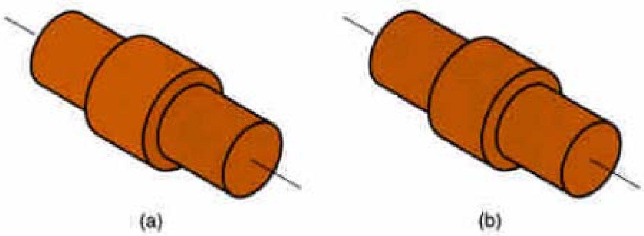


Figure 3.16 Identical Shapes Difference in Manufacturing

(a) 1,000,000 units/yr, tolerance = ±0.010 inch, 1015 CR steel, nickel plate
(b) 100/yr, tolerance = ±0.001 inch, 18-8 stainless steel

As an example, Figure: 3.17 show ten parts that are different in size and shape, but quite similar in terms of manufacturing. All parts are machined from cylindrical stock by turning; some parts require drilling and/or milling.

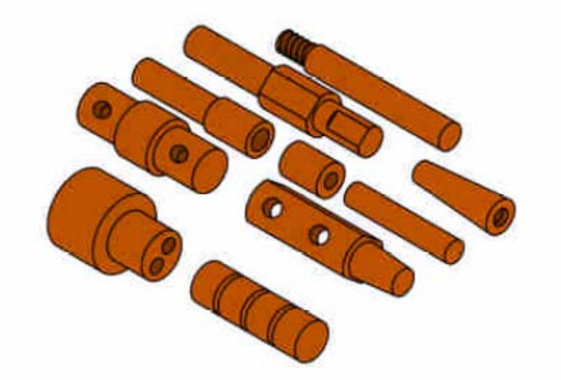


Figure 3.17 Identical Shape Parts Grouped

Three types of activities are necessary for applying group technology:

1. determination of critical part attributes that represent the criteria for part family membership
2. allocation of parts to established families ; and
3. retrieval of part family members and related information

Classification and coding systems can assist in these tasks by providing a structure for the classification of parts into groups based on selected part attributes, and by assigning a code to each part. This code aids information retrieval for that part. A code is a string of alphanumeric characters which, when interpreted, provides information about that part. This is in contrast to a part number, whose purpose is item identification, not description. Although so called `significant part numbers' contain some meaningful information about parts, these are not considered `codes' for the purpose of this study [85].

The process of coding a part is preceded by the classification of the part, which is the determination, for each critical attribute, of the class to which the part belongs. Each such class is represented by a code identifier. For example, design attributes for a wooden bookshelf might be the number of shelves, shelf width and depth, and color of the stain. On the other hand, manufacturing attributes might be, how the wood is cut, how the shelf is assembled, and the methods for actually staining the shelf. The process of coding and classification may be manual or computer-assisted with interactive expert system like queries from the computer.

Part families can be determined by using codes. At first, part-family application objectives must be determined. Part families for design applications often rely on quite different part attributes than those for manufacturing applications; hence, the reasons for generating part families must be made clear. Once the objectives are determined, relevant part family attributes are identified, and codes that correspond to these attributes are specified. The database of coded part is then used to retrieve part family members.

3.14 Existing GT Classification and Coding Systems

Many commercial and non-proprietary coding systems are in existence. The non-proprietary Opitz system, developed in the 1960s in West Germany, is perhaps the best known. It is applicable to both machined and non-machined parts, and has been widely used in Europe. The Brisch Birn system was developed in the UK over 40 years ago. This `system' is actually a coding shell customized to a particular firm's coding needs.

Recent commercial coding systems take advantage of the databases, which are made possible by today's advanced computing technology. Rather than storing strings of symbols that represent classes into which an item falls, these databases capture the exact dimensions or attributes of a particular item. Often, this information is structured as a relational database, which may be accessed using a `natural language' interface (despite the fact that these modern systems do not always use coded data).

Some of the important systems

- Opitz classification system –the University of Aachen in Germany, nonproprietary, Chain type.
- Brisch System –(Brisch-Birn Inc.)
- CODE (Manufacturing Data System, Inc.)
- CUTPLAN (Metcut Associates)
- DCLASS (Brigham Young University)
- MultiClass (OIR: Organization for Industrial Research), hierarchical or decision-tree coding structure
- Part Analog System (Lovelace, Lawrence & Co., Inc.)

Rather than employing a commercial system, firms may choose to combine a (perhaps existing) company database with a database organization and extraction tool to achieve GT intents. New CAD software which can support direct `classification' from CAD databases via graphical attributes of the part raises an interesting issue to what degree is the classification task minimized due to this automation of the data capture process. CAD capabilities do greatly reduce data capture and maintenance costs. On the other hand, problems arise regarding appropriate graphical standards and attributes, and potential limitations on data capture to only design (not manufacturing or other) attributes. This is a relevant technical research area.

3.15 Conclusion

In this chapter, we have seen how concurrent design of product and process can help the organization. A comparison of traditional design with the concurrent design is done, with the discussion on benefits of the CE in manufacturing environment. How CE concepts will benefit the organisation to achieve DFM is explained. It has been discussed how DFM will help the organisation to come up with product with higher quality with lesser design time and cost. Process planning is having an important role to play in the concurrent design of a product and process. Different approaches used for process planning was explained further in this chapter. Object oriented database, which is popularly used as a tool for the information modeling application was explained with the details of SQL. Use of SQL for data mining applications in decision support systems is explained further. Group technology and classification systems were explained with its advantages in the last part of this chapter.

Linking the design and process planning with suitable method is an important point to be addressed in this research. Hence, a discussion on the above topic was done in this chapter to give better understanding on the information requirement in the developed system, in the design and process-planning domain. The next chapter will give details on the information content and codification of this domain knowledge.

Chapter 4: Information Content and its Codification in the System Developed

Machine tool manufacturing is diverse in nature and manufacturers frequently specialise in selected product lines. In addition, with rapid development of manufacturing technology, products that have new features and new manufacturing technologies are introduced constantly. As a result, it is often difficult to develop a classification and coding Group Technology (GT) system for manufacturing of machine tool.

Variety reduction is a popular technique for controlling the costs associated with creating a new part number including administration, stockholding, obsolescence, service and reduction due to economies of scale. Actual figures for creating a new part are difficult to derive reliably but are often quoted as lakhs of rupees per part per annum. Many companies use standards and preferred item catalogues to control the proliferation of common parts such as fasteners, but this approach is ineffective for non-standard items. What the designer requires is an easy means of retrieving a suitable existing part that is significantly quicker than the alternative of drawing a new one.

Part numbering systems exist in most companies and they were used to retrieve information about parts. However, since these systems exist primarily to provide unique identity, they offer very limited search facilities. Product data management (PDM) systems do allow searches on other fields, properties or special keywords and most CAD systems allow text searching on the drawing description. The effectiveness of all these techniques depends on rigorous application of naming conventions and none allows the search to be based on the part geometry. In this chapter, we present a discussion on part codification of the system developed as a part of this research.

4.1 Methodology for Developing a Classification and Coding System

An initial breakdown into major family is a first step in developing a classification and coding system. Each family are characterised by its own set of attributes. These attributes are defined based on their applications of the code. For the classification of parts, the hierarchy decision tree is the most suited in terms of being able to group, divide and search through different application concepts. The multicode structure is usually uses a hierarchical tree to define product families, each with its own polycode set of attributes. The first level of the tree consists of the basic parts families. Each family of parts is mutually exclusive in terms of design attributes and geometric considerations. One of the major elements in the development of an appropriate coding scheme is the ability to identify families and parts that possess similar characteristic. In order to identify such groups the application of coding system should be taken into consideration. A coding scheme for process planning may require definition of major families, which could be different from those developed to support design functions, since the part characteristic and attributes for both applications are different. Although it is possible to develop a single coding system to encompass several application areas, e.g., design, process planning, manufacturing. A survey and analysis of all the important attributes for each application will help to develop meaningful families to support a single coding system.

The coding follows each level of the decision tree and one digit assigned to each level. Once the tree is defined and the parts classified, the coding identifies the parts and could be used in computer applications. The number of digits, which was assigned to describe each of the attributes, depends on the number of attribute values. An attribute with ten or less value was assigned with a single decimal digit. The alphabetical codes or hexadecimal digits were used for attributes with more than ten values. The decimal and hexadecimal digits are preferable in some computer applications. This could facilitate the use of bar-coding scanner for reading the GT codes. When an attribute has a wide range of possible values, several digits was used to describe it and a hierarchical structure is derived. For example, when describing part families, the first digit was used to define a major product family while the next digit was used to define groups within that family. One of the major advantages of using polycode scheme is its scope for future expansion. Because of the infinite variations in the design, technical content, methods of manufacture, new parts always need to be created, classified and added to the database. Thus, there must be room to expand the hierarchical tree and the code. The ploycode scheme allows room for growth and is therefore best suited for the purpose of the research. Figure 4.1 illustrates the process of classification and user code design.

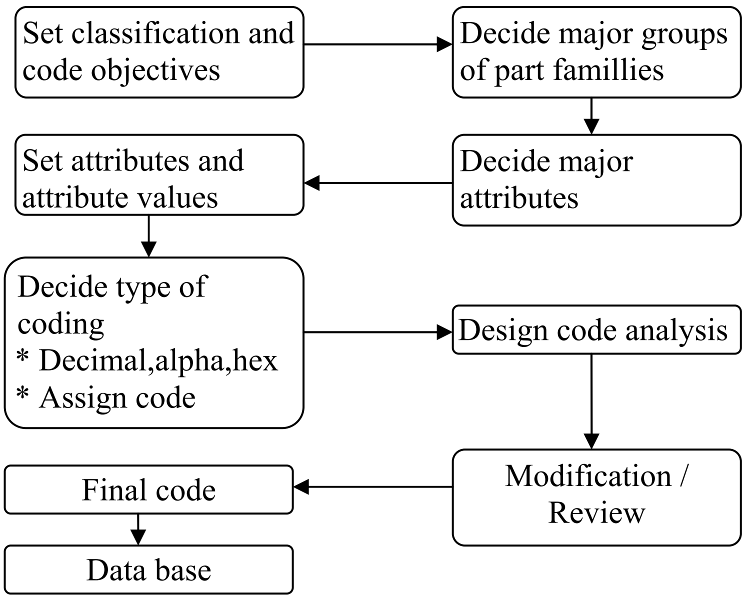


Figure 4.1 Diagram Showing the Process of User Code Design

It is important that classification structures meet application objectives, and are flexible to support future product mixes, new product and process technologies and database integration. At the same time, codes should be as short as possible since long, complex codes require great data collection efforts and greatly reduce ease of use. The ability of more recent systems (which do not use codes) to store exact part attributes in relational databases greatly increases flexibility and case of use, but does not reduce the importance of deciding what data should be captured.

4.2 Coding and Classification System Developed for the Machine Tool Manufacturing Firm

It was necessary to define the application-related attributes for each major family in order to identify the major attributes that distinguishes like and unlike parts. Care was taken to see that, this set should be applicable to all the parts, which are included in the family and should encode parts features, which are relevant to the application for which the code is designed. Each attribute was assigned a set of distinguishing values to capture the differences between parts of a given family. The values may be discrete or non-discrete type, a continuous scale or division of values into appropriate ranges. The number of digits, was assigned to describe each of the attributes, depends on the number of attribute values. Systems was designed considering different part design attributes such as; major dimensions, basic external shape, basic internal shape, length to diameter ratio, material type, tolerances, etc.. In developing the definition of the attributes and various attribute values, the invaluable knowledge of experienced process planner and designers is utilized.

4.2.1 Numbering and Coding System of Design

Depending on the design features and attributes, numbering was done using 19 digits as shown in Figure 4.2. Each of the attributes is further explained.

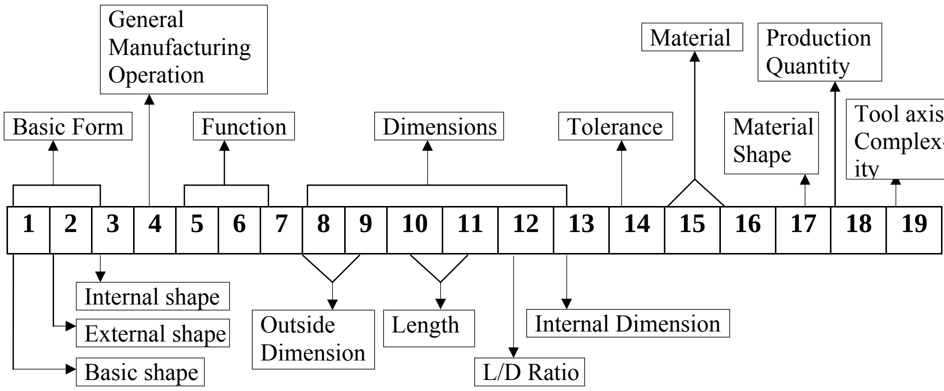


Figure 4.2 Numbering System for Design Attributes Extraction

4.2.2. Basic Shapes Classification for Coding

From the overall shape and size of the component, the basic form to which the component belongs is to be decided. Basic form is decided by basic shape, external shape and internal shape.Basic shape and the corresponding alphabet

Table 4.1 Basic Shapes Coding System

BASIC SHAPES					
1. Rotational symmetrical components	***BASIC SHAPE***	***2. Non-Rotational symmetrical components***	***BASIC SHAPE***	***3. Miscellaneous components***	***BASIC SHAPE***
L/D > 3, Solid/ Axial Hole with or without spur/ helical gear teeth Circular/Hex/Sq sections	**A**	Enveloping Sq <=200 Thickness/Length >3 mm	**F**	Spring: Tension/Compression Wire Cross-section: Circular/Sq/rectangular Tubes & Pipes :Wall thickness <= 4mm without internal machining others than threading Sheet Work . Rolled Sections: Non-Rotational Symmetrical. Unclassified Shapes	**H**
L/D < 3, Axial through opening without gear teeth Circular/Hex/Sq sections	**B**	Enveloping Sq >200 Thickness/Length >3 mm	**G**		
L/D < 3, No Axial through opening without gear teeth Circular/Hex/Sq sections	**C**				
L/D < 3, With Spur or Helical Gear Teeth Sprockets Ratchets	**D**				
Bevel Gears/ Worms/ Worm wheels and other type of gears	**E**				

are then selected as shown in Table 4.1. By external shape, the components are principally classified into three main groups and further sub-classified to eight sub-groups by alphabets A to H.

4.2.3 Special Shapes Classification for Coding

The next two digits are to be selected based on special shape for that basic shape, as shown in Table 4.2 to Table 4.7. To define the special shape, special shape numbers are given for each basic shape depending on the external and internal machining done on the components.

A. Terminology used in the Special Shapes

The terminology used in the case of the special shapes are given below:

1. Holes

As Referred in Basic shapes A, C, D and E: Circular openings with or without threads but co-axial with the axis of rotation of the part. No significance is attached to the tolerance on the diameter.

As Referred in Basic Shapes B: Circular openings with or without threads but co-axial with the axis of rotation of the part. No significance is attached to the tolerance on the diameter. Threads holes are treated separately as 'holes with threads'.

As Referred in Basic Shapes F, G, and H: Circular openings with or without threads having tolerance on diameter coarser than quality IT 8.

2. Accurate Holes

As Referred in Basic shapes F, G and H: Circular openings with or without threads having tolerance on diameter finer than quality IT 8 or equal to quality IT 8.

Accurate holes <= Ø10 will be treated as 'holes'.

3. Aligned Accurate Holes

As Referred in Basic shapes F, G and H: Accurate holes whose centre distance is dimensionally tolerated to quality IT 8 or finer with respect to some reference line.

Table 4.2 Coding of the Details of Machining (Shape A & B)

Details of Machining					
Basic	Special	Internal			External
A	0	Plain/stepped/Tapered+/- Knurled		0	Short hole, Plain/stepped/Tapered
	1	0 + Threads		1	Deep Hole, Plain/Stepped/Tapered
	2	0 + Keyway		2	0 + Keyway +/-Non-axial holes
	3	0 + Spl / Po1		3	0 or 1 + Spl/ Po1 +/- Non-axial holes
	4	2 + Spl /Po1		4	0 + Non-axial holes
	5	2 + Threads		5	1 + Non-axial holes
	6	0 + Flat/Concave m/c on OD /FM		6	Solid
	7	1 + Flat/Concave m/c on OD/FM		7	Solid + Non Axial holes
	8	With gear teeth- other m/c		8	
	9	Other m/c		9	
B	0	Plain / Knurled		0	Hole, Plain/stepped/Tapered
	1	Stepped /Tapered +/- Knurled		1	0 + Threads
	2	0 or 1 + Keyway		2	0 + Keyway
	3	Threads +/- Other m/cs		3	0 + Spl / Po1
	4	0 + Flat/Concave m/c on OD		4	1 + Non-axial holes
	5	1 + Flat/Concave m/c on OD		5	0 + Non-axial holes
	6	0 or 1 + Face m/cs		6	2 + Non-axial holes
	7	Slitted Bais Shape B +/- Other m/cs		7	3 + Non-axial holes
	8	Face claws +/- other m/cs		8	Internal serations Other m/c
	9	Other m/cs		9	Other m/cs

4. Short Holes

As Referred in Basic Shapes A Only: Holes having L/D ratio equal to or less than 6.

5. Deep Holes

As Referred in Basic Shapes A Only: Holes having L/D ratio greater than 6.

6. Non-axial Holes

As Referred in Basic Shapes A, B, C, D and E: Circular openings with or without threads but not co-axial with the axis of rotation of the part, irrespective of the dimensional accuracy.

7. Threads- External

As Referred in Basic Shapes A, B and C: Threads for fastening, power transmission (except worms) and other types are all treated as external threads.

Table 4.3 Coding of the Details of Machining (Shape C & D)

Details of Machining					
Basic	**Special**	**Internal**			**External**
C	0	Plain / Knurled		0	Hole, Plain/stepped/Tapered
	1	Stepped /Tapered +/- Knurled		1	Solid
	2	0 or 1 + Keyway		2	
	3	0 or 1 + Threads		3	
	4	0 + Flat/Concave m/c on OD		4	1 + Non-axial holes
	5	1 + Flat/Concave m/c on OD		5	0 + Non-axial holes
	6	0 or 1 + Face m/cs		6	
	7	3 + Flat/Concave m/c on OD/FM		7	
	8	Not machined		8	
	9	Other m/cs		9	Other m/cs
D	0	No boss		0	Hole, Plain/stepped
	1	Boss on one side		1	Tapered Hole
	2	Bose on both sides		2	0 + Keyway
	3	1 + Keyway		3	0 + Spl / Po1
	4	2 + Keyway		4	1 + Keyway
	5	Multiple gears +/- other m/cs		5	0 + Non-axial holes
	6	1 or 2 + Spl /Po1		6	2 + Non-axial holes
	7	Sprocket Wheels, Ratchets & Change Gears +/-OM		7	3 + Non-axial holes
	8	Gear with face claws +/- Other m/c		8	Internal gear+/- Other m/c
	9	Other m/c		9	Other m/cs

8. Key Way

As Referred in Basic Shapes A, B, C, D and E: Slots open or closed or through, parallel to the axis of the rotation of the part and centrally placed with reference to the same axis.

9. Axis

As Referred in Basic Shapes F and G: Any of the three conventional axes, which are mutually at right angles as referred to any three-dimensional object.

10. Boss

As Referred in Basic Shapes D and E: That portion of the step projecting on one side or both the sides of a gear wheel, the diameter of which is well below the root diameter of the gear, wheel gear teeth are not cut.

11. Face Machining Operations

As Referred in Basic Shapes A, B and C: Operations on the end faces of rotational symmetrical components other than facing them square to the axis of rotation.

12. Guideways:

As Referred in Basic Shape G: Machined profiles excluding circular profiles, which are generally referred as guideways and slideways in machine tools. These can be defined broadly as machined profiles which guides the mating part so that it has relative freedom for 'to and fro motion' in one direction only.

13. Abbreviations:

As Referred in All Basic shapes:

Pol - Polygon

L/D - Ratio of maximum overall length to maximum outside diameter/side of square/width across flat.

FM - Face machining

OM - Other machining

\+ - With

\- - Without

14. Other Machining:

As Referred in all Basic Shapes: Such of the machining external/internal on the components, which cannot be classified by the numbers 0 to 8 detailed in special shape text.

15. T-slots:

As Referred in all Basic Shapes G: T-slots are self-explanatory; they include other slots also for numbering.

Other Slots: Such of the slots, which facilitate fixing of movable dogs etc. They are defined here as slots, where the ratio of length to maximum width of the slot is greater than 10.

Table 4.4 Details of Machining (Shape E)

Details of Machining					
Basic	**Special**	**Internal**			**External**
E	0	Straight bevel gears +/- boss		0	Hole, Plain/stepped/Tapered
	1	0 + Keyway		1	Solid
	2	Straight bevel gears with face claws +/- OM		2	0 + Keyway
	3	Spiral bevel gears +/- boss		3	0 + Spl / Po1
	4	3 + Keyway		4	1 + Non-axial holes
	5	Spiral bevel gears with face claws +/- OM		5	0 + Non-axial holes
	6	Worm Wheel +/- Other m/c		6	2 + Non-axial holes
	7	Worm +/- Other m/c		7	3 + Non-axial holes
	8	Worm + Spur or helical gear teeth		8	Internal gear - Other m/c
	9	Other m/c		9	Other m/cs

Abbreviations

Pol - Polygon

L/D - Ratio of maximum overall length to maximum outside dia/side

FM - Face machining

OM - Other machining

\+ With

\- Without

B. Machining not to be Considered

The following machining detailed below should not be considered for numbering purpose.

1 In Basic Shapes A, B, C, D and E

1.1. Chamfers 45^0, 30^0, 15^0 internal

1.2. Retaining ring grooves internal or external

1.3. Undercuts internal or external

1.4. Relieving grooves for machining internal keyways, gears etc.

1.5. Entry guides internal or external

1.6. Center bores

2. Common to all Basic Shapes

2.1 Oil grooves straight, curved or circular

2.2 Assembly operations

2.3 In components using non-standard preformed raw material, shape of the unmachined part is not to be considered.

Table 4.5 Coding of the Details of Machining (Shape F)

Details of Machining					
Basic	**Special**	**Internal**			**External**
F	0	Surface machined any axis without steps		0	Not machined
	1	Surface machined any axis with step machining		1	Hole parallel to one axis
	2	1 + Surface machined inclined to any axis		2	Hole parallel to more than one axis
	3	Two opp surface m/c parallel & flat without steps & the external profile defined by straight + curved profile but not forming a Sq/Rectangle		3	Hole inclined to any axis +/- 1 or 2
	4	Levers and forks without external turning operation/Gear teeth		4	Accurate holes parallel to one axis +/- 1 or 2 or 3
	5	Gibs + / - Other machining		5	Accurate holes parallel to more than one axis +/- 1 or 2 or 3
	6	With external turning operation but without gear teeth +/- other m/c		6	Alighned accurate holes parallel to one axis +/- 1 or 2 or 3 or 4 or 5
	7	Welded/ Built up parts		7	Alighned accurate holes parallel to more than one axis +/- 1 or 2 or 3 or 4 or 5
	8	With gear teeth +/- other m/c		8	Accurtae holes with keyway / Spl +/- other m/c
	9	Other m/c		9	Other m/c

C. Built –Up- Parts

1. Built-up-parts with Permanent Fastenings

e.g., Welded /Brazed/ Soldered/ Riveted etc.

Rotational/non-rotational symmetrical parts, which are built-up by permanent fastening of two or more components in the manufacturing shop and go as one component on the machine, are to be classified under basic shapes F and G depending on their overall size and numbered accordingly. The details of the built-up-part and the components that go to make it should be covered by one drawing number and drawn on one or more standard drawing sheets.

Table 4.6 Coding of the Details of Machining (Shape G)

Details of Machining						
Basic		**Special**	**Internal**			**External**
G	**a**	0	Surface machined any axis without steps		0	Not machined
		1	Surface machined any axis with step machining		1	Hole parallel to one axis
		2	1 + Surface machined inclined to any axis		2	Hole parallel to more than one axis
		3	Two opp surface m/c parallel & flat without steps & the external profile defined by straight + curved profile but not forming a Sq/Rectangle		3	Hole inclined to any axis +/- 1 or 2
		4	Levers and forks without external turning operation/Gear teeth		4	Accurate holes parallel to one axis +/- 1 or 2 or 3
	b	5	Gibs + / - Other machining		5	Accurate holes parallel to more than one axis +/- 1 or 2 or 3
		6	With external turning operation but without gear teeth +/- other m/c		6	Alighned accurate holes parallel to one axis +/- 1 or 2 or 3 or 4 or 5
		7	Welded/ Built up parts		7	Alighned accurate holes parallel to more than one axis +/- 1 or 2 or 3 or 4 or 5
		8	With gear teeth +/- other m/c		8	Accurate holes with keyway / Spl +/- other m/c
		9	Other m/c		9	Other m/c

4.2.4 Functions Classification for Coding

Next three digits are for the functional identification, which is based on the grouping of the component and end use of the component. The first digit is a character, which generally decides which general function it is having. For example, shaft type item it is represented as ‘S’ and gear type it is represented as ‘G’. The next two digit of the functional identification is for the subsequent sub classification followed in the company. In our example shaft can be further grouped with ‘S01’ for spindle type items with L/D ratio more than 5 and ‘S02’ for spindle type items with L/D ratio less than 5. Functional identification can follow the naming convention followed in the each company.

Table 4.7 Coding of the Details of Machining (Shape H)

Details of Machining					
Basic	**Special**	**Internal**			**External**
H	0	Compression spring: Section-Circular/Square/Rectangular		0	No specification
	1	Tension spring: Section-Circular/Square/Rectangular		1	
	2	Tube and Pipe 1)		2	With holes
	3	Sheet work without bending operation 2)		3	Opening of straight profiles +/- holes
	4	Sheet work with inscription anodized/printed		4	Opening of straight + curved profiles +/- holes
	5	Sheet work with inscription etched/engraved +/- other operations		5	Splines/Polygon/Keyway
	6	Sheet work with bending operation and with no inscriptions		6	5+/- Holes
	7			7	2 +/- accurate holes
	8	Non rotational symmetrical rolled section Egg; Angle/Channel/Tee/I etc		8	With aligned accurate holes
	9	Unclassified shapes		9	

4.2.5 Size Classification for Coding

The six digits of size classification are to be selected based on the ranges of the sizes for the basic shape, length, L/D ratio and internal dimension. The first two digits of size classification are to be selected based on the ranges of the sizes for the basic shape.

Size classifications for each basic shape are given in Table 4.8 to Table 4.12. The first digit of size classification numbers for basic shapes A to E represents, over a range, the maximum OD for circular or side of square for square or width across flats for hexagonal sections. The second digit represents, over a range, the ratio of the overall length to the diameter in the case of circular; to the side of the square in the case of square or to the width across flats in the case of hexagonal sections as given in Table 4.8.

Table 4.8 Size Classification and Coding for Shape A, B, C, D, and E

x	Max OD for circular, side for Sq. and width a/f for Hex. Section		L/D Ratio			
	ABCDE		A		BCDE	
	Over	Upto	Over	Upto	Over	Upto
0	0		3	4	-	0.1
1	12	20	4	5	0.1	0.2
2	20	26	5	6	0.2	0.2
3	26	35	6	7	0.2	0.3
4	35	48	7	8	0.3	0.4
5	48	63	8	9	0.4	0.5
6	63	80	9	12	0.5	0.7
7	80	125	12	20	0.7	1.0
8	125	200	20	30	1.0	2.0
9	200	-	30	-	2.0	-

For basic shapes F & G, the first digit represents over a range, the side of the square prism which is nearest in volume to the components and the second digit represents over a range, the length of the square prism. The side of the square prism is found as follows:

Table 4.9 Size Classification and Coding Shape D7

MODULE				**Serial Number**	
X	Module			XXX	Alloted for
	Over	Upto		000 to 099	Sprocket wheels and Ratchets
1	0	1.5		100 to 199	
2	1.5	2		200 to 299	Change gears
3	2.5	3		300 to 399	
4	3	3.5		400 to 499	
5	3.5	4		500 to 599	
6	4	-		600 to 699	
7				700 to 799	
8				800 to 899	
9	Diametric Pitches			900 to 999	

Table 4.10 Size Classification and Coding for Basic Shape F

Arrange the dimensions of the rectangular prism in the ascending order a, b, c.

(Refer Figure 4.3 for Dimensional details)

If $b/a < c/b$ then b2 is the enveloping Square and ‘c’ is the length.

If $b/a > c/b$ then c2 is the enveloping Square and ‘a’ is the length.

X	Side of the Enveloping Sq in mm		Length or thickness in mm	
	Over	Upto	Over	Upto
0	0	16	-	10
1	16	32	10	20
2	32	40	20	45
3	40	50	45	71
4	50	63	71	112
5	63	80	112	180
6	80	100	180	280
7	100	125	280	560
8	125	160	560	1250
9	160	200	1250	-

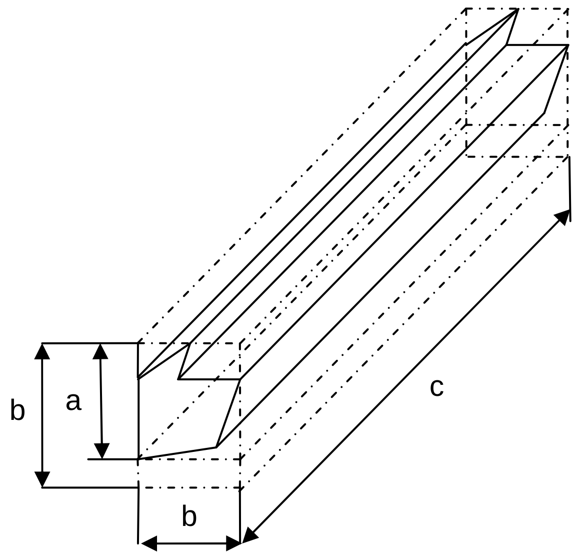


Figure 4.3 Enveloping Square for Basic Shapes F, G, H

Table 4.11 Size Classification and Coding G5 to G9

X	Side of the Enveloping Sq in mm		Length or thickness in mm	
	Over	Upto	Over	Upto
0	200	240	-	25
1	240	280	25	40
2	280	340	40	79
3	340	400	79	125
4	400	475	125	225
5	475	560	225	400
6	560	670	400	710
7	670	800	710	1500
8	800	1600	1500	3000
9	1600	-	3000	-

Table 4.12 Size Classification and Coding for H0 to H8

X	Comp and Tension spring				Tube and Pipe				Sheet and Rolled section *			
	Outside dia of spring		Circular/square/Rectangular section **		Max Outside dia		Developed length		Side of the enveloping square		Length or thickness in mm	
	Over	Upto	Over	Upto	Over	Upto	Over	Upto	Over	Upto	Over	Upto
0	-	6	-	0.4	-	4	-	10	-	35	-	1
1	6	8	0.4	0.6	4	5	10	20	35	50	1	1.6
2	8	10	0.6	1	5	6	20	40	50	70	1.6	32
3	10	12	1	1.6	6	8	40	80	70	100	32	6
4	12	14	1.6	2.5	8	10	80	160	100	125	6	12
5	14	18	2.5	4	10	16	160	320	125	180	12	24
6	18	24	4	6	16	22	320	640	180	250	24	24
7	24	36	6	12	22	32	640	1280	250	355	24	480
8	36	72	12	24	32	45	1280	2560	355	500	480	960
9	72	-	24	-	45	-	2560	-	500	-	960	-

* Consider the developed dimension of components for fixing the size classification number
**Wire dia for circular, side for square, larger side for rectangular cross sections

Of the three overall dimensions of the component the larger of the two, which are geometrically nearer, is taken as the side of the square prism and the remaining dimension as the length. The dimensions of this square prism are considered for size category numbers, as given in Table 4.10 and Table 4.11.

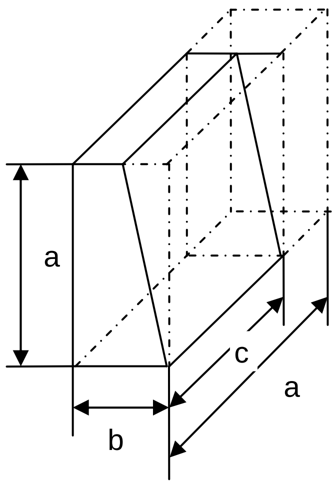


Figure 4.4 Overall Dimension of Square Prism

Exmaple: Enveloping Square for Basic F, G, H

(This is with respect to Figure 4.4)

1) Overall dimensions of the component

a = 75, b = 25, c = 125

Method: Arrange the dimensions in the ascending order

25, 75,125

Find the ratio of the middle number to the first, and last number to the middle and the pair with less ratio value is geometrically nearer.

75/25 =3 125/75 = 1.7 (Approx)

Therefore, the side of the square prism of nearest volume is the greater of the two dimensions forming the geometrically nearer pair i.e., 125 sq and the length of the square is the third dimension i.e., 25.

2) Overall dimensions of the component

c =180, b= 49, a = 25

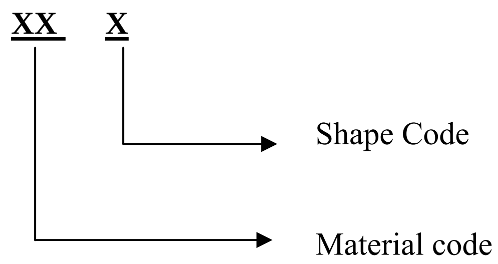
Ascending order 25, 49,180

49/25 = 2 180/49 =8.6

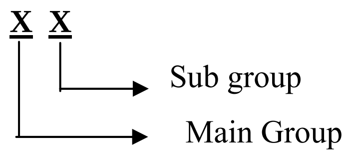
49 sq X 180

4.2.6 Numbering System for Materials for Coding

This system of metallic material is represented by seven-digit number as given below:



Material code (XX)



For details of Main group and sub group, refer Table 4.13 and Table 4.14.

Table 4.13 Material Coding and Classification Steel

Main Group / Sub Group	0	1	2	3	4
	Cast Iron	Grey Cast Iron	Construction Steels	Cast, Forged & other Steels	Tool Steel
0			Mild Steel		
1	SG1	G1(FG150)	C1,C1S(C45)	Cast Steel S1	T1(105WCr6)
2	SG2	G2(FG200)	C2R(15Ni7cr4Mo2)	Cast Steel S2	04Cr18Ni 10Ti20
3	SG3	G3(FG260)	C3R(36CrNiMo4)	20Cr13	T3(100Cr6)
4		G4(FG300)	C1F(45S20)	12Cr13	St42-1079
5	G5	M11	C5(Ck40)	Forged Steel	T5(X210Cr12KU)
6		M12	C6	M2	T6
7		Sintered Iron	C7	M5	Fe410-S
8			C8(50CrV4)	S15	24345(HF15)
9					

Details of specification of hot rolled and forged constructional steel referred in Table 4.14 is given as page 1 of Appendix 1 [86].

Details of specification of grey iron castings referred in Table 4.13 are given as page 2 of Appendix 1.

Table 4.14 Material Coding and Classification Other Materials

Main Group / Sub Group	5	6	7	8	9
	High Speed Steel	Aluminium Alloys	Copper Alloys	Construction steel & Others	Miscellaneous Materials and Auxiliary Items
0		B6T	Copper	N2	
1	H1	A1	Sintered Bronze	N1	
2	835M15 (EN 398)	A2(IS4600)	B3(DIN1703)	C2	
3	H3(S6-5-2)	A3	B4(DIN1716)	C2M(16MnCr15)	
4	H3C(S6-5-2-5)	A7(IS19000)	B6(DIN1714)	C2A(21NiCrMo2)	
5	H5	A5	B7(DIN1716)	C3	
6	H5A(S10-4-3-10)	A6(IS19500)	Ba3	C2MS	
7		AZ1	Ba2	PB	
8		AZ2	B5(DIN1705)	C7-h	
9					

Details of specification of Bronze referred in Table 4.14 are given as page 3 of Appendix 1.

Details of specification of Aluminium castings referred in Table 4.14 are given as page 4 and 5 of Appendix 1.

Details of specification of Steels used in Table 4.14 and its equivalents national standards are referred in Table 4.13 & Table 4, 14 are given as page 6 of Appendix 1.

Specification details of Castings and Steel used with heat treatment details is given in Appendix 2 [87].

<u>**Shape Code (X):-**</u> Raw metallic materials are classified into six different shapes as detailed below:

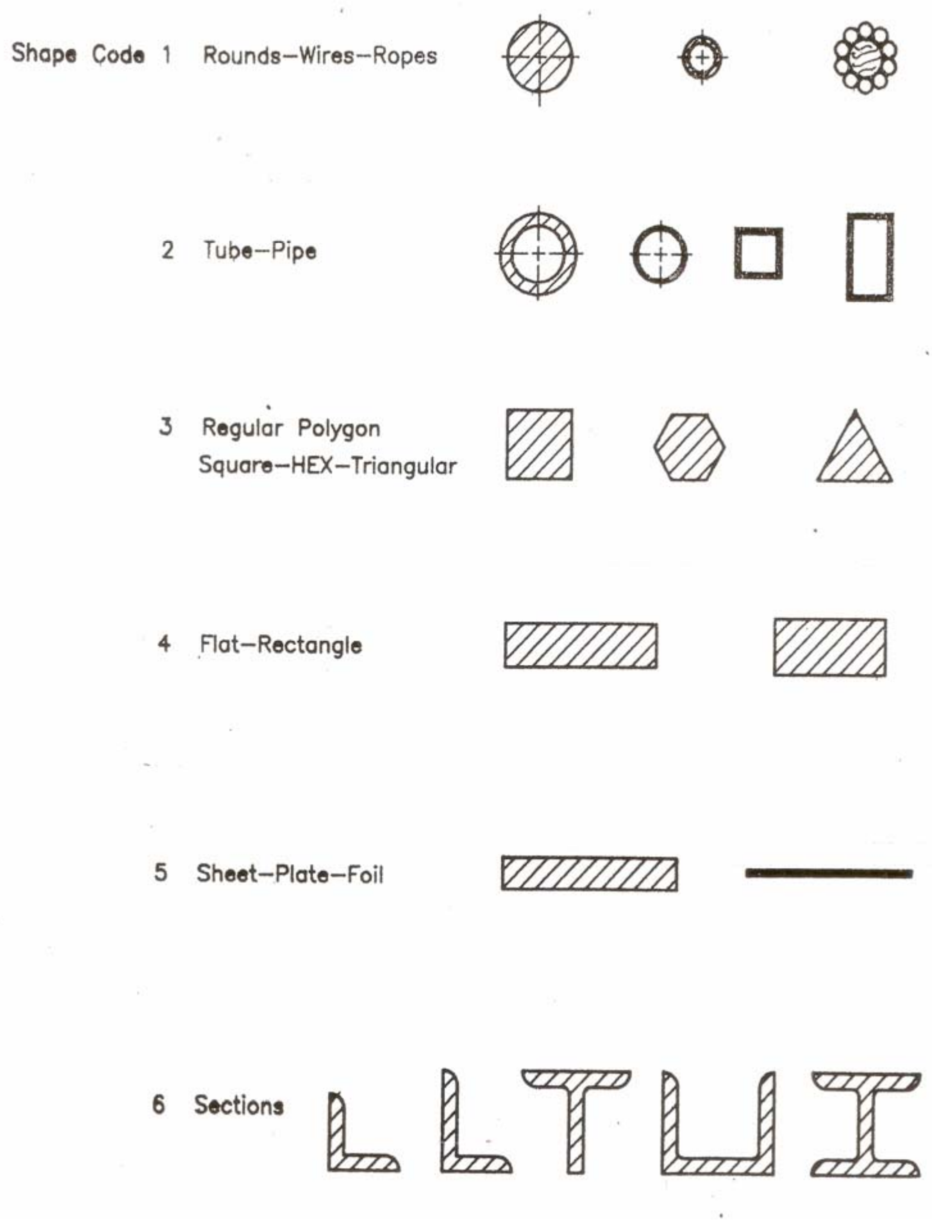


Figure 4.5 Shape Code Details

a) Rounds, Wires & ropes
b) Tubes & Pipes
c) Regular polygons – Square, Hexagon & Triangular
d) Flat & Rectangle
e) Sheet, plate & Foil
f) Sections

For details of shape code refer Figure 4.5.Only these digits are considered for the general design feature coding extraction, since this is having more importance to arrive at the general design parameters.

Surface Condition/ Size No/Serial No (XXXX): The first one or two digits of the four digits are used for surface condition/treatment code and rests of the digits are used for size No. / Serial No. or all the four digits are used for Size No. /Serial No. wherever applicable. Whenever it is not possible to give the size directly, serial numbers are allotted. For details of Surface condition/Size No. /Serial No. refer Appendix 3 Sheet numbers from 1 to 4.

4.2.7 Tolerance Classification for Coding

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 [47] research, they are classified these into three subclasses: dimension capability, precision capability, and surface finish capability. It was pointed out that dimension and precision modeling is a very complicated domain. There are a lot of intricate and unpredictable reasons that cause different kinds of deviations. Therefore, the experience in part families' BOP becomes quite precious, and it can be 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 [57]. For example, the dimension capability of a horizontal machine tool is the diameters of its round workbench, which at the same time constrain the fixtures' dimensions.

2. Precision Capability

Precision capability is 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. 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. Details of the Fits. Tolerance, Surface finish and different convention by which it is represented are detailed in Appendix 4 [88]. More details are available with chapter 3 of PSG data handbook.

Form tolerance types are shown in Table 4.15. Details of the Form Tolerance and process by which can achieved is detailed in Appendix 5 [87]. More details are available with pages 498 -522 of CMTI Machine Tool Design Handbook.

Depending on the form tolerance information and surface finish in formation of main surfaces, different tolerance class numbers are assigned as given in Table 4.16 to the component. Lower tolerance is in the range of IT 12 to 16, Medium is in the range IT 8 to 11, and high is in the range IT 4 to 7. (IT Grade is detailed in Appendix 4).

Table 4.15 Tolerance Classification

Tolerance	
Dimension	
Form	Straightness
	Flatness
	Circularity
	Cylindricity
Orientation	Parallelism
	Perpendicularity
	Angularity
Position	Location
	Concentricity
Runout	Circularity
	Total
Profile	Line
	Surface

Table 4.16 Tolerance Coding

Description of Tolerance	Numbering
IT 1 to 3 Tolerance and Close Form Tolerance	0
IT 4 and 5 Tolerance and Close Form Tolerance	1
IT 6 and 7 Tolerance and Close Form Tolerance	2
IT 8 and 9 Tolerance and Open Form Tolerance	3
IT 10 to 12 Tolerance and Open Form Tolerance	4
IT 12 to 16 Tolerance and Open Form Tolerance	5
IT 1 to 3 Tolerance and Open Form Tolerance	6
IT 4 and 5 Tolerance and Close Form Tolerance	7
IT 6 and 7 Tolerance and Open Form Tolerance	8
Open Tolerance	9

4.2.8. Production Quantity Coding

A feature's manufacturing strategies are defined as the candidate routines of processes to manufacture the feature. The major factors that affect process selection are (1) material factors; (2) part geometry factors, such as part shape, tolerances and surface finish; (3) and production factors, including time to market, production quantity, and production rate.

Time for manufacturing a component is derived as the the sum of operation time (time actual machining is performed) and set up time for the component as given below:

$$T_m = \sum_{i=1}^{N} T^{i}_{activity}$$

$$= \sum_{i=1}^{N} [\, T^{i}_{processing} + T^{i}_{setup} \,]$$

Where

t_m = estimated manufacturing time

i = index

N = total number of manufacturing activities applied to manufacture an artifact

$T^{i}_{processing}$ = processing time of activity i

T^{i}_{setup} = setup time of activity i

= Total Set up time for a batch / Batch Quantity.

As the size of the batch quantity increase the manufacturing time is being reduced. Again, batch quantity has a direct bearing on fixture and tooling design. Type of fixturing to be used i.e., modular fixture design, standard fixture, dedicated fixture, multi-part fixture, design is decided by the batch quantity.

Batch quantity can be decided as high, low, or medium. Low volume is below 10 items; High volume is above 50 items and between this is considered as medium. Details of the numbering scheme is given in Table 4.17.

Table 4.17 Production Quantity Numbering

Description	Numbering
Single of Item	0
Quantity 2 to 5	1
Quantity 6 to 10	2
Quantity 10 to 20	3
Quantity 20 to 30	4
Quantity 30 to 50	5
Quantity 50 to 100	6
Quantity 100 to 500	7
Quantity 500 to 1000	8
Quantity above 1000	9

4.2.9 Tool Axis Complexity Coding

Most mechanical parts consist of more than one feature, and they are usually in different normal directions. Some of them have complex position and orientation relationships, such as perpendicularity, angularity, parallelism, position, concentricity, circular runout, and total runout. If all features could be machined in one setup, the position and orientation tolerance requirements could be satisfied by the machine tool itself. Otherwise, they must be guaranteed by a certain combination of machine tools and fixtures. In other words, the capability to generate feature position and orientation is obtained by the combination of the machine tool and fixtures.

One setup is a group of manufacturing processes that can be carried out on one fixture and one machine tool. Since the fixtures are used to hold a part onto machine tools and align manufacturing features' normal directions with the cutter approaching directions. The orientation capability is achieved by the cutter approaching directions, which are provided by the machine tool and fixtures. If more than one cutter approaching direction can be provided by the combination of machine tools and fixtures, features that have different normal direction can be machined in one setup, so that the manufacturing costs and time are greatly reduced. The strategies of setup planning to be adjusted according to the orientation capability of machine tools and fixtures. Figure 4.6 shows the details of the position and orientation capability represented in a block diagram.

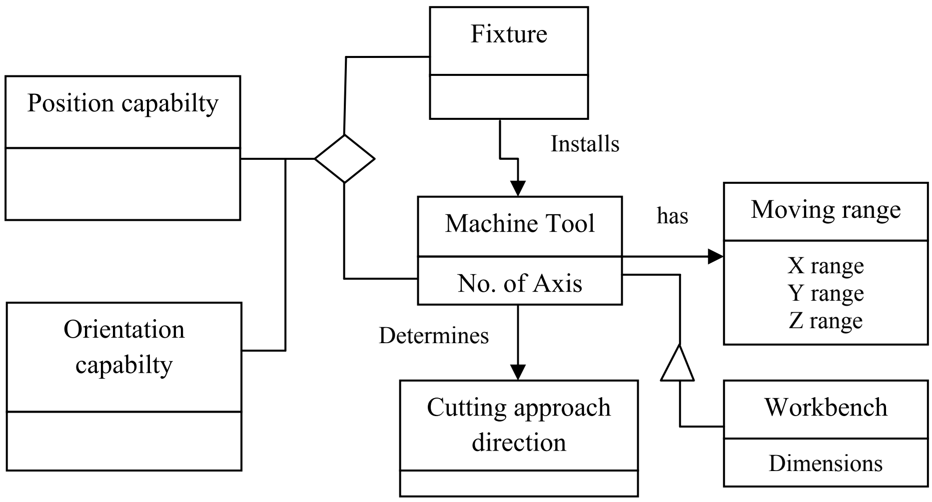


Figure 4.6 Position and Orientation Capability

Table 4.18 Tool Axis Complexity

Description	Numbering
Simple and Straight approach	1
Simple and can achieve with care	2
Complex tool approach and can achieve with care	3
Complex tool approach and Difficult to achieve	4
Complex tool approach and which requires special tooling and fixturing	5
Complex tool approach and which requires special machines	6
Complex tool approach and not possible easily some methods to be evolved	7
Difficult and not possible by known methods	8
Others	9
Not possible	0

Different values assumed are complex tool approach, simple/straight approach, complex but can be achieved with care, difficult and which requires special toolings and fixturing, not possible easily some methods to be evolved i.e., Tough , etc., as shown in Table 4.18.

4.3 Coding System for Processes

Systems was designed considering different part manufacturing attributes such as; major process, minor process, major dimensions, basic external shape, basic internal shape, length to diameter ratio, material type, tolerances, etc.. In developing the definition of the attributes and various attribute values, the invaluable knowledge of experienced machine tool process planners was utilized. The codes developed have flexibility in the coding structure to take into account the future changes in technology and their application. Figure 4.7 gives details on the Coding System for the Process, with various attributes extracted is given below.

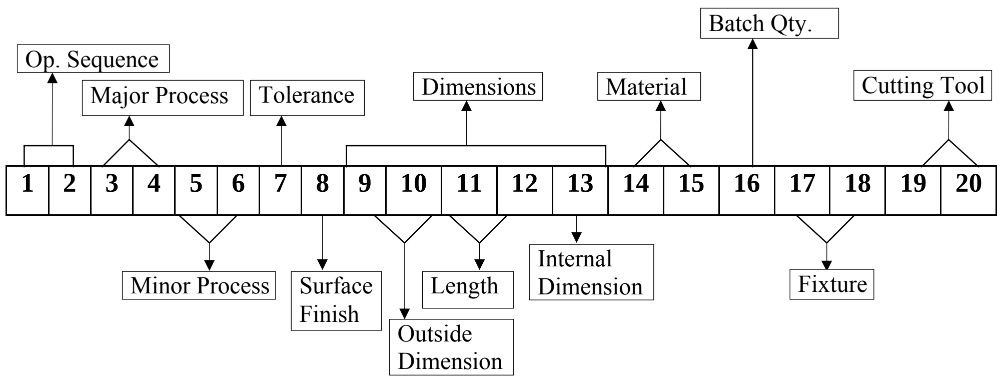


Figure 4.7 Coding System for the Process

4.3.1 Operation Sequence Coding

Number of operation sequence depends on the complexity of the features to be manufactured. The total number of operation for processing a component in a machine tool manufacturing can vary between 5 to 100. Each operation can have its own parameter like major process, minor operation, surface finish etc. Operation sequence can assume value in the range of 00 to 99.

4.3.2 Major Process Coding

Each operation can have major process as well as minor operation. Major operation is identified as operations other than the minor machining operations such as

* Facing	* Centering
* Chamfering	* Parting
* Marking	etc.

This is a two digit number with first digit represent the type of machining process and second digit represent the further sub-classification of this machining process.

Appendix-6 gives details of the different machining process followed in a machine tool company. In this machine group is represented as three-digit number where first two digits represent the major process code followed.

***Example*:** <u>Machine group</u> <u>Machine Group Details</u>

1 2 5	Conventional Center lathe
<u>1 4 5</u>	CNC Lathe

Serial Number

Sub Classification

Type of Process

Table 4.19 gives the details of the type of the process and code number

Table 4.19 Process Numbering

Description	Numbering
Hand operations and heat treatment	0
Turning (Conventional and CNC)	1
Milling (Conventional and CNC)	2
Plaining (Conventional and CNC)	3
Drilling and Boring (Conventional and CNC)	4
Grinding /Honing (Conventional and CNC)	5
Gear Cutting (Conventional and CNC)	6
Sheet Metal Operation and Heat Treatment	7
Other Misc. Operations	8
Other Misc. Processes	9

4.3.3 Minor Operations Coding

Minor operation that follows the major machining operations such a Facing, Centering, Chamfering, Parting, Marking, deburring etc.. This can also be an independent operation, but not as important as the major operation. For example, after a turning operation some time deburring has to be carried out, hence can be treated as operation goes alone with the turning but has to be performed.

This can take code numbers from 00 to 99 inline with the machine group numbers given in Appendix-6. In Appendix 6, many heat treatment operations can be treated as minor operation that follows the major operation.

4.3.4 Tolerance Coding

Form tolerance types are shown in Table 4.15. Details of the Form Tolerance and process by which they can achieve are detailed in Appendix 5. Depending on the form tolerance information and surface finish in formation of main surfaces, difference tolerance class numbers are assigned as given in Table 4.16 to the component. Lower tolerance is in the range of IT 12 to 16, Medium is in the range IT 8 to 11, and high is in the range IT 4 to 7. (IT Grade is detailed in Appendix 4).

4.3.5 Surface Finish Coding

Surface finish depends on machining methods, cutting condition, cutting tool material, and work piece material. It is assumed in this research that the manufacturing methods from part family's BOP will ensure the surface finish requirement. Details of the Surface finish, different convention by which it is represented, and manufacturing process by which it can be achieved is detailed in Appendix 5.

Depending on the surface finish requirement on main surfaces, difference code numbers are assigned as given in Table 4.20 to the component. Lower surface finish is in the range of 25 µm and High surface finish is in the range of below 3.2 µm. In between, the surface finish is considered as Medium. (Appendix 5; Table 192).

Table 4.20 Surface Finish Classification

Description of Surface finish	Numbering
Surface roughness 0.012 to 0.05 µm	0
Surface roughness 0.05 to 0.2 µm	1
Surface roughness 0.2 to 0.4 µm	2
Surface roughness 0.4 to 0.8 µm	3
Surface roughness 0.8 to 1.6 µm	4
Surface roughness 1.6 to 3.2 µm	5
Surface roughness 3.2 to 12.5 µm	6
Surface roughness 12.5 to 25 µm	7
Surface roughness 25 to 50 µm	8
Surface roughness above 50 µm	9

4.3.6 Fixture Coding

Depending upon the machine tool, set up type and cutting condition different fixturing arrangements are to derived. The numbering convention will follow a method of type specification and complexity of the fixture. In first digit represent the type and second digit represent the complexity of the fixture with referenced to the accuracy level of the fixture (Table 4.21). Detailed numbering of the fixture with description of the special feature, overall dimension, weight etc. will be stored as a separate database, which can be referred for more details.

Table 4.21 Fixture Numbering

1 St Digit	1 St Digit Description	2 nd Digit	2 nd Digit Description
F	Fixture (Conventional)	0	Able to produce IT 1 to 3 Tolerance
J	Jigs (Conventional)	1	Able to produce IT 4 to 5 Tolerance
M	Fixture (Modular Type)	2	Able to produce IT 6 to 7 Tolerance
K	Jigs (Modular Type)	3	Able to produce IT 8 to 9 Tolerance
N	Fixture (Combination)	4	Able to produce IT 10 to 11 Tolerance
L	Jigs (Combination)	5	Able to produce IT 12 to 16 Tolerance
S	Special type Fixtures	6	IT 1 to 3 Tolerance and Close Form Tolerance
T	Special type Jigs	7	IT 4 and 7 Tolerance and Close Form Tolerance
C	Custom made Fixtures/Jigs	8	IT 8 and 10 Tolerance and Close Form Tolerance
O	Other types	9	Open tolerance /No complexity

4.3.7 Cutting Tools Coding

In job and batch production objectives are to produce customized parts while trying to maintain minimum manufacturing cost by using of standard cutters, fixtures and machine tools. Due to the use of combination cutters in mass customization for a part family, a more complicated feature shape can be achieved in one process. Depending on the complexity of the operation, special cutting tools may be required.

The numbering convention will follow a method of type specification and the context in which it being used. In first digit, represent the type specification and second digit represent the context in which it is used (Table 4.22). Detailed numbering of the fixture with description of the make, context in which it is used, in combination with which machine tools, special feature, overall dimension etc., will be stored as a separate database, which can be referred for more details.

Table 4.22 Cutting Tool Numbering

1 St Digit	1 St Digit Description	2 nd Digit	2 nd Digit Description
H	Hand operations	0	Able to produce IT 1 to 3 Tolerance
T	For Turning	1	Able to produce IT 4 to 5 Tolerance
M	For Milling	2	Able to produce IT 6 to 7 Tolerance
P	For Paining	3	Able to produce IT 8 to 9 Tolerance
D	For Drilling	4	Able to produce IT 10 to 11 Tolerance
G	For Grinding /Honing	5	Able to produce IT 12 to 16 Tolerance
R	For Gear Cutting	6	IT 1 to 3 Tolerance and Close Form Tolerance
S	For Sheet Metal Operation	7	IT 4 and 7 Tolerance and Close Form Tolerance
B	For Boring. Operations	8	IT 8 and 10 Tolerance and Close Form Tolerance
O	Other Misc. Operations	9	Open tolerance /No complexity

4.4 Manufacturing Plan Generation

The next step of the IPPPIS is manufacturing plan generation, which determines the selection of machine tools, the process sequence of all parts on the fixtures, and the process parameters. Cycle time is the most important factor, which influences manufacturing costs in mass customization. The adjustment of process sequence, process parameters, and the global tool paths may decrease cycle time and increase productivity. Hence, algorithms are developed to generate feasible manufacturing plans, and the company-specific adjustment strategies are incorporated in the system developed.

Process planning is defined by SME as "the systematic determination of the methods by which a product is to be manufactured economically and competitively". The basic tasks of CAPP for metal removal include the following steps:

- Design analysis and interpretation
- Process selection
- Tolerance analysis
- Operation sequencing
- Cutting tools, fixtures, and machine tool specification
- Cutting parameters determination

The variant and generative approaches are two fundamental methodologies used to develop CAPP systems. 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 labour. In addition, procedures can be standardized by incorporating a planner's manufacturing knowledge and structuring it to company specific needs. Therefore, variant systems can organize and store completed plans and manufacturing knowledge from which process plans can be quickly evaluated.

Variant approach is used in the work presented in this thesis by enhancing the efficiency by:

* The quality of the plans is ensured by incorporating BOP and human planners' experience.

* Providing consistency in classifying and coding parts, are missing, by adequate classification models.

* Available manufacturing resources modeling are done to come up with good plan.

Manufacturing knowledge in the 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 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 work piece.
- 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.

4.4.1 Process Modelling for Manufacturing Strategies of Combined Features

Manufacturing strategies of combined features are intended to design a sequence of processes to remove required machining volume of the features while maintaining manufacturing costs and process constraints. In general, the following manufacturing knowledge is used to determine a feature's manufacturing strategies:

1. A feature's shapes and sizes that a process can produce, or, inversely, the process that can create a given feature.
2. The dimensions and tolerances that can be obtained by a process
3. Geometric and technological process constraints that determine the conditions under which a process is applicable.
4. The economics of a process

In the research, a process model is established to capture the fundamental characteristics of combined feature's manufacturing strategies. These characteristics include customized cutters and tool paths, which imply the requirement for a machine tool's motion. No specific machine tools are used in this stage. The dimensions of cutters and tool paths are driven by combined features' parameters. Hence, when the design of combined features change, their manufacturing strategies can be changed automatically.

4.4.2 Establishing Coupling Mechanism

A process model hinges on a product model. Therefore, a coupling mechanism is required to make the process model map to the corresponding product models. The model coupling mechanism was established and expressed by Figure 4.8.

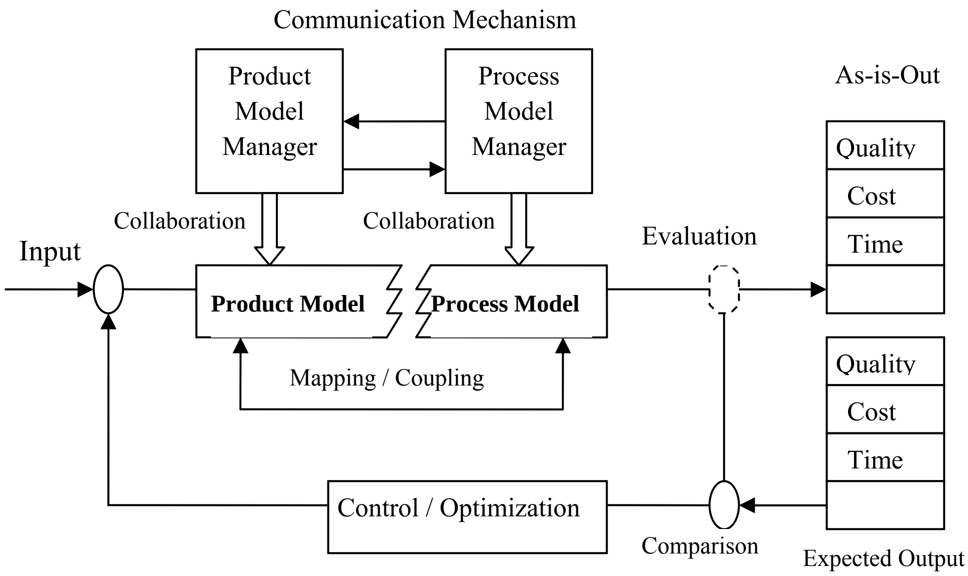


Figure 4.8 Coupling Mechanisms of Product Model and Process Model

4.5 Manufacturing Plan Generation in *IPPPIS* Developed

Manufacturing plan generation is a special step for the CAMP of mass customization. In this step, multi-part fixtures are used to maximize the utilization of machine tool capability and improve productivity. Cycle time is the critical factor used to evaluate a manufacturing plan. The part layout on the fixtures, the sequence of the processes carried out on one fixture, and the corresponding tool path generation is the major tasks of manufacturing plan generation and will be discussed in detail.

4.5.1 Tasks of Manufacturing Plan Generation

It is known that in overall cycle time, non-cutting time, including cutter change time, cutter rapid traverse time, and machine tool table index time, takes important portion. In the CAMP, in order to improve productivity and reduce cycle time, multi-part fixtures are widely used in the real production. This involves mounting several parts onto a fixture so that the processes that use the same cutters can be carried out sequentially, and non-cutting time on each part can be greatly reduced. Manufacturing plan generation include different steps (refer Figure 4.9 for details), in which machine-level decision-making strategies that abstracted from BOP are applied to achieve optimal cycle time. Appendix 7 (Page 1- 4) gives the some of the BOP used in machine tool manufacturing company.

4.5.1.1 Machine Tool Selection

Candidate machine tools are those that fulfilled the entire requirement for machine tool capabilities from setup planning, including the number of axis of machine tools. Machine tool is selected based on the process capability of the machine, which is being assessed periodically for the machines available inside the factory.

Appendix 8 (Page 1- 7) gives the some of the process capability estimation methods used in machine tool manufacturing company.

Depending upon the type of the machine, sophistication or number of axis the machine is having, process capability, skill level of the operator to be deployed to operate the machine, overhead and resources required to operate the machine etc., machine hour rate of the machine is worked out. This is being used for further deriving the cost of the process using that machine. This machine hour rate is updated half yearly or yearly depending upon the company policy.

Appendix 6 (Page 1- 7) gives the some of the machine hour rate estimation used in a machine tool manufacturing company.

4.5.1.2 Conceptual Fixture Design and Part Layout Design

In the IPPPIS, fixture design issues are divided into two steps: conceptual fixture design and detail fixture design. Conceptual fixture design provides ideas about what kinds of fixture bases are used and how many parts are held on the fixture bases. The initial solution of conceptual fixture design is derived from machine-level BOP, which includes machine tool selection, fixture base selection, and part layout on fixture bases. The part layout in BOP is based on previous detail fixture design, which determines the fixture structure and fixture components. Necessary verifications of fixture performance are needed in detailed fixture design, such as interference free, chip shedding to avoid chip accumulation, locating accuracy, stability problems, clamping sequence, error proofing, and ergonomic issues.

The conceptual fixture design is considered an extension of machine tool capabilities. Not only can the same setups be machined on a fixture, but also the different setups are expected on the fixture. Hence, the requirement for the machine tools may be changed to accommodate bigger range. As a result, the machine tool capability should be rechecked after part layout design.

4.5.1.3 Global Process Sequence and Tool Path Generation

In order to reduce the non-cutting time on each part, the processes that use the same cutters should be carried out sequentially. Hence, a sequence is needed for all the manufacturing processes on the multi-part fixtures. A corresponding tool path is generated without interference with fixture components, machine tools, etc.

4.5.1.4 Cycle Time Calculation

Cycle time is the critical factor in choosing the optimal manufacturing plan in mass customization. Hence, the estimation of cycle time is indispensable for manufacturing plan.Figure 4.9 gives manufacturing plan generation as a flow chart with various activities we have discussed.

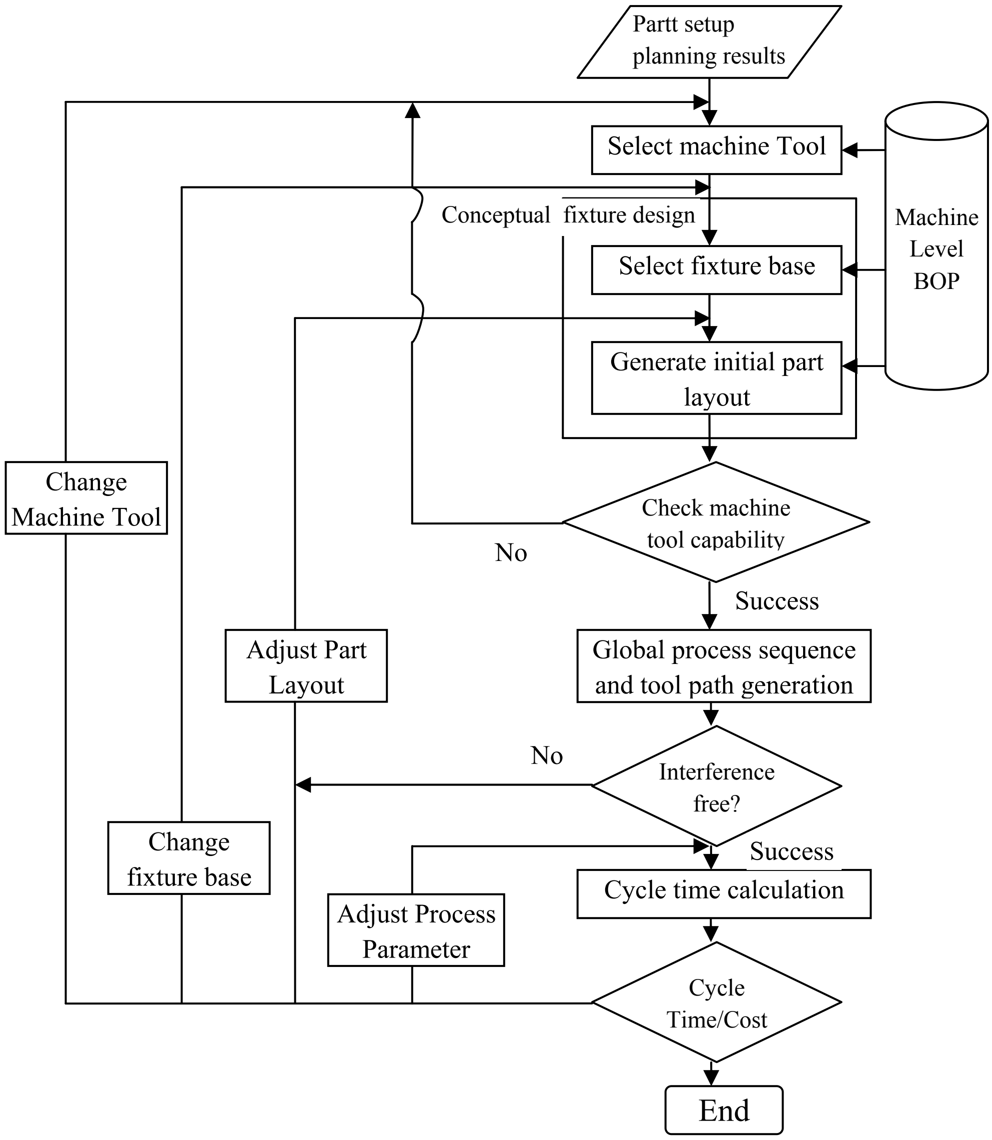


Figure 4.9 Flow Chart of Manufacturing Plan Generation

Appendix 9 (Page 1- 4) gives the some of the Time estimation standards, and sample time estimation sheet for a typical component in machine tool manufacturing company.

4.6 Conceptual Process Planning Information Modelling Fundamentals

The conceptual process planning activity (A2) is decomposed into three sub activities (Activity A1 is conceptual design). Figure 4.10 shows sub activities A21 to A23 and the data flow. Activity A21 is to determine manufacturing processes. Depending on conceptual product information, such as material, form, structure, and tolerances, primary manufacturing processes are selected, such as casting, forging, moulding and machining. This activity also includes the subsequence of processes to complete the manufacturing of the product. Activity A22 is to select manufacturing resources. Based on the selected manufacturing processes, choose appropriate manufacturing resources including both physical resources and human resources. Resources include machines, tools, and labour skills. Activity A23 is to estimate manufacturing cost. Based on overhead, selected manufacturing processes, and resources, A23 estimates manufacturing cost and time. Manufacturing cost covers material, purchased parts, labour, tooling, capital, machine usage and overhead.

In Figure 4.11, activity A22 covers a series of resource selection functions and decomposed further into three sub-activities. Activity A221 is to select machines. Based on the selected manufacturing processes, machines available in the factories are selected for manufacturing the designed product. Machines include machines tools, forging machines, casting machines, material handling and assembly machines, and measuring machines. Activity A222 is to select tools and fixtures. Based on the selected machines, tools and fixtures that are necessary for supporting manufacturing processes are selected. Activity A223 is to select labour skills. Based on the machines and tools, labour skills to operate the machines and use tools for production are selected in A223.

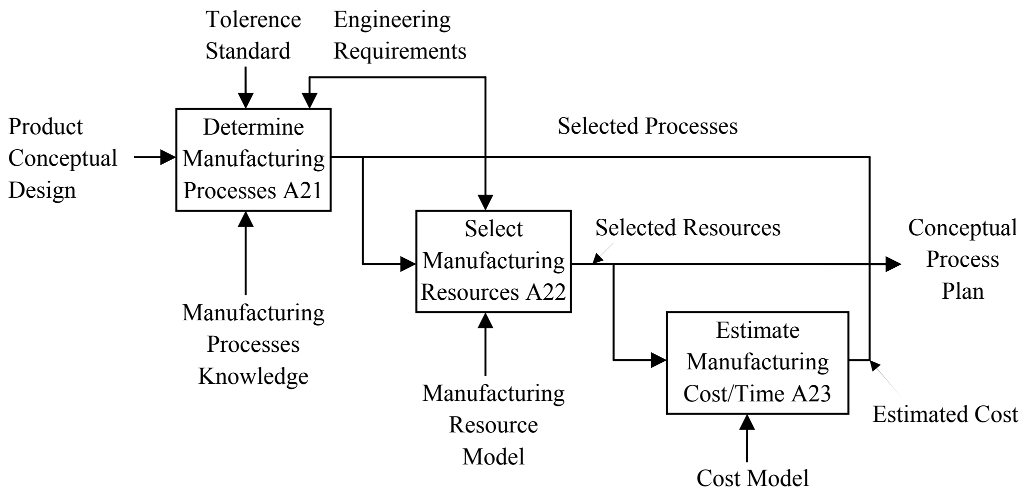


Figure 4.10 Functional Decomposition of Conceptual Process Planning

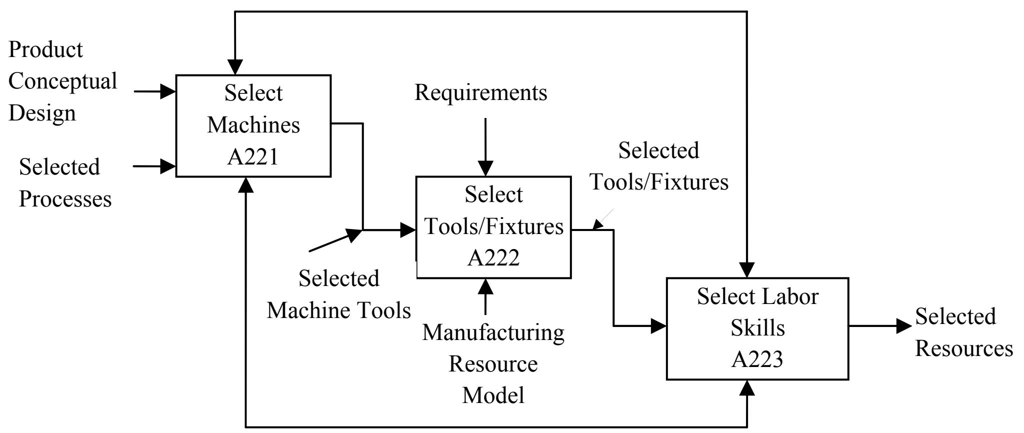


Figure 4.11 Manufacturing Resource Selection

4.7 Manufacturing Cost and Time Calculation Method

Manufacturing cost and time estimations is built into the object model. The activity based costing method has been adopted to form the basis for estimating the cost and time described in this paper. A manufacturing process consists of many manufacturing activities. Each manufacturing activity can be one of many processing activities, such as setup, load/unload, handling and processing. Each processing activity involves the cost of using any resources and overhead cost. Cost and time estimating equations are described as follows.

Activity-based Manufacturing Cost Estimation

[Cost of manufacturing a component is the sum of the cost of the different activities performed on that component. Cost for an activity is the some of, processing cost, setup cost, handling cost, load-unload cost, idling cost and overhead cost.]

$$C_m = \sum_{i=1}^{N} C^i_{activity}$$

$$= \sum_{i=1}^{N} [\, C^i_{processing} + C^i_{setup} + C^i_{handling} + C^i_{load\text{-}unload} + C^i_{idling} + C^i_{overhead} \,]$$

Where

C_m = manufacturing cost of an artifact

i = index

N = total number of manufacturing activities applied to manufacture an artifact

$C^i_{activity}$ = manufacturing cost of activity i

$C^i_{processing}$ = processing cost of activity i

C^i_{setup} = setup cost of activity i

$C^i_{handling}$ = handling cost of activity i

$C^i_{load\text{-}unload}$ = load and unload cost of activity i

C^i_{idling} = idling cost of activity i

$C^i_{overhead}$ = overhead cost of activity i

4.7.1 Processing Cost Calculation

[Processing cost of an activity is calculated as the sum of equipment cost, labour cost, material cost and tool cost]

$$C^i_{processing} = [\, C^i_{equipment} + C^i_{labor} + C^i_{material} + C^i_{tool} \,]$$

$C^i_{equipment}$ = equipment cost of activity i. Equipment cost is decided by the time the equipment is used and the cost per unit time.

C^{i}_{labor} = Labor cost of activity i
$C^{i}_{material}$ = material cost of activity i
C^{i}_{tool} = tool cost of activity i

4.7.2 Manufacturing Time Estimation

[Time for an activity is the some of, processing time, setup time, handling time, load-unload time and idling time.]

$$t_m = \sum_{i=1}^{N} t^{i}_{activity}$$

$$= \sum_{i=1}^{N} [\, t^{i}_{processing} + t^{i}_{setup} + t^{i}_{handling} + t^{i}_{load\text{-}unload} + t^{i}_{idling} \,]$$

Where

t_m = estimated manufacturing time of an artifact
i = index
N = total number of manufacturing activities applied to manufacture an artifact
$t^{i}_{processing}$ = processing time of activity i
t^{i}_{setup} = setup time of activity i
$t^{i}_{handling}$ = handling time of activity i
$t^{i}_{load\text{-}unload}$ = load and unload time of activity i
t^{i}_{idling} = idling time of activity i

4.7.3 Cycle Time Calculation

It is always a challenge for engineers to find the most economical solution. Basically, process economics means determining the cost efficiency of processes. For the CAMP, 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 is used to select the best solution. Cycle time calculation is known as the most effective determinant for mass customization. A cycle time calculation model can be stated as:

$$T = \sum_{i=1}^{N} \left(\sum_{j=1}^{M_i} T_{process} + M_i * T_{tool\_change} \right) / P_i$$

Where

T = Cycle time for fabricating one part

i = index for set up

j = index for process

N = Number of setups used to fabrication

M_i = Number of global process in i th setup

$T_{process}$ = Time of one global process finished by one cutter.

T_{tool_change} = Time for changing one cutter, which is determined by specified machine tools.

P_i = Number of parts machined on i th setup

In the model, the time of one process is composed of the cutting time, tool rapid traverse time and machine tool table index time.

$$T_{process} = T_{cutting} + T_{rapid} + T_{table\_index}$$

Where

$T_{cutting}$ = Cutting time is associated with process types

T_{rapid} = Tool rapid traverse time, which includes the time when cutter travels from tool change position to the starting point of toolpath, the time used for its rapid motion in the toolpath of a process and the time when the cutter returns to tool change position. The tool change position is specified in a machine manual or achieved from experiments.

T_{table_index} = Machine tool table index time is proportional to the rotational displacement of the worktable, which is specified by a machine tool manual.

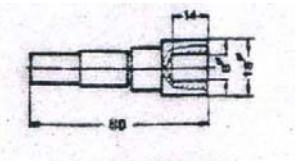
4.8 Coding Example

A trial was conducted to test the method of coding with the sample components with variety of features in the machine tool manufacturing firm. The method of coding for design and process attributes extraction was done using the user interface screens developed with the computer. To make it more clear some of the sample components are given below as examples.

Figure 4.12 to Figure 4.14 shows sample components in different basic shapes and the corresponding attributes codes extracted by the method described above. Figure 4.12a shows the coding of 3 components marked i,ii,iii of i.e., components A1, A2, A3, in shape code category A. Figure 4.12b gives coding details of the same marked as i, ii, iii . Figure 4.13a shows the coding of 3 components marked i,ii,iii of i.e., components C1, C2, C3, in shape code category C. Figure 4.13b gives coding details of the same marked as i, ii ,iii .

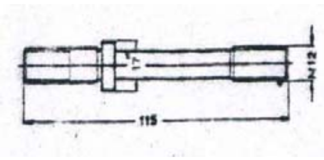
Figure 4.14a shows the coding of 3 components marked i, ii, iii of i.e., components D, E, F, in shape code category D, E, F. Figure 4.14b gives coding details of the same marked as i, ii, iii .

Each of the example components are selected in such way that, it is typical in nature and belongs to different basic shapes to clearly illustrate the technique. Most of the attributes are extracted from the drawing manually the same can be done through the IPPPIS developed, which is explained in the subsequent chapters.



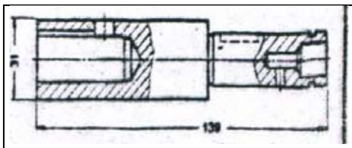
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A1																			
	A	0	0	M	S	0	2	0	1	0	3	0	2	8	2	0	1	2	0

(i)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A2																			
	A	2	2	M	S	0	3	0	1	0	7	3	0	8	2	1	1	2	0

(ii)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
A3																			
	A	2	2	M	S	0	4	0	3	0	5	1	3	8	2	3	1	2	0

(iii)

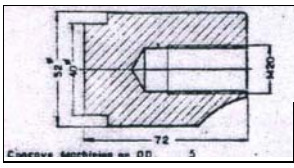
(a)

SHAPE- A								
	Ist Drawing (A1)			2nd Drawing (A2)			3rd Drawing (A3)	
		Code			Code			Code
Basic Shape		A			A			A
External Shape	Stepped	0		Threads	1		KeyWay	2
Internal Shape	Short Hole	0		Solid	5		KeyWay+Non Axial Hole	2
Basic Manu. Operation	Machining	M		Machining	M		Machining	M
Function	St.Shaft 18/60	S02		St.Shaft 17/15	S03		St.Shaft W. Key Way	S04
Outside Dia	18mm	01		17mm	01		31mm	03
Length	60mm	03		115	07		139mm	05
Length/Dia	60/18 <3.3	0		115/7 <6.7	3		139/31 <4.4	1
Internal Dia	13mm	2		0	0		25mm	3
Tolerence	Nil	8		Nil	8		Nil	8
Material	MS	20		C1	21		C1F	23
Mat Shape	Round	1		Round	1		Round	1
Prod Qty	15 Nos	2		15 Nos	2		15 Nos	2
Tool Axis Complexity	Nil	0		Nil	0		Nil	0

(i) **(ii)** **(iii)**

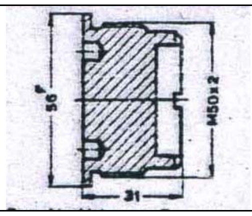
(b)

Figure 4.12 a,b The Component in Basic Shape of A-Type



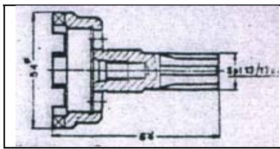
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C1	C	5	9	M	Q	1	1	0	5	0	8	8	2	8	2	0	4	1	0

(i)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C2	C	7	5	M	F	2	2	0	5	0	4	5	0	8	2	1	1	3	1

(ii)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
C3	C	9	2	M	L	3	2	0	5	0	8	8	4	8	2	3	1	2	1

(iii)

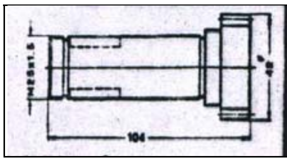
(a)

SHAPE- C								
	Ist Drawing (C1)			**2nd Drawing (C2)**			**3rd Drawing (C3)**	
		Code			Code			Code
Basic Shape		C			C			C
External Shape	Concave m/c on OD	5		Threads+Face m/c	7		Other Machning	9
Internal Shape	Other m/cing	9		Non Axial Holes	5		Non Axial Holes	2
Basic Manu. Operation	Machining	M		Machining	M		Machining	M
Function	Sq. Sect. In Tread 72/52*M20	Q11		Flange With Ext Thread 31/56 *M50	F22		Spline Shaft Non Axial Holes 84/54	L32
Outside Dia	52mm	05		56mm	05		54mm	05
Length	72mm	08		31mm	04		84mm	08
Length/Dia	72/52 <2	8		31/56 <0.5	5		84/54 <2	8
Internal Dia	M20	2		0	0		40mm	4
Tolerence	Nil	8		Nil	8		Nil	8
Material	MS	20		C1	21		C1F	23
Mat Shape	Rectangular	4		Round	1		Round	1
Prod Qty	5 Nos	1		25 Nos	3		15 Nos	2
Tool Axis Complexity	Nil	0		Non Axial Holes	1		Non Axial Holes	1

(i) **(ii)** **(iii)**

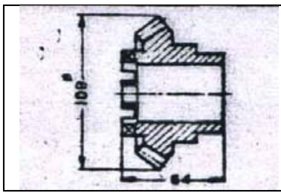
(b)

Figure 4.13 a,b The Component in Basic Shape of C-Type



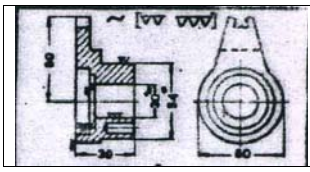
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
D																			
	D	9	9	M	S	3	5	0	5	1	1	9	0	8	2	3	1	1	0

(i)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
E																			
	E	2	0	M	G	5	4	1	1	0	7	6	6	8	2	1	1	3	0

(ii)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
F																			
	C	6	4	M	R	6	4	0	6	0	2	2	4	6	2	1	4	2	0

(iii)

(a)

SHAPE D,E,F								
	SHAPE D			**SHAPE E**			**SHAPE F**	
		Code			Code			Code
Basic Shape		D			E			C
External Shape	Other m/cing9	9		Face claws + OM	2		With External Turning	6
Internal Shape	Other m/cing	9		Plain	0		Accurate Holes	4
Basic Manu. Operation	Machining	M		Machining	M		Machining	M
Function	Shaft with KeyWay &Gears 104/42	S35		Bevel Gear With Face Claws	G54		Fork With accurate Holes-Non Round	R64
Outside Dia	42mm	05		102mm	11		90 mm	06
Length	104mm	11		64mm	07		38mm	02
Length/Dia	104/42 > 2	9		64/102 =.6	6		38/90 <0.5	2
Internal Dia	0	0		60	6		30mm	4
Tolerence	Nil	8		Nil	8		N6	6
Material	C1F	23		C1	21		C1	21
Mat Shape	Round	1		Round	1		Rectangular	4
Prod Qty	5 Nos	1		25 Nos	3		15 Nos	2
Tool Axis Complexity	Nil	0		Nil	0		Nil	0

(i) **(ii)** **(iii)**

(b)

Figure 4.14 a,b The Component in Basic Shape of D,E,F-Type

4.9 Automated Coding and Retrieval of Parts in the IPPPIS

Design retrieval is fundamental to the control of variety since it is allows a designer to check if a part already exists that can be used before they create a brand new one. Control of part variety offers cost benefits that extend well beyond those that are generated in the design office itself. Indeed, it is likely to be the downstream cost savings that flow from re-use of existing parts that are likely to be most significant. Many estimates are available for the cost incurred during the life of a part created unnecessarily. Savings in design and development are difficult to validate but product development costs were directly proportional to the size of a company's parts range as asserted by Barton and Love [89].

The prospects for automation of the coding process are affected by the nature of the retrieval problem. GT applications require a high level of discrimination in the retrieval mechanism since inappropriate parts cannot be tolerated in the family. The cell has to be designed to manufacture every member of the family so that parts that do not 'fit' have to be detected and removed manually. High levels of discrimination help that process but risk rejection of other parts that should be included, thus representing a serious challenge to any retrieval system based on data that can be automatically extracted from the drawing. However design retrieval applications require much less precision in the retrieval process since the designer will simply ignore inappropriate items and select the best fit part providing it is displayed in a convenient manner.

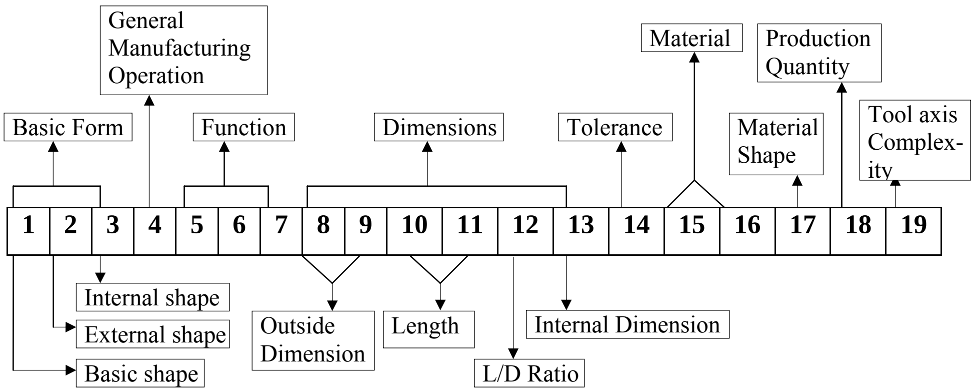
GT family formation also differs from design retrieval in that it requires the system to return a cluster of parts that are similar to a 'seed' component rather than one good matching item. Ideally, the cluster should be as large as possible, consistent with limited range of manufacturing processes supported by the cell. The design case is exactly the opposite – the designer wants to examine as small a set of parts as possible, consistent with finding an optimal match. This distinction is of interest because some approaches to design retrieval on a technology that is cluster-based and thus inherently more suited to GT family formation. In any search, the system can only return one cluster per search so that a user will remain unaware that other matches may exist in the database. This issue is particularly serious when the search requirement is defined loosely. There are problems returning parts based on an incomplete definition of the desired characteristics because a match would occur for parts located in many clusters. In the case of design, this is likely to be a common requirement and one that is easily met by more conventional coding structures used by most other systems where parts of the code are used to represent particular characteristics. For example, a search for all long rotational parts that have a through bore can be carried out in the Opitz code by matching on values in the first and third digits. This could calculate the degree of 'similarity' that existed between the search criteria code and that of each part in its database. This will provide a 'fuzzy' search capability. This could return the results of a search in order of '*similarity*'. The designer could then scan the list accordingly.

Similarity Coeffcients

The machines parts with maximum similarity are grouped to form machine-cells (part-families). Therefore, for solving the GT problems, different researchers have proposed different similarity coefficients for cluster analysis, but the coefficients in most of the cases are suitable for specific problems. It is evident from the literature that there exist a large number of similarity coefficients for cluster analysis. Among these coefficients, the first one is the Jaccard similarity coefficient. The property of this coefficient is that there exists a maximum similarity of 1 between a pair of objects when both the objects have identical attribute values. This coefficient is sensitive to the direction of coding, meaning that interchanging the elements 1 and 0 in an incident matrix usually changes the similarity values between the objects.

Deriving the Similarity Score Value

Attribute values of the sample component is extracted as code. This attributes values of the sample component are then compared with the other component. This comparison results in the value (Ci) 1 or 0 (1 is for similar and 0 is for not similar) for each attribute of the components. Figure 4.15 gives details with an example of attribute comparison and deriving the similarity score value. For every attribute of a component there is a positional weight (Wi) attached to it. Different weight ages can be given for the different features by assigning different weights between 0-100. If the user is not assigning any weights, the system will automatically take the pre assigned weights. The weights are decided by the order of importance of the features.



Atrributes Positions in Number	→	1	2	3	4	5,6,7	8,9	10,11	12	13	14	15,16	17	18	19
Atrributes Positional Weights (Wi)	→	12	7	5	10	5	7	5	7	7	10	10	5	5	5
Atrributes Comparison value with trial component [Ci)	→	1	1	1	1	0	1	1	1	1	1	1	0	1	1
Atrributes score Si = Wi x Ci	→	12	7	5	10	0	7	5	7	7	10	10	0	5	5
Atrributes Total score ∑Si	=	90													

Figure 4.15 Example of Attribute Comparison and Similarity Score Value

The comparison result value of the each attributes of a component is multiplied with their positional weight. . Output similarity score value of the each of the component (Si) is decided by adding the individual score of the all this positional attribute (Ci) multiplied with their positional weight (Wi). The highest score value group of components represents the group to which the part belongs. If the difference between the actual output and target output is above the threshold value then the weight vectors are adjusted such that the error is reduced. Thus, depending upon the weightages given, the components with similar features are retrieved from the relational database depending upon the score secured in comparison with the existing components in the database.

4.10 Conclusion

In this chapter, we have seen the information used in the development of the IPPPIS, with the details on codification methods and GT system, for a machine tool manufacturing factory where this work was carried out. The methodology used for developing the classification and coding system with the steps involved was explained later. Different attributes used in generating the codes in the classification system for a machine tool manufacturing firm has also been explained.

Coding system of process with different attributes involved was been explained further. After discussing the different method generally used for manufacturing plan generation, the method used in this research for manufacturing plan generation had been presented. Process modeling for manufacturing strategies of combined features, describing the coupling mechanism developed has been explained. Since, process plan generation is one of the important outcomes of this research, various components involved in manufacturing plan generation, i.e., fundamental elements for conceptual process planning information, modelling, etc. have been described with block diagrams.

Manufacturing cost and time calculation methods with its components of processing cost, manufacturing time estimation, cycle time calculation have been discussed. Towards the end examples of how coding is done with details of retrieval mechanism of parts has been presented. Thus the theory, information base, coding system and its implementation have been illustrated. The technique used for similarity determination has also been presented. These have been implemented in the IPPPIS developed as a part of this research.

Chapter 5: The Process Design and Information Modeling

The way existing design tools represent information and communicate with each other is often not consistent. The design tools used in the stages of part design, tool design and process design, do not communicate well with each other, since different representations are used by these tools. IPPPIS is developed using information models in this work integrates product design and manufacturing cycles in a systematic way to facilitate the swift, cost-effective progression of new products from concept to final product. Information models are data structures that represent information content. A large amount of information in manufacturing planning needs to be computerized so that IPPPIS can use them. All this information is identified and represented by information models.

In this chapter, task clarification of the IPPPIS is presented in the first part. The process planning approach is detailed with functional structure used in the system. Information content in the IPPPIS is discussed, with different approaches and modeling methods to represent this information. This chapter is concludes with details on the systematic information modeling hierarchy and UML class diagram to represent this hierarchy of information.

5.1 Introduction

Traditionally, when designing a new product, a team of designers usually participates in what is known as a product development cycle. In general terms, the first stage in designing a new product is that of concept design, in which overall needs and aims are addressed. Next is the initial design stage. The initial design stage comprises of steps for designing the part, then choosing the materials and determining the process to make the part, and finally designing the tool to make the part. For example, if the part is to be a computer keyboard, first the size and shape of the keyboard (i.e., the part) is determined by a part engineer. Next, when the part has been designed, a second engineer determines the design of the tool that can be used to make the keyboard. Separately, a process engineer determines the materials and process to make the part, selects the process parameters and the rate of production of the process. The next stage, after a prototype of the part has been made; revision of the design is done. The above-mentioned steps of part, tool and process design are repeated until a satisfactory part is produced, satisfying both design and cost of production targets.

Traditionally, each of the above steps is carried out sequentially, usually by different people. One person may design the part, another tool, and a third the process. Collaboration between these designers is usually minimal. Where many revisions have to be made, numerous iterations are needed and a long period passes until a satisfactory part is produced. Using present design approaches and tools, there is incomplete knowledge of the required manufacturing steps to produce the part, and inadequate consideration of the variety of other downstream influences that shape time to market, marketplace acceptance, and product longevity. Often neglected, but of importance in part design are the constraints added by environmental concerns relative to the product and its process of fabrication. These flaws lead to a multitude of costly and time-consuming design reworks, or difficult process modifications, as unanticipated problems occur that must be rectified.

5.2 Task Clarification of the *IPPPIS*

A model has have been developed using object oriented technology, after analysing the fundamental elements necessary for modeling manufacturing and process planning framework used in collaborative design and manufacturing in a selected machine tool manufacturing company. The performance of this model is shown by using real world case. The manufacturing information based design tool integrated with an intelligence design system developed, can be used for collaborative design and manufacturing. This will support machine tool designers' effort to achieve cost effective and timely design by performing various tasks as described below:

1. Establishing a library of default process steps and product design data, including a parts list library of preferred components associated with model configurations and sequence of events configurations for the part.
2. Initiating a new part design for the part based on the library and periodically checking new part design against a predetermined set of new part requirements.
3. Establishing a complete sequence of events for new part design for the part.
4. Identifying a default process step in said library of default process steps incompatible with production of the new part design within the part requirements.
5. Replacing the default process step with a revised step compatible with production of the new part design within the part requirements.

To enable correct part design, the present model provides the part designer with all relevant information effecting the part design (such as, for example, information about the processes and materials used to make the part) while the part is being designed. Further, the designer and the process designer are also provided with all relevant information affecting their designs. The information supplied to the part designer, the tool designer and the process designer is the same "model" of relevant information. This model of information can be shared concurrently by each designer. Design decisions made by each designer can be included as a factor in the design decisions by other designers. As such, the functions of part designer, tool designer and process designer often merge and overlap when the present invention is utilized. The method for development of the proposed CAPP in IPPPIS is given in Figure 5.1.

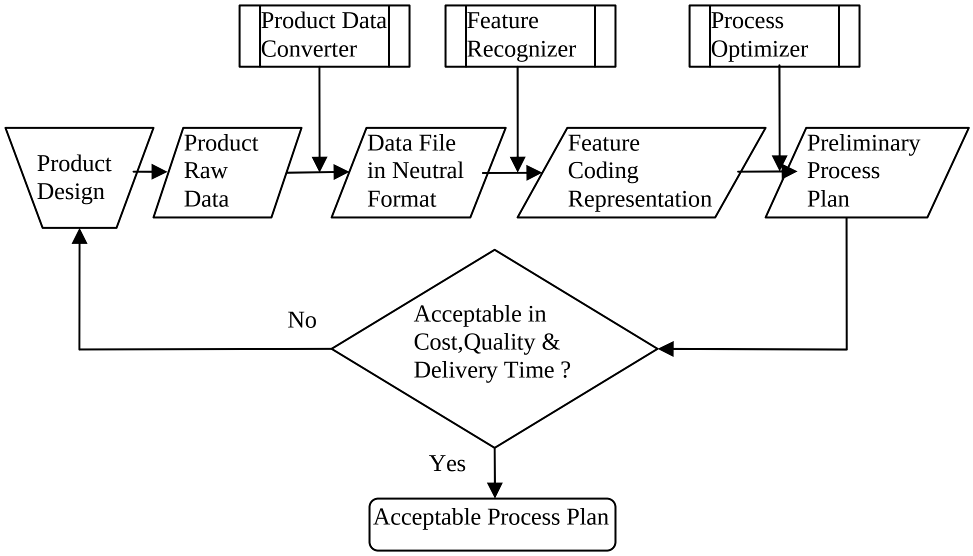


Figure 5.1 The Process for Development of the Proposed CAPP in IPPPIS

5.3 Process Planning Approach in the *IPPPIS*

The two types of approach used for CAPP systems are referred to as variant and generative. The first approach consists of using generic process planning for a part family that is modified to adapt to the characteristic features of each one. Because of its nature, this approach does not fully address the problem of generating a plan. However, it does enable the integration of process planning into other company activities. The generative approach consists of generating a process plan each time; automating this stage and enabling its integration into other activities. There is need for setting up models that enable the development of CAPP systems with an optimum degree of generality and flexibility. Some of the aspects that, largely, determine the operation and application of a CAPP system are as follows.

**** Planning Methodology:*** All the steps needed for process planning, i.e., it sets out the planning method. The methodology must enable work to be carried out on any geometry of parts, while at the same time being dependent from manufacturing technology and resources. Consequently, the CAPP system will not only be able to operate on any parts families, but will be able to develop in line with the company, the technology implemented and the resources available. An important aspect of the planning methodology used is the generation of alternative process plans that provides several route sheets for the parts. This optimizes the planning and control of production and the result is a high degree of productivity in the manufacturing system.

The requirements demanded of a methodology for developing general and flexible CAPP systems for machining parts are as follows.

- Independence from the geometry or shape of the part.
- Take into account not only the machining processes, but also other processes closely linked to it in the final stages of part manufacture such as heat treatment, coating, cleaning and deburring operations.
- Independence from production resources, operating on various types and configurations of these resources.
- Assess process plans with regard to the quality obtained in the product and the manufacturing costs, by performing an in-depth study of the resources used.
- Enable the generation of alternative process plans at all levels: processes, machines, fixtures, etc., assessing the production cost in each case.

**** Architecture of the System*:** Structure of the various elements making it up (functions, databases, etc.) and, more importantly, their interrelations. The architecture of a CAPP system must be able to support the planning methodology, while controlling its integration with other production system tasks.

**** Information System:*** specifies the data stored and their structure. Here the data used for representing parts, production resources and the description of processes available is particularly noteworthy. The information system must be sufficiently general to represent any type of part and production resources. In this way, it allows general CAPP systems that are not dependent on parts, resources and technology.

The overall functions a CAPP system must have to make a process plan is extremely wide and varied. It must decide on the processes to be applied, their sequence and all of the resources to be used (machines, fixtures, tools, etc.). It must also ensure that the plan is valid at all times. As a result, each of its functions-although they operate together-focuses on specific, individual aspects. Among these functions, it is worth pointing out those that play a role in determining alternative plans. Because of their impact, they subsequently provide production planning control with greater options for obtaining high performance and flexibility in the manufacturing system.

5.4 Process Planning in the *IPPPIS*

Using the methodology process planning was done as shown in Figure 5.2. As mentioned above, the methodology starts from part information using machining features and its quality specifications. Its purpose is to establish all the viable alternative process plans, organizing them as sequences of phases, set-ups and operations.

**** Raw Material***: The first stage is to determine the raw material for machining the part. In a part model based on machining features, this raw material may be specified in the part model. Otherwise, this stage is responsible for specifying raw material taking into account other forming processes to obtain the preform (moulding, plastic deformation, cutting, welding, etc.). Therefore, this function includes process planning for processes that are different to machining. As a result, it is placed in the context of a generic planning or a macro-plan before machining.

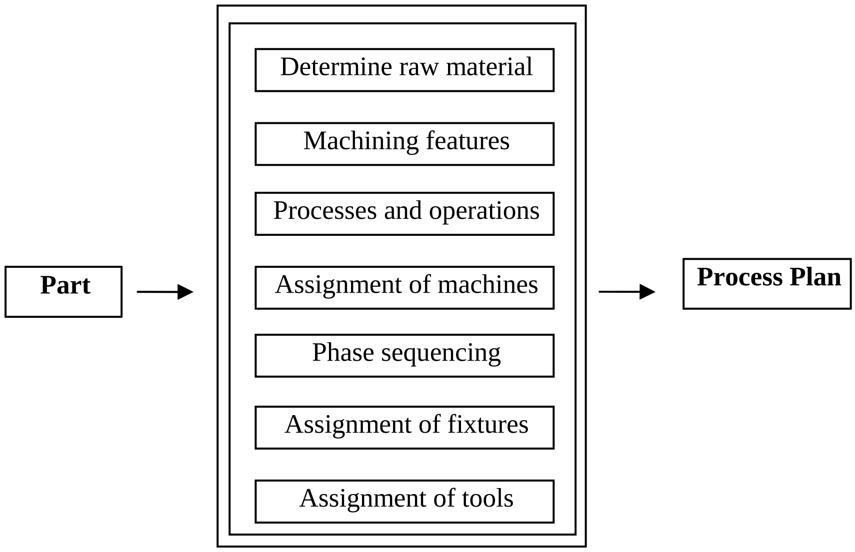


Figure 5.2 Process Planning in the IPPPIS

* ***Machining Feature:*** Using the part's input model, this step consists of determining the model that the system will use to work with. This model is based on the definition of the part with certain machining features, complying with two conditions that distinguish it from the input format. The first condition is that all the machining features will be simple. For this purpose, compound features will be broken down into simple features. The second condition is that the properties for each of these simple machining features include both their shape and quality specifications for manufacture. It also considers the part as a whole, taking into account factors such as, for example, its accessibility. This means moving on to a model of machining features where the definition of each feature contains individual information as well as information about the rest of the part.

**** Assignment of Processes and Operations:*** Using the part model obtained in the previous stage and based on simple machining features, it is possible to determine the processes that are technologically able to achieve them and the operations necessary for these processes. The strategy proposed is to assign to each feature all the processes and operations that may be applicable to that type of feature and that are wholly or partly capable of satisfying any of the quality requirements (Fgure 5.3). This bears in mind that a process may be applied to the type of machining feature, as well as the ability of its operations to satisfy the feature's quality specifications. For this purpose, process modeling establishes the capacity margin for each operation, including the machines, fixtures and tools that provide it with support. This definition of capacity enables processes and operations to be initially assigned without considering specific resources (machines and fixtures) [90].

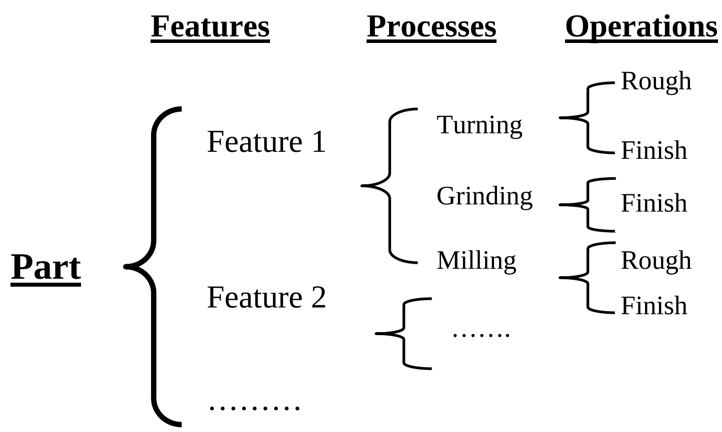


Figure 5.3 Assignment of alternative processes and operations

Assignment of Machine: All possible machines are determined for each of the alternative processes and operations proposed in each machining feature of the part. This offers a wide range of solutions to the problem at phase or machine level. It enables selecting those machines that are most suitable and that satisfy the constraints imposed on the sequences of operations. The potential use of a machine in an operation depends on its assessed capacity. This not only takes into account the capacity values of the machine itself, but also the productive resources it uses, such as fixtures and tools. As the number of alternative machines increases, sequence phase options quickly increase and in the interests of obtaining time-efficient procedures, a reduction in alternatives is applied. Equivalent machine groups are set up for machining the part. This is done by grouping different machine options according to similarity.

***Machine Sequencing:** At this point, where all possibilities have been determined for operations, processes and machines for each machining feature; the possible phases and their sequence are determined. First, the precedence's these operation sequences must comply with are established. These affect all levels, e.g., the finishing process of a machining feature follows the rough operation. Once these precedence's are established, a general algorithm for the formation and sequencing of phases is applied to develop all the options. Before sequencing, machine group alternatives that might lead to non-optimal sequences are rejected. The criteria used by the sequence formation algorithm correspond to the minimum number of phases. Lastly, sequences furthest from the optimum were rejected. For this purpose, the operational cost of each sequence was estimated and the least favorable sequences were deleted. This leaves the solution open for the following stages in which the plan will be specified.

* ***Assignment of Fixture:*** For each of the phases obtained in the previous point, a possible fixture or alternative set-ups are established. At this level, it is worth pointing out that the number of alternative fixtures for each machine stage should not be excessively high. Furthermore, some of the phase sequences proposed above is rejected because of set-up problems. For each of the set-ups, it is essential to conduct the capacity study to obtain part specifications and bear in mind the specific capacities of each fixture. Each of the set-ups sequences proposed is then assessed by using a cost estimate.

*** *Assignment of Tools***: The problem of assigning tools to operations and sequencing is resolved within each set-up in order to reduce the number of tools and settings. As a result, the tools assignment depends on the sequencing of higher levels, such as phase and set-up levels. The reason for this is that tools represent the least critical and most flexible resource.

One of the most out standing features of the proposed methodology is the generation of alternatives with a hierarchical construction of plans, i.e., first determining the required phases or machine sequence, then the set-ups and finally the tools. As a first step in this procedure, all the possibilities are determined for processes and operations applicable to the part's machining features. In this way, a process of grouping these processes was initiated while gradually opening up to other possible alternative solutions. As the plan is specified, many of these are rejected as impractical and are arranged according to their estimated cost.

The methodology proposed is supported by several models of generic information that enable the: definition of a part on the basis of machining features; the definition of production resources and their capacities; and the definition of processes to be considered. Together with the methodology itself, these models become a key factor in applying the system, to various production environments with different part forms and geometry. Information content in the developed system is shown with the help of a flow diagram for better understanding in Figure 5.4.

5.5 *IPPPIS* Functional Structure

The implementation of the methodology has been hierarchical structured. At the initial level (Figure 5.5) five functions have been taken into account.

**** Determine Raw Material***. Function responsible for deciding raw material for machining the part. It establishes high-level process planning in order to determine the preform or raw material.

* ***Determine Options for Operations, Processes and Machines***. Function for selecting production resources needed to establish the process plan at phase level. Considering alternatives for these resources represents a key factor in establishing alternative process plans at all levels.

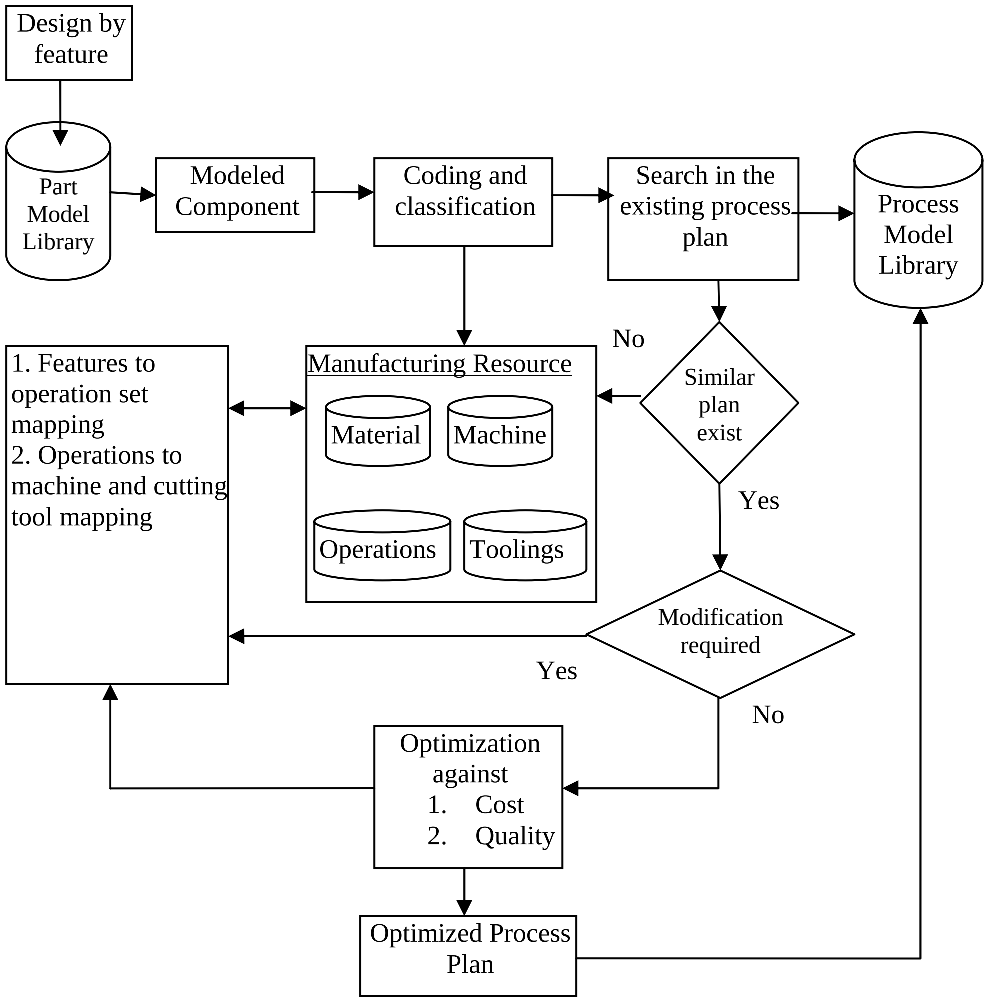


Figure 5.4 Information Content in the System Developed

* ***Select and Sequence Machines and Fixtures***. The aim of this function is to establish alternative phase and set-up sequences for manufacturing the part. It uses the alternative production resources proposed for the previous function.

**** Determine Tools and Work Conditions.*** Function for specifying micro planning details relating to operations level. This function determines the tools, work conditions and sequence of operations for each set-up in order to reduce the number of tool changes.

***** ***Write Results***. Generator functions for the output of results in suitable formats, such as: route sheet, raw material requirements, cost data, etc.

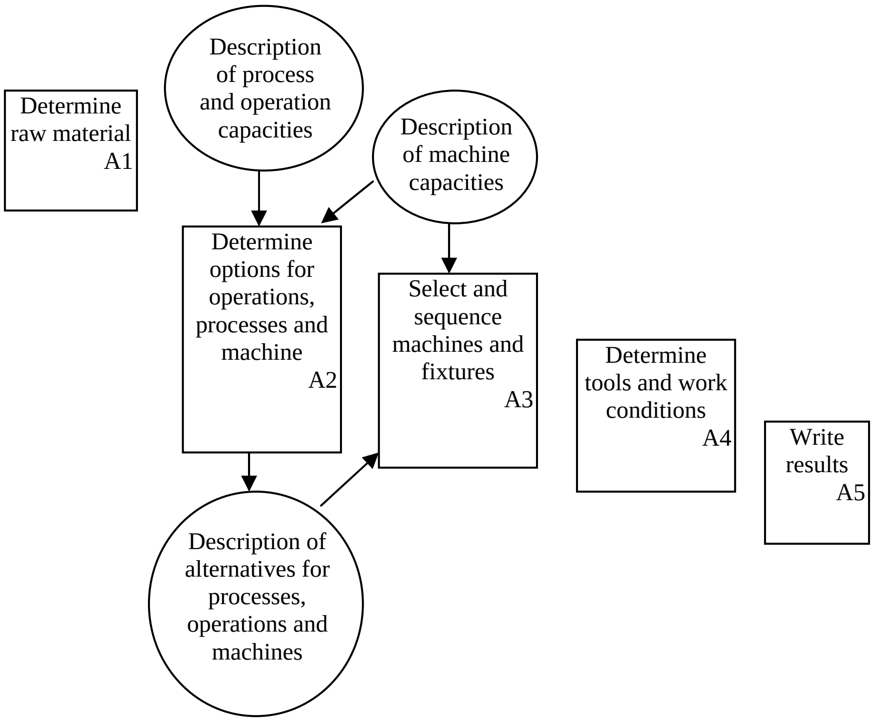


Figure 5.5 First Functional Level of CAPP System.

The function determines options for operations, processes and machines' have been structured in five functions. Figure 5.6 shows the functions and information exchanges, including the following:

**** Analyse and Describe Machining Features.*** The aim of this function is to establish the description of the part based on the information model proposed for machining features. The advantage of this characterization is to provide a complete, individual description of the machining features. This enables the independent assignment of processes, operations and machines.

**** Select Possible Processes and Operations***. This function assigns processes and operations to each machining feature. In the assignment, alternative processes and operations were deemed to those that are able to satisfy feature specifications, as well as those that only manage to come close. These are structured in a general way following the same pattern for all the processes and operations. This knowledge is independent from process and operation capacities. A general information model was used for their description. The developed rules store only qualitative information about process and the operations, such as: type of machine; comparison of requirements and capacities; assessment of optimization for the process and operations, etc..

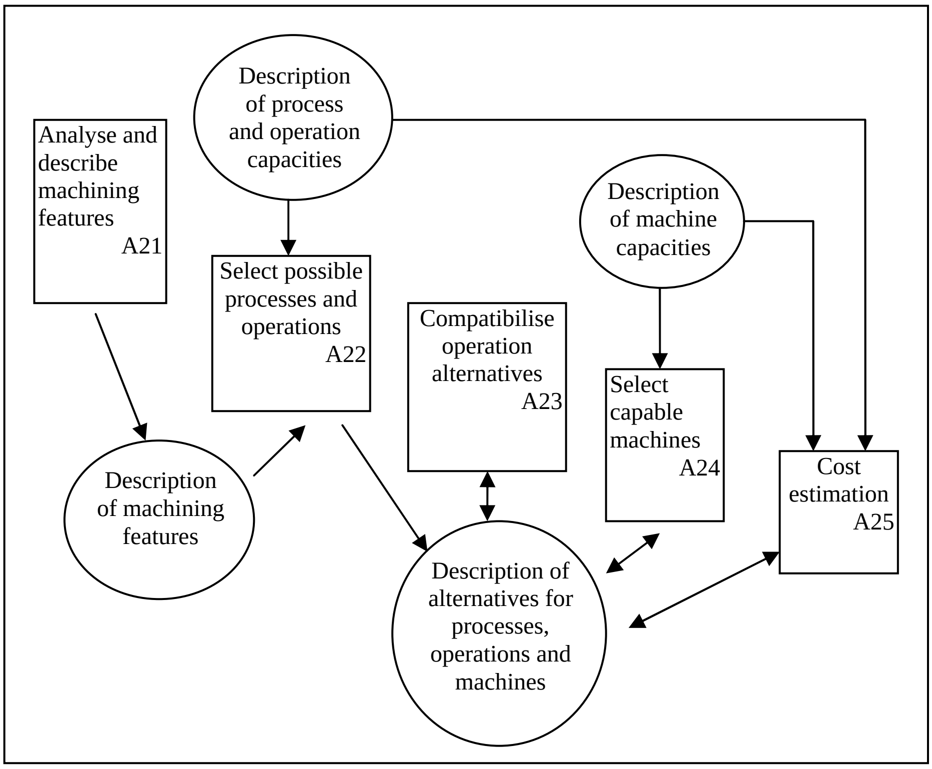


Figure 5.6 Functional Model Proposed for Function Information Exchange.

***** *Making Operation Alternatives Compatible*. Once all the alternative processes and operations have been proposed, they must be made compatible as described in the methodology. This allows the alternatives to be processed in a general way, enabling them to be combined independently with each other. Compatibility requires equivalence or exchangeability between processes and this is achieved by homogenizing their ability to produce the machining feature. A general functional procedure has been developed for this.

**** Select Capable Machines.*** The aim of this function is to assign alternative machines to each of the alternative processes. However, this is via the machine groups described in the methodology. The machine groups are made up of equivalent or exchangeable machines that are specifically determined for each part. Three important aspects are taken into account when making up the groups, such as: the type, quality and size of the machines. In connection with the aspects of quality and size, the proposed operation requirements for the part are taken into account. This enables machine groups to be set up that suit the parts requirements most accurately.

**** Cost Estimation.*** The aim of this function is to estimate the cost of operations, specifying it for each of its alternative processes and optional machines. For this purpose, it uses a model of costs that takes into account the cost factors attributable to the machine and the individual factors of the process and operation. These costs will be necessary during the phase or machine sequencing to establish the estimated cost of each one of the sequences.

5.6 Type of Information used in the IPPPIS

There are basically four categories of information in the IPPPIS:

Design Information: Design information is the input of IPPPIS. Generally, part information, including part geometry information, tolerance information, functional information, and production information (production volume, material), are analyzed and stored in an IPPPIS.

Manufacturing Resource Information: Manufacturing resources may include cutting tools, machine tools, fixtures, and inspection tools. Some of them are standard tools and are readily available. Others were designed specifically for particular processes used in manufacturing plans.

Manufacturing Knowledge: Manufacturing knowledge is used to help engineers make the right decisions. It is composed of general manufacturing rules and best practice knowledge that is summarised by manufacturing industries.

Information Generated by IPPPIS: Information models to describe the result generated by IPPPIS systems. This consists of process information, including the utilization of manufacturing resources and process parameters, setup information, and manufacturing planning information. Several information models have been provided for representing and storing the above information. Group technology and coding systems have been applied to represent part design information by fixed-length codes or flexible-length codes. These codes have been used to group parts into part families that link them with standard process plans. Decision tables and decision trees have been used to computerize the decision-making procedures that incorporate manufacturing knowledge. Relational databases have been employed to store part design and manufacturing resource information.

5.7 Design Retrieval and Cost Reduction Through Automated Coding

In designing new products, the ability to retrieve drawings of existing components is important if costs are to be controlled by preventing unnecessary duplication of parts. Variety reduction is a popular technique for controlling the costs associated with creating a new part number including administration, stockholding, obsolescence, service and reduction in the economies of scale. Actual figures for creating a new part are difficult to derive reliably but are often quoted as thousands of pounds per part per annum [91]. Many companies use standards and preferred item catalogues to control the proliferation of common parts such as fasteners, but this approach is ineffective for non-standard items. What the designer requires is an easy means of retrieving a suitable existing part that is significantly quicker than the alternative of drawing a new one.

Part numbering systems exist in most companies and they can be used to retrieve information about parts. However, since these systems exist primarily to provide unique identity, they offer very limited search facilities. Product data management (PDM) systems do allow searches on other fields, properties or special keywords and most CAD systems allow text searching on the drawing description. The effectiveness of all these techniques depends on rigorous application of naming conventions and none allows the search to be based on the part geometry.

Many coding and classification systems have been developed for use in manufacturing industries, either for variety control or cell family formation [3]. Once a part's shape information has been encoded into a code 'number', similar parts can be found since they will have identical or similar code numbers.

5.8 Information Content in the Model

A systematic information modeling ontology have been used to describe the information relationships and associativities, in which Object-oriented Systems Analysis (OSA) approach is employed to establish the information models. The concept of an object is derived from software engineering and is considered as the computerized representation of entities in the real world. The OSA uses three kinds of models: an Object-Relationship Model (ORM) describes the static characteristics such as information composition of objects; an Object-Behavior Model (OBM) defines the dynamic characteristics of objects; an Object-Interaction Model (OIM) pictures information association and interactions between objects.

By using the OSA approach, a system model has been used for the high-level view, as shown is Figure 5.7. It is divided into four object packages: part design and manufacturing planning packages; manufacturing activity knowledge; manufacturing resource; and manufacturing cost and time packages. The arrows in Figure 5.7 indicate the relationship and interaction between these object packages. The part information is the input, which is composed of features and the relationships between features and feature's manufacturing strategies are linked with features. Manufacturing planning

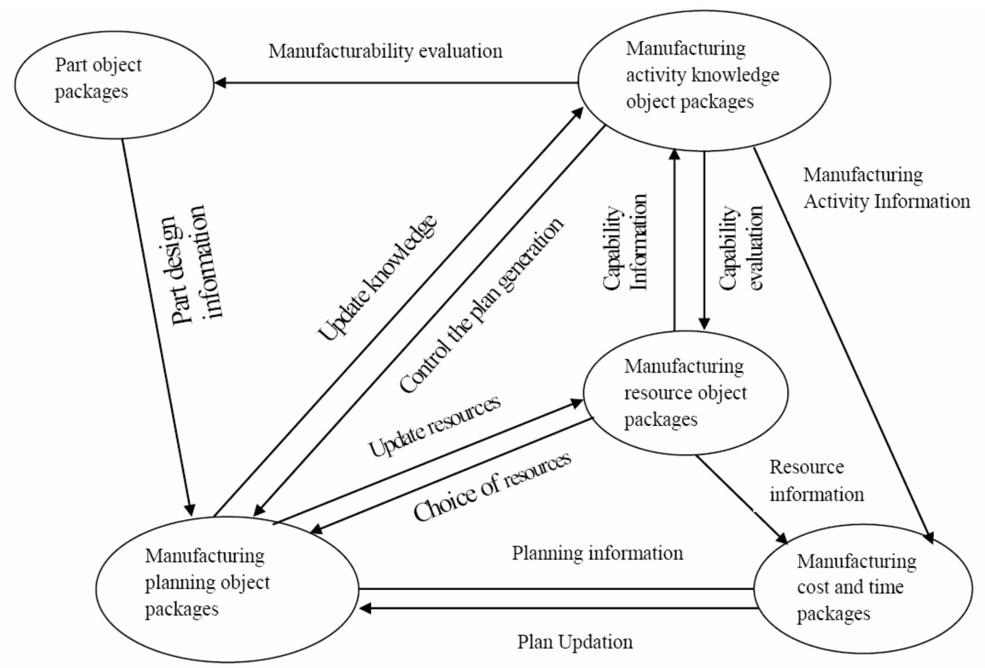


Figure 5.7 Information Modeling

package includes both part level and machine-level decision-making strategies. The manufacturing activity knowledge package provides the knowledge constraint to control the manufacturing planning behaviors. The manufacturing resource package provides the description of the manufacturing resources, such as machine tools, cutters and fixtures in specific manufacturing companies. Each object packages in the system model will be broken down into low-level objects.

5.8.1 Conceptual Design Feature Information Content

In the conceptual design stage, the combinations of geometric patterns as well as interactions among them realize product functions are looked at. Conceptual design feature geometry only includes those geometric entities, which are indispensable for realizing the function. A conceptual design feature definition is given Table 5.1.

Table 5.1 Conceptual Design Feature

Attributes	semantics; functions; behaviors (input and output); dimensions; tolerances; and material specifications
Constraints	spatial constraints; functional constraints
Geometries	critical geometrical-entities
Methods	create; edit; check validity; query information

5.8.2 Detailed Design Feature Information Content

In the detailed design stage, the conceptual design, i.e., critical geometric entities and interactions among them, are further refined into complete product geometries and specifications. A primitive detailed design feature is defined as a set of related geometric entities and has is given as Table 5.2.

Table 5.2 Detailed Design Features

Attributes	Semantics; patterns; parameters (e.g. diameter); dimensions; tolerances; positions; orientations; material; roughness
Constraints	geometric constraints; algebraic constraints
Geometries	parts; assembly; components; features; geometric and topological entities; references; derived entities
Methods	create; edit; check validity; query information

5.8.3 Machining Feature Information Content

Feature-based process planning covers two processes, operation planning and machining passes. Machining operations can be defined according to setup or cutter changes. Machining parameters are determined in the scope of each pass. A primitive machining feature is defined as a set of related geometric entities that represents the volumes removed or faces generated during a machining cut. The primitive machining feature definition is given below in Table 5.3.

Table 5.3 Machining Features

Attributes	semantics; machine information; tools; machining parameters; operational and locating datum; dimensions; tolerances and roughness of the machined faces
Constraints	Machining constraints (power, workspace, etc.); tool constraints (cutter radius, flute length, etc.); geometric constraints
Geometries	features; geometric and topological entities describing the workpiece before and after the operation or cutting pass
Methods	create; edit; check validity; query information

5.9 Object-Oriented Systems Analysis (OSA) Approach

O-O modeling is recognised as a powerful tool to model real-world systems. An object is an encapsulation of data and procedures (or methods) that operate on the data. An object can be defined as an existing entity in the real world such as a part, a manufacturing plan, and a machine tool. The real world can be considered as a group of interacting objects. The interaction is described according to the way that human beings think. Therefore, O-O modeling can create information models that exhibit close resemblance to real world systems, and the main task of O-O modeling for a system is to identify objects and analyze their interaction within the system. Here are some basic concepts used in O-O modelling:

Object: - An object is a bundle of variables and related methods. A variable is an item of data named by an identifier. An object implements its behaviour with methods. A method is a function associated with an object.

Class: - A class is a set of objects that have shared properties. A class is represented by a rectangle in the diagram.

Encapsulation: - Packaging an object's variables within the protective custody of its methods is called encapsulation.

Relationship: - A relationship establishes a logical connection among objects.

Inheritance: - Inheritance is a kind of relationship between objects. O-O modeling allows classes to be defined in terms of other classes. For example, a rotational part is a kind of a part. Therefore, the part is a superclass and the rotational part is a subclass.

In the research, the OSA approach is used to analyze the information in the IPPPIS. The ORM is used to represent the static relationships between objects. The OBM describes the behavior of individual objects and how objects respond to dynamically occurring events and conditions. The OIM expresses the information associations between objects.

5.9.1 Object-Relationship Model (ORM)

An ORM is created to represent the static relationships between objects. ORM's are usually described by ORM diagrams. Users can define their own relationships with the specific relationship name attached to ORM diagrams. There are two basic relationships used frequently, and specific symbols are assigned to represent them in ORM diagrams.

1. Generalization-Specification Relationship

In an ORM diagram: a rectangle represents an object; an ellipse represents a variable of an object; and a transparent triangle represents the generalization-specification relationship (Figure 5.8). The relationship in Figure 5.8 (a) is read as: "special class is a kind of general class." The special class inherits the variables and methods of the general class, which is implied by the Generalization-Specification relationship.

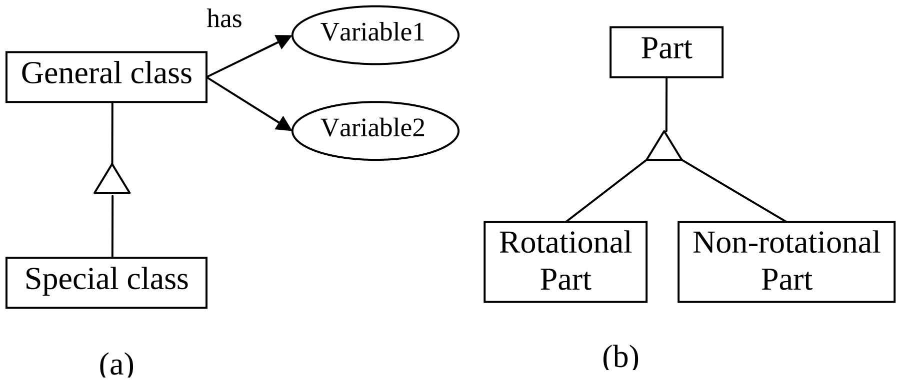


Figure 5.8 Generalization-Specification Relationship

2. Hole-Part Relationship

Another type of relationship that appears often is the Whole-Part relationship. The relationship declares that an object, called a super object, is composed of other objects called sub-objects. Figure 5.9 shows an example of a hole-part relationship. Figure 5.9b is read as “The block is composed of a flat surface, a hole feature and a slot feature.” A solid-filled triangle is used to represent the whole-part relationship.

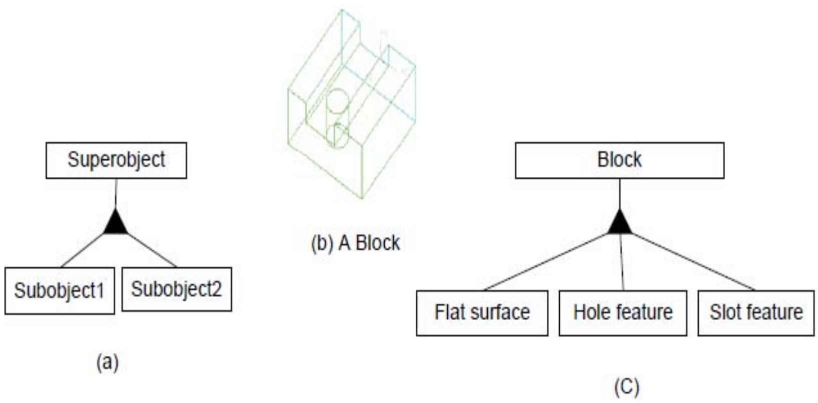


Figure 5.9 Hole-Part Relationships

3. User-defined Relationship

In the CAMP, the user-defined relationships reflect the pre-defined information relationships, which may come from the BOP or general manufacturing knowledge. For example, a hole feature has 5 alternative manufacturing processes. The feature is defined as an object, and a process is defined as another object, as shown in Figure 5.10.

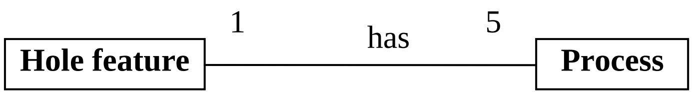


Figure 5.10 User-Defined Relationships

By using of generalization–specification, whole-part and user-defined relationship, the system's ORM can be setup as shown in Figure 5.11, so that information can be classified into objects. For example, in order to describe the part shown in Figure 5.9, a part object is created to represent the design information of the part which is composed of a flat surface object, a hole object and a slot object. Each feature is associated with specific processes. At the same time, this part is a non-rotational part. Thus, a non-rotational part object is associated with the part object so that the part object can have all the characteristics of non-rotational part.

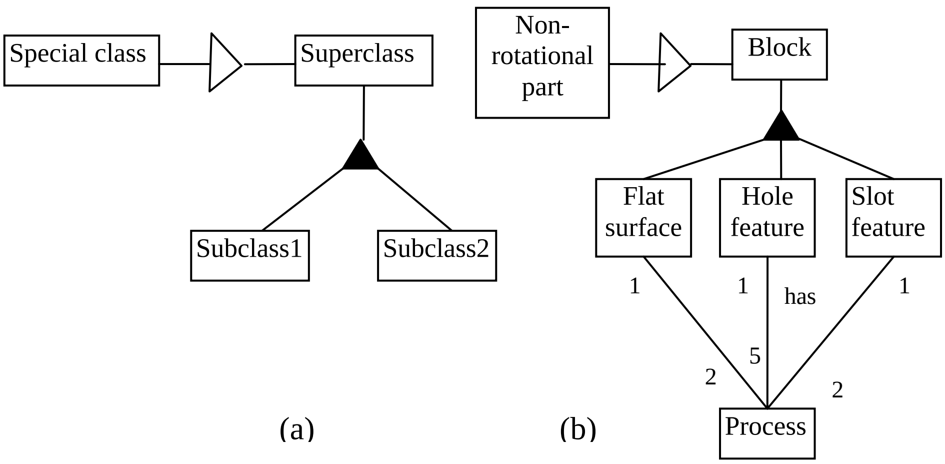


Figure 5.11 An ORM diagram for the Block and its Features

5.9.2 Object-Behaviour Model (OBM)

The objective of a behavior model is to describe the way that each object in a system interacts, functions, responds or performs. A behavior model for an object is similar to a job description for an object. In this research, state nets are used to represent OBM. A basic concept of behavior modeling is the set of states that an object exhibits in a system. In OSA, a state represents an object's status, phase, situation or activity. Figure 5.12 shows some states of process objects. The procedure of changing the state of an object is called

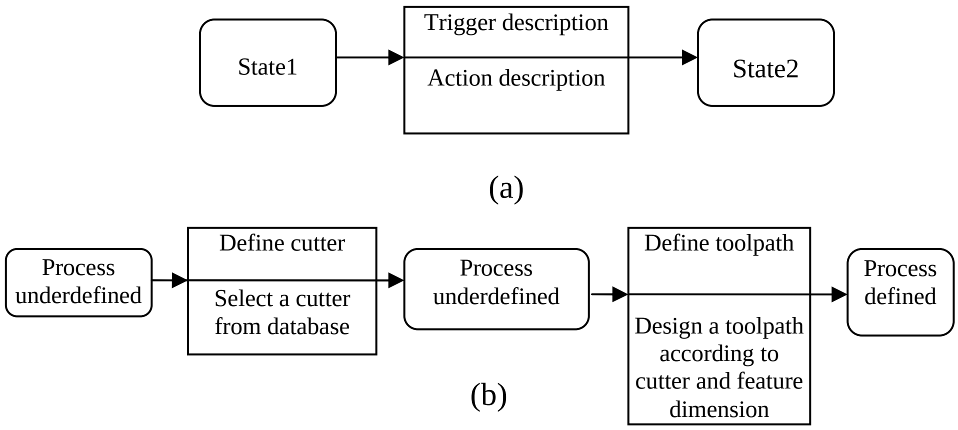


Figure 5.12 A State Net for a Process Object

transition. The events and conditions that activate state transitions are called triggers. The activity that an object performs is called action. A state net is a configuration of symbols representing states and state transitions for an object. In state net, rounded rectangles represent states. Rectangles that are divided into two sections represent transitions. The top section contains a trigger description. The bottom section contains the actions. For example, Figure 5.12(a) shows the components that construct a state net. Figure 5.12(b) shows an example of the activities to define a process object. There are three states of a process object: process undefined, process under defined and process defined. The first step of a process object is to select a cutter that is used in this process. The process is incomplete when it only has cutter information and the state is under defined. The second step is the definition of toolpath. After this step, the definition of a process is finished.

5.9.3 Object-Interaction Model (OIM)

The ORMs describe the static relationships among objects. The OBMs describe the behavior of an object, but in isolation from other objects. An OIM model is used to describe the interaction such as information associations among objects. One object interacts with another in many different ways. For example: an object may send information to another object; an object may request information from another object; an object may alter another object; and an object may cause another object to do some actions. Figure 5.13 shows an example of the interaction between a part object and its process object, which were defined in Figure 5.10 and Figure 5.12.

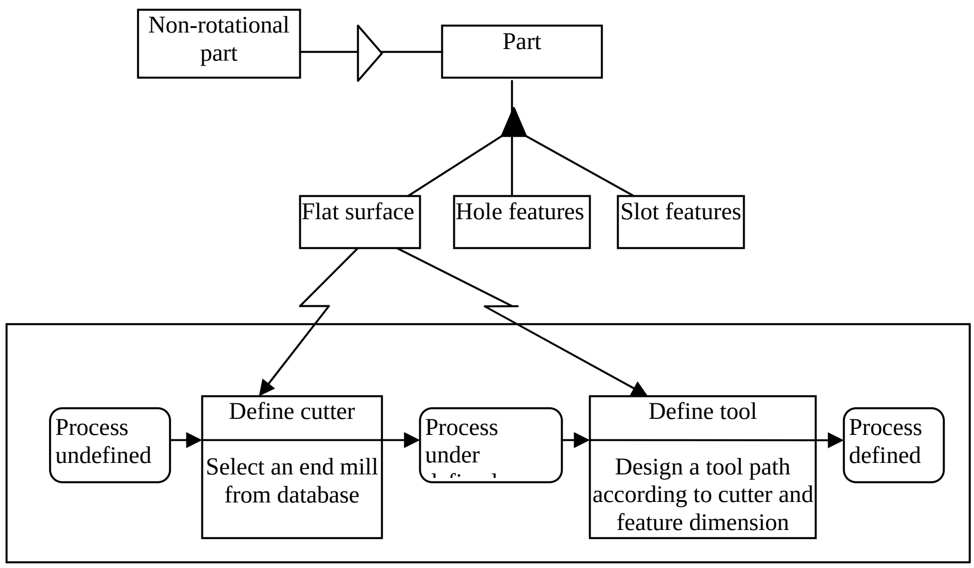


Figure 5.13 OIM Between a Part Object and One of the Process Objects

The part object is composed of a flat surface, a hole feature and a slot feature. Each feature has its own parameters. When choosing the process to machine the flat surface, the cutter and the toolpath in the process are determined by the feature's parameters. The two zigzag arrows in Figure 5.13 show the parameter-driven interaction between the flat surface and the process. When the dimensions of the flat surface are changed, the process to machine the flat surface may change accordingly. The zigzag arrow indicates that programming work is needed to implement this interaction activity.

5.10 Systematic Information Modeling Used

When using OSA approach to model a complex system in the research, high-level abstraction of objects is applied to reduce complexity and make the information models easy to create, maintain, and display. A high-level object groups relative objects and the relationship among the objects into a single object [40]. The top-down approach is used to expand a high-level object into low-level objects and relationships. Figure 5.14 shows the hierarchic structure of system information models.

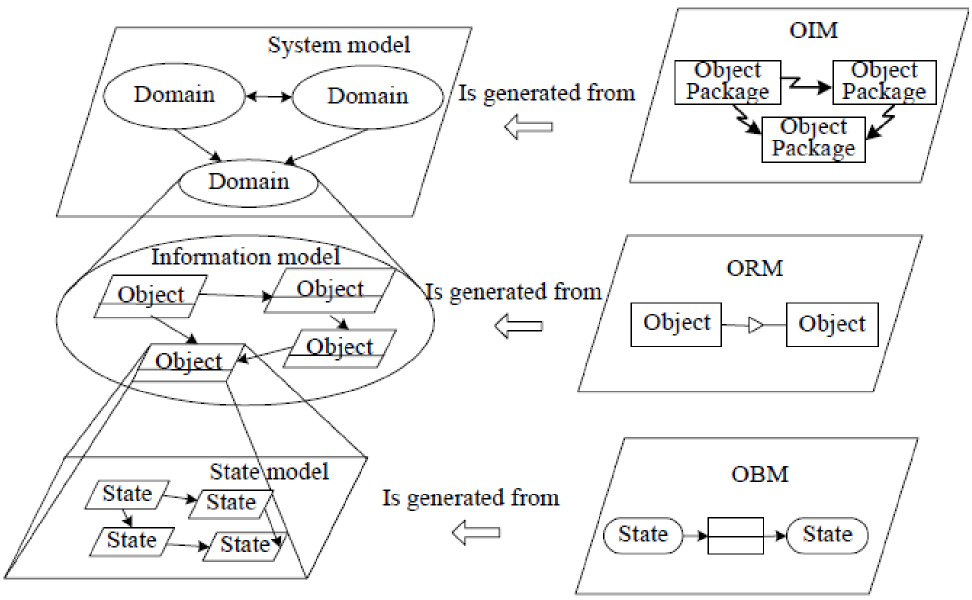


Figure 5.14 Systematic Information Modeling Hierarchies

The building of the information models is split into three levels:

1. The definition of a system model, which contains domains that are subdivided into subsystems. The system model may be derived from analysis of the system's high-level object interaction models.
2. The definition of an information model, which contains objects that are subdivided into states.
3. The definition of the state model, which describes the behaviour of objects.

5.11 UML Class Diagram for the Information Modeling

Among competing object-oriented analysis and design tools, the authors have selected the Unified Modeling Language(UML). The UML is the standard universal language is approved by the object management group for representing (i.e., specifying, building, and documenting) every kind of software system.The UML defines a metamodel-based graphical notation for O-O analysis and design. This is embracing all the features of the O-O paradigm such as reusability, representational versatility, inheritance property and rapid prototyping [92]. In other words, the UML is a formal semantic metamodel defining basic modeling concepts (object, class, association, etc.) and it also is a graphical notation for system representations including eight different diagram types. It embraces all the features of the O-O paradigm through a synergistic combination of various proven techniques including encapsulation, inheritance, polymorphism, and generalization [58].

The UML is not a programming language but a design language. It is a modeling language that specifies semantics and notation but it is not a methodology and does not define a software design procedure. In building the model, the UML may be used to:

- display the requirements of a system and its major functions using use-case diagrams and actors;
- illustrate use-case realizations with interaction diagrams (sequence

and collaboration diagrams);

- represent a static structure of a system using class diagrams;
- model the behavior of objects with state transition and activity diagrams;
- reveal the physical implementation architecture with component and deployment diagrams.

UML with its use-case view diagrams, logical view diagrams and component view diagrams develops three orthogonal models: functional; object; and dynamic models [93]. The functional model represents the transformational aspects of the system and it captures what the system does without specifying how it works. The object model represents the static structural aspects of the system, in which objects, their entities, their attributes, their operations and their relationships with other objects are described in detail. The dynamic model represents the temporal behavioral aspects of the system, in which any change is described by activities and events, sequences of events, and states [69].

UML have been used as a tool for developing manufacturing system control software. By means of few diagrams, proposal is made on a systematic design methodology to make the task of developing the control software system easier.

The class is an information entity, which has one or more attributes, zero or more methods, constraints and relationships. Entity is something in the real world that you wish to describe or track. Attributes define what the classes attribute consists of and have identification name, data and definition. Methods define what the functions class performs. Constraints limit the behaviour of class. Relationships relate the class with others in the model. A relationship includes inheritance, composition, aggregation, and recursion. An object is one instance of a class with specific data. A class diagram is a visual model of the classes and associations in an organisation [63].

Multiplicity is shown as a number for the minimum value, ellipses and the maximum value. An asterisk (*) represents an unknown quantity of many.

Many times a relationship requires both of the entities to exist. For example, what happens if you have a manufacturing activity, which incurs a cost and time, but there is no data on the file for that? There is a referential relationship between the manufacturing activity and the cost and time. Business rules require cost and time data, which must be available to make use of it in manufacturing activity. This relationship can be denoted by specifying the minimum value of the relationship (0 if it is optional, 1 if it is required).

5.12 Conclusion

Task clarification of the IPPPIS has been done in this chapter, with the details on the method used for development of the proposed CAPP in the IPPPIS. Process planning approach in the model was given with explanation of planning methodology, architecture of the system and information system. How the process planning was carried out is outlined with the different steps involved in the selection, such as raw material , machining features, assignment of processes and operations, assignment of machines, machine sequencing, assignment of fixtures and assignment of tools. Functional structure of integrated system developed has been explained in detail, with various components its structure. (i.e., determine raw material, determine options for operations, processes and machines, select and sequence machines and fixtures, determine tools and work conditions, write results, analyse and describe machining features, select possible processes and operations, compatibilize operation alternatives, select capable machines and cost estimation.)

Subsequent sections in this chapter explained the information modeling methods and approaches with the information content on the IPPPIS developed in this research. Different approaches and models such as OSA, ORM, OBM and OIM were explained in detail, along with the application of UML class diagrams for the information modeling. Next chapter gives details on the how modeling of domain specific knowledge in a machine tool factory was done using the modeling methods and tools explained in this chapter.

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

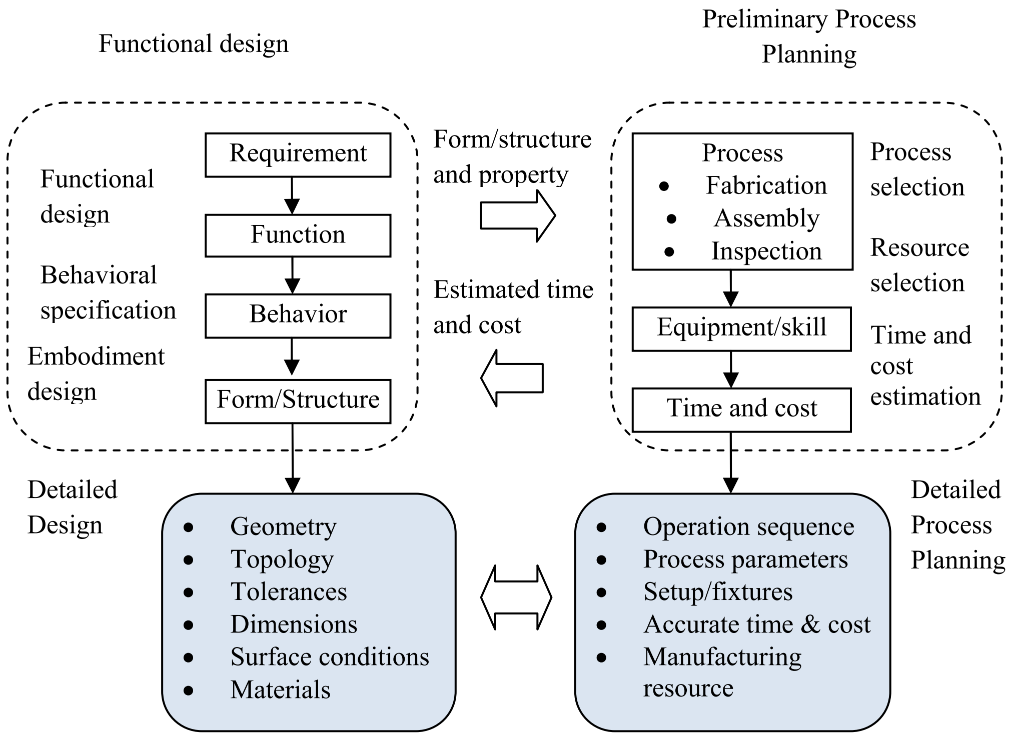


Figure 6.1 Integration Framework of Preliminary Design and Preliminary Process Planning [36]

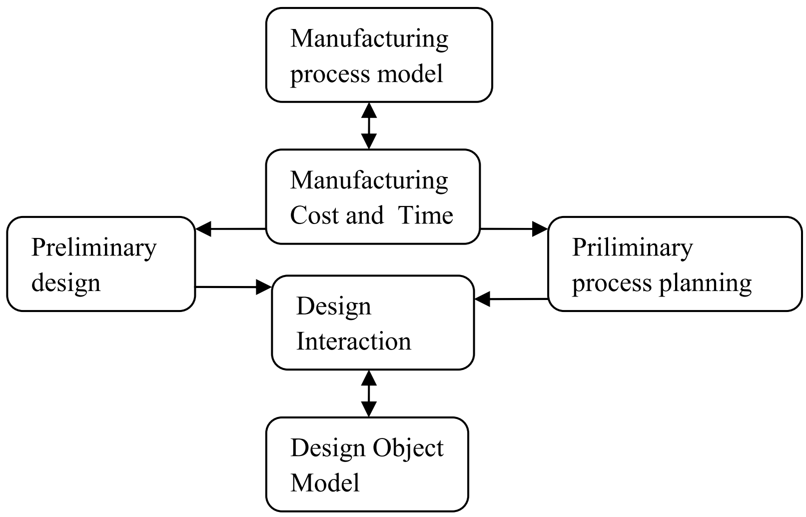


Figure 6.2 Communication Between Design and Process Planning based on Integrated Design and Manufacturing Process Object Model

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.

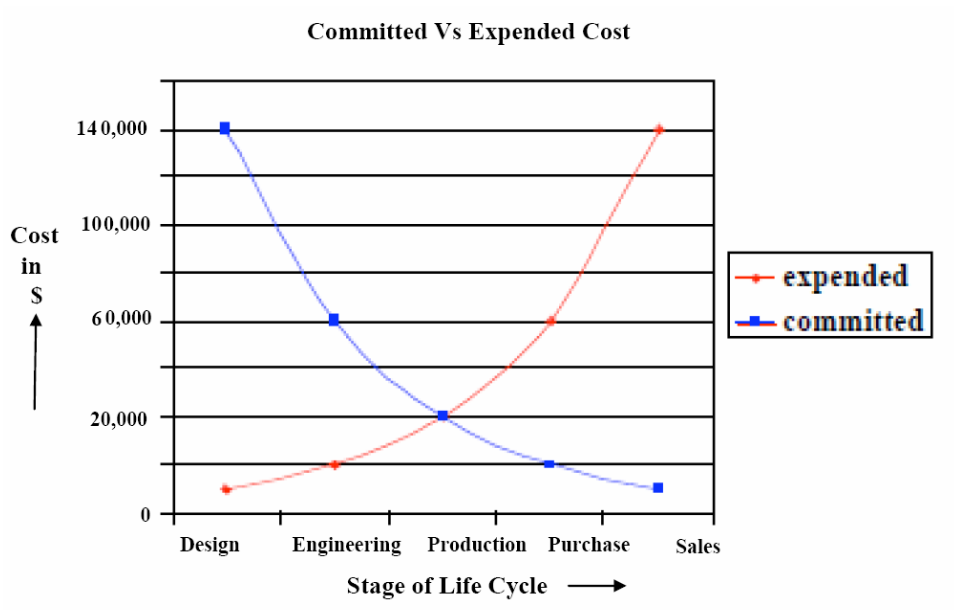


Figure 6.3 Cost Advantage of Early Decisions

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.

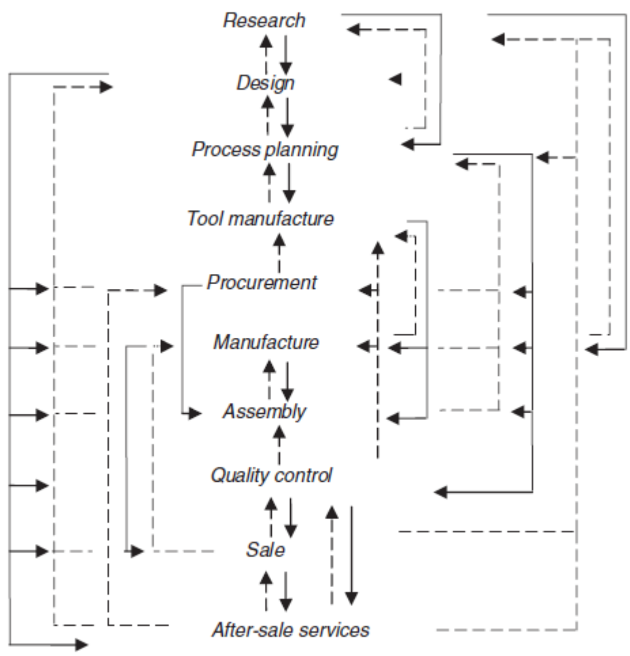


Figure 6.4 Typical CE Network in a Machine Tool Manufacturing Company

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.

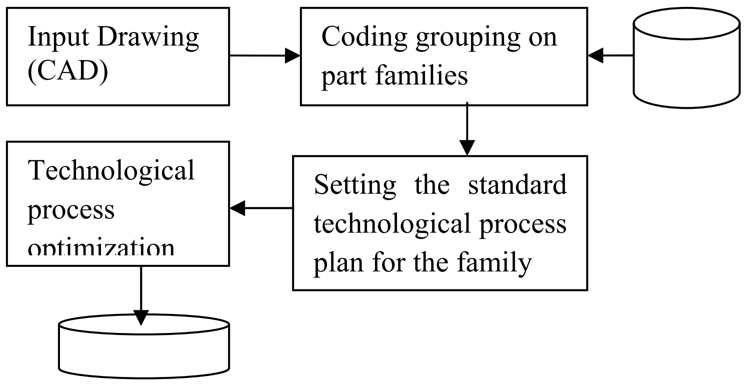


Figure 6.5 The Scheme of the Work Structure in a PPM

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

Figure 6.5, the scheme of the work structure in a PPM through variants is presented.

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].

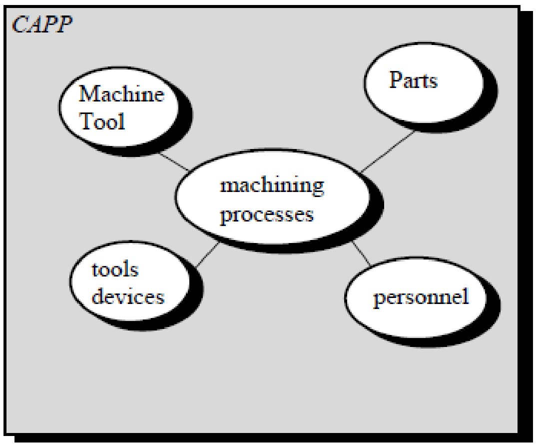


Figure 6.6 Composition of the Objects Used in the Case Study

The realisation of the object-oriented database for the computer-aided conceptualization of manufacturing processes, makes it possible to use the object-oriented programming for drawing out the technical documentation. Beginning with the systemic approach of the mechanical machining process (Figure 6.6), by defining the subsystems that intervene in the manufacturing system the objects can be defined for each program. Let us look at the example given in Figure 6.7, which is object for machine tools. Each objects being characterised by state, behavior, and identity. The information about 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

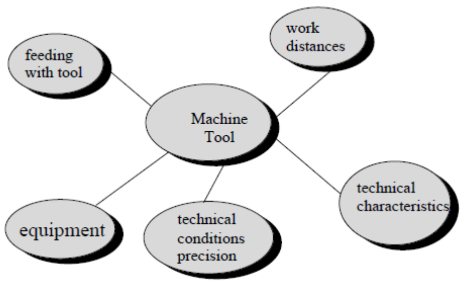
Object - machining process
Class – milling
attributes
operation number <integer>
speed <float>
feed <float>
rotation <float>
methods
operation_creation()>
parameter_calculation()>
parameter_modificaion()>
parameter_optimization()>

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).



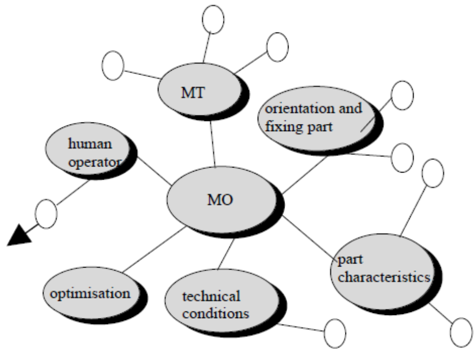


Figure 6.8 Tasks of the Machine-Tool Object

Figure 6.9 Components of the Object-Machining Task

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).

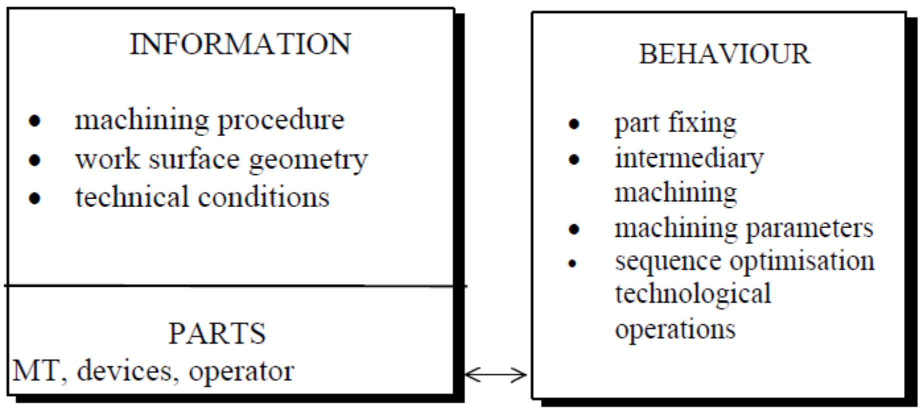


Figure 6.10 Information Structure Object

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.

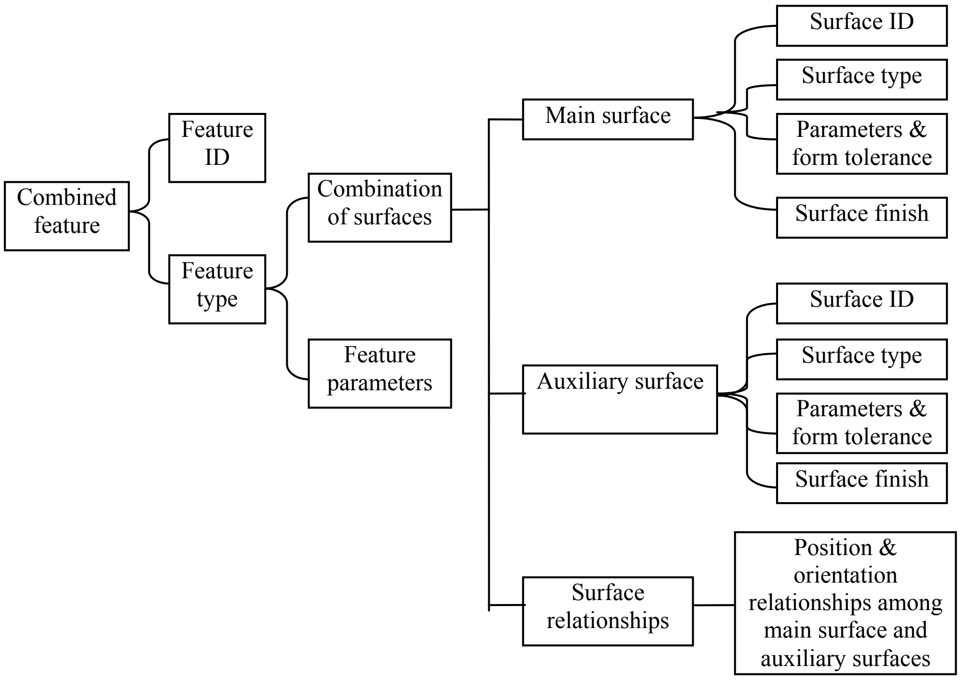


Figure 6.11 Combined Feature Information Structure.

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.

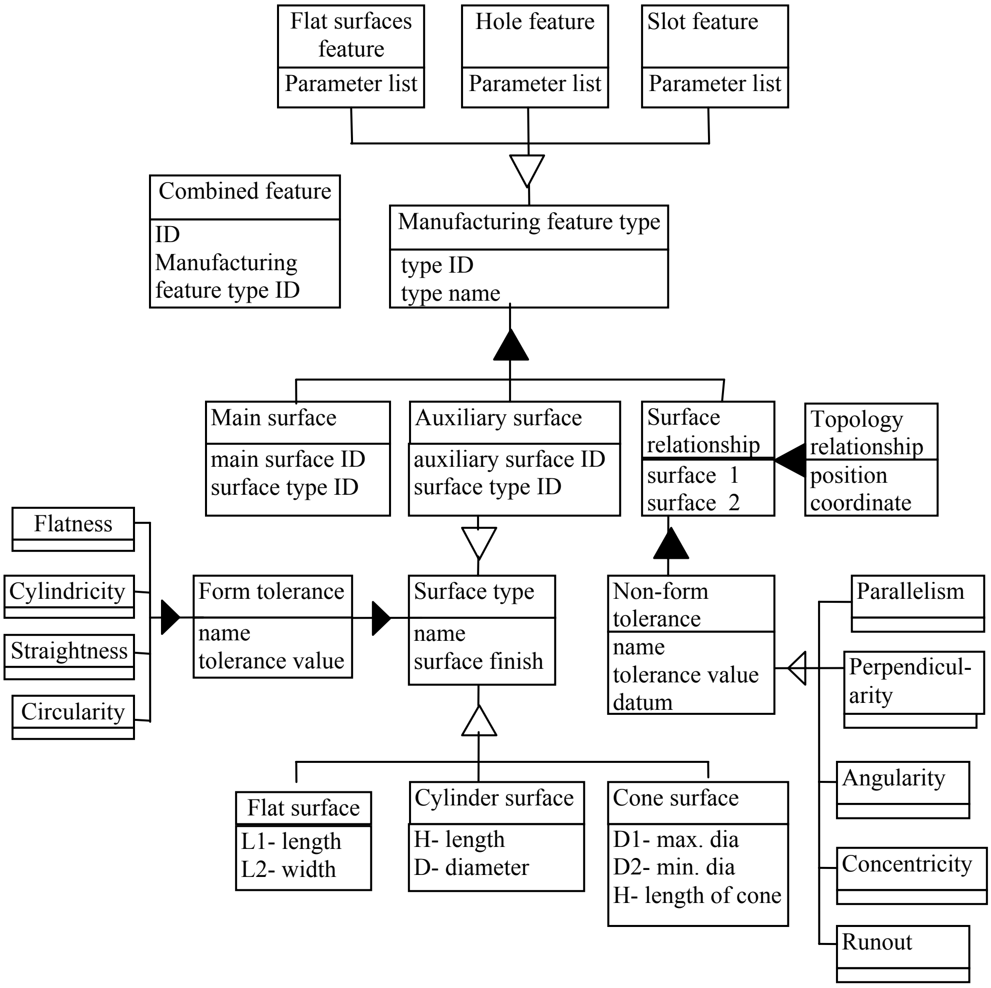


Figure 6.12 ORM of Combined Features

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.

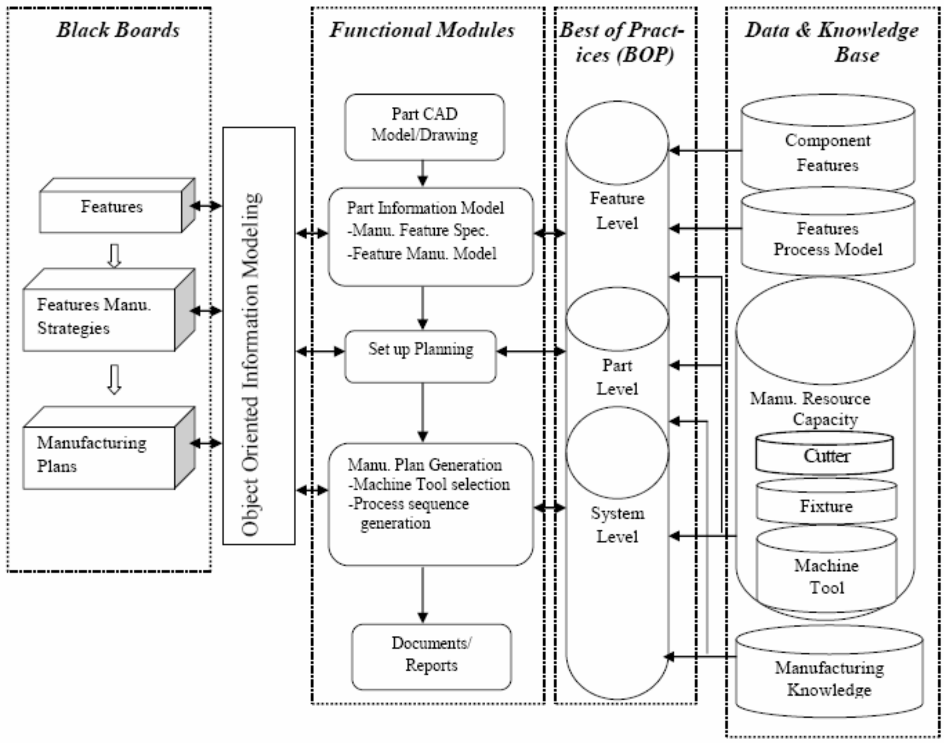


Figure 6.13 Information Content in the System Developed

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.

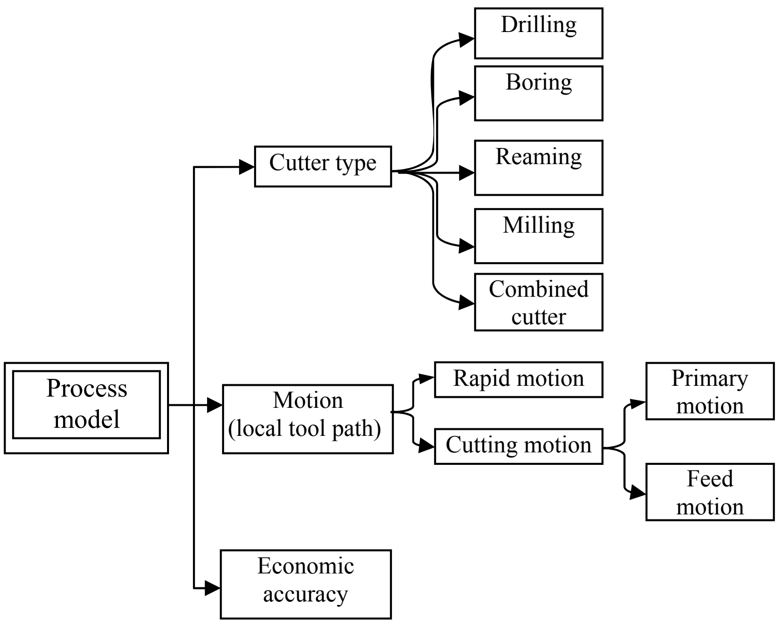


Figure 6.14 Information Structure of the Process Model

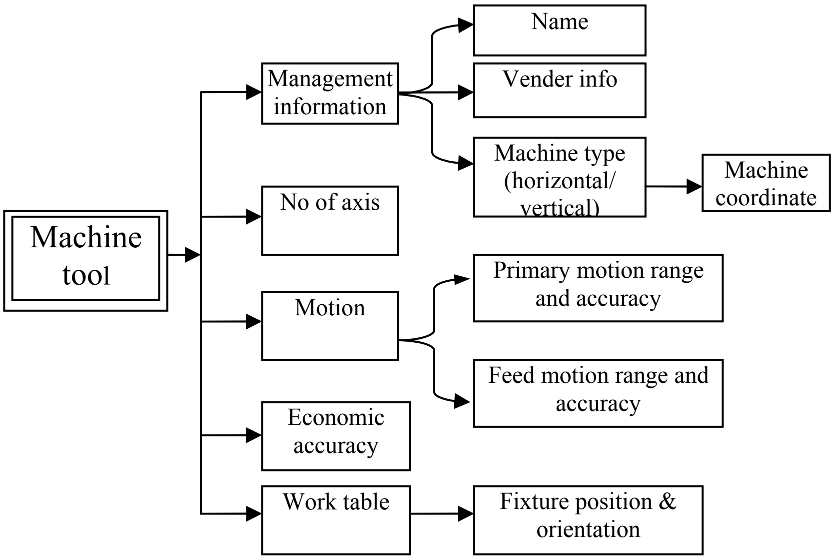
Using the process model, it is expected that a user can add new cutting tool descriptions and corresponding tool path descriptions to the process model easily. This challenge is handled in two ways. First, establish extensible cutter and tool path representations so that users may easily add their own 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

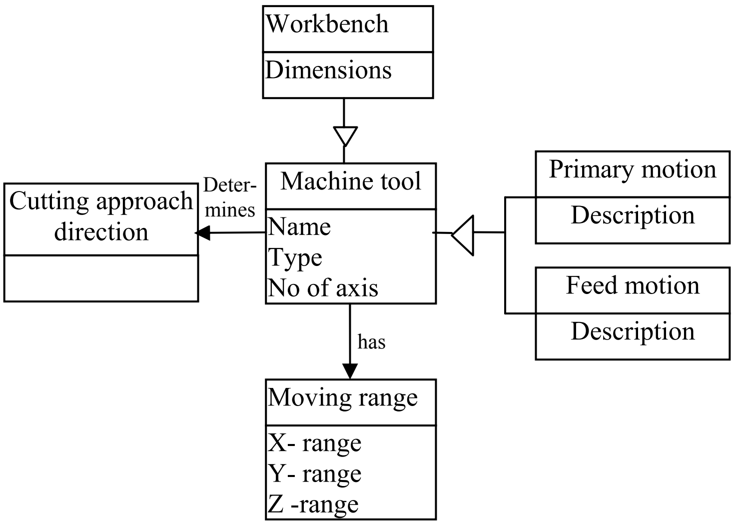
Task of manufacturing plan generation with its various components, like machine tool selection, conceptual fixture design and part layout design, global process sequence and tool path generation, cycle time calculation is described in chapter 4. Machine tool information modeling, planning strategies,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



(a) Machine Tool Information Structure



(b) ORM of Machine Tool Information Model

Figure 6.15 a,b Information Model of Machine Tool

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.

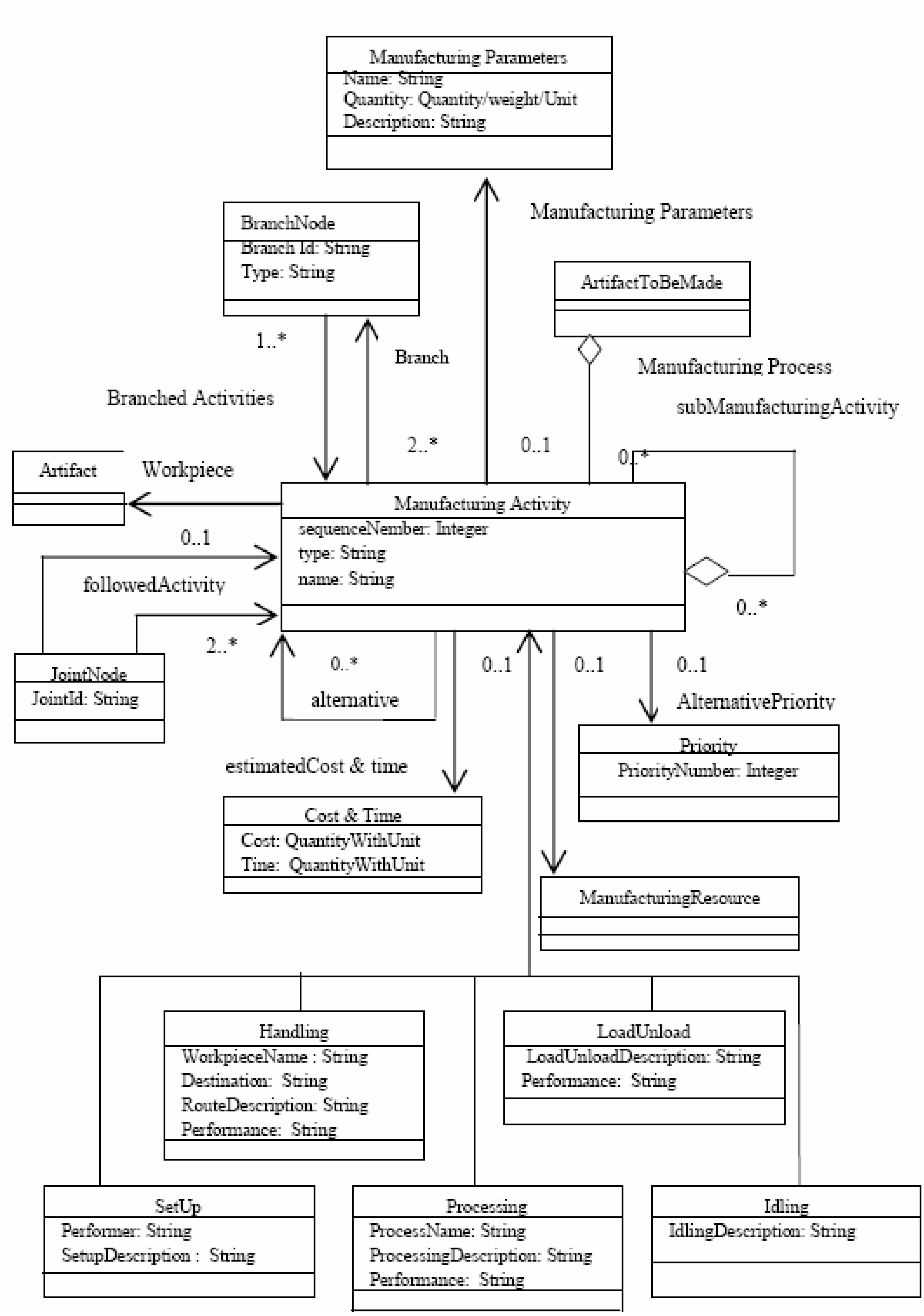


Figure 6.16 Manufacturing Activity Class Diagram

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

Level	Name	Objective
1	Feature manufacturing strategy determination	Selection of combination cutters and toolpath for individual features
2	Setup planning	Determination of machine tools and fixture's capabilities
3	Manufacturing plan generation	Determination of machine tools and fixtures used in the manufacturing system

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

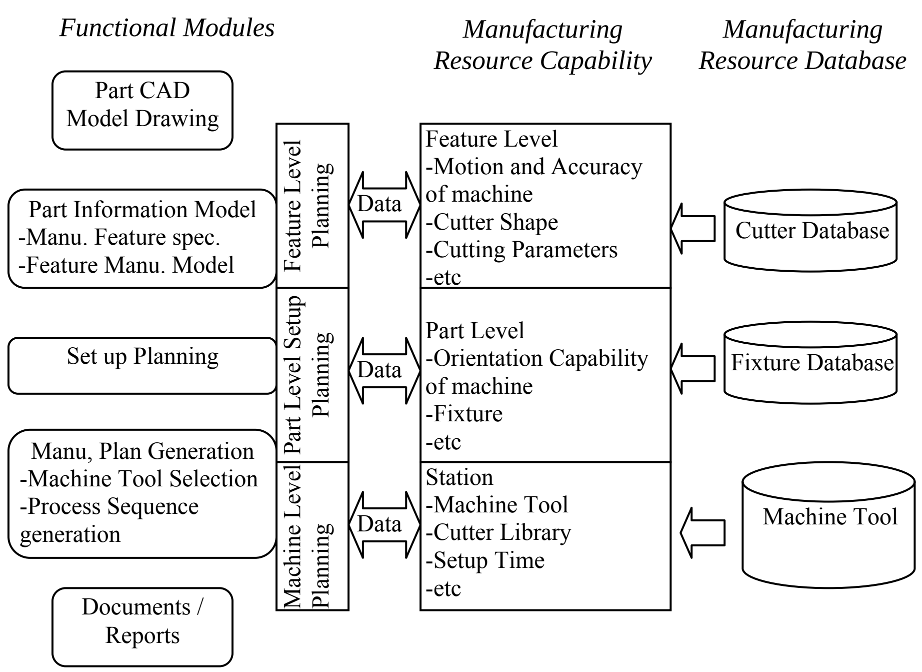


Figure 6.17 Integration of Manufacturing Resource Capability in the IPPPIS

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.

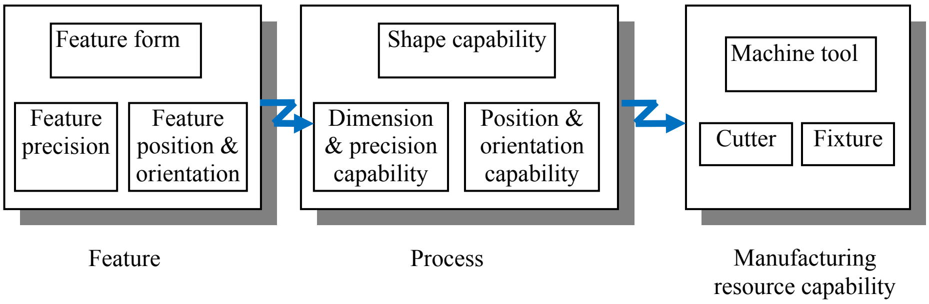


Figure 6.18 Manufacturing Resource Capabilities Mapped to Feature's Attributes

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.

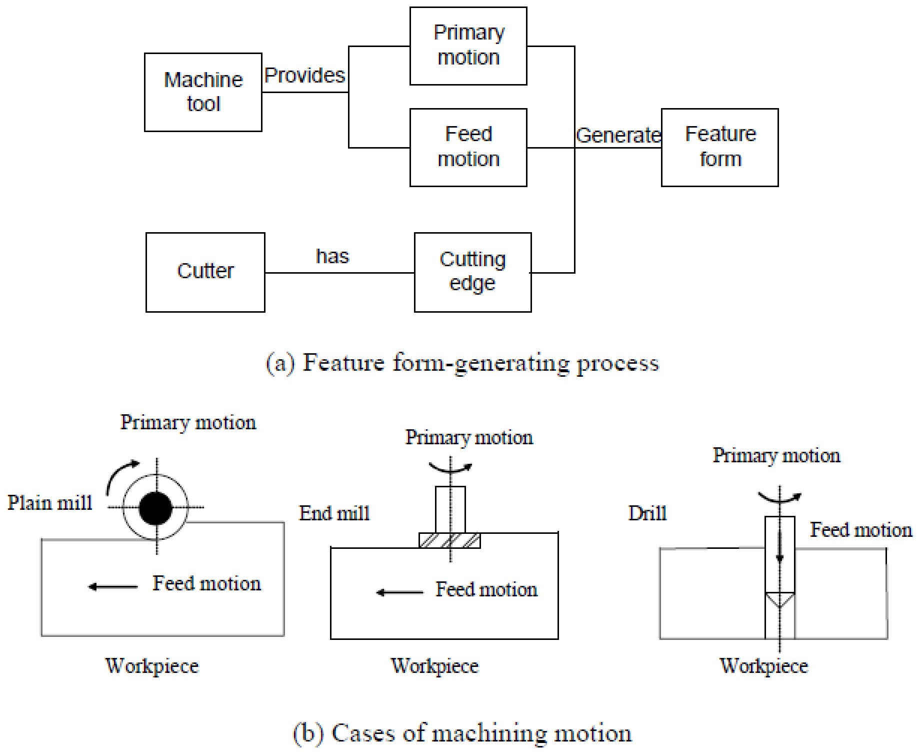


Figure 6.19 Feature Form and Shape Generating Processes

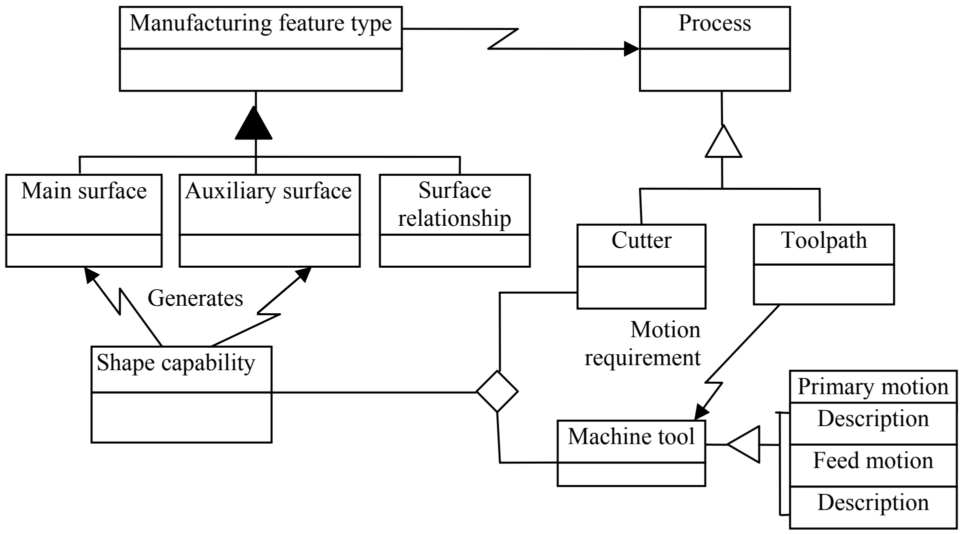


Figure 6.20 Shape Capability Information Model

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.

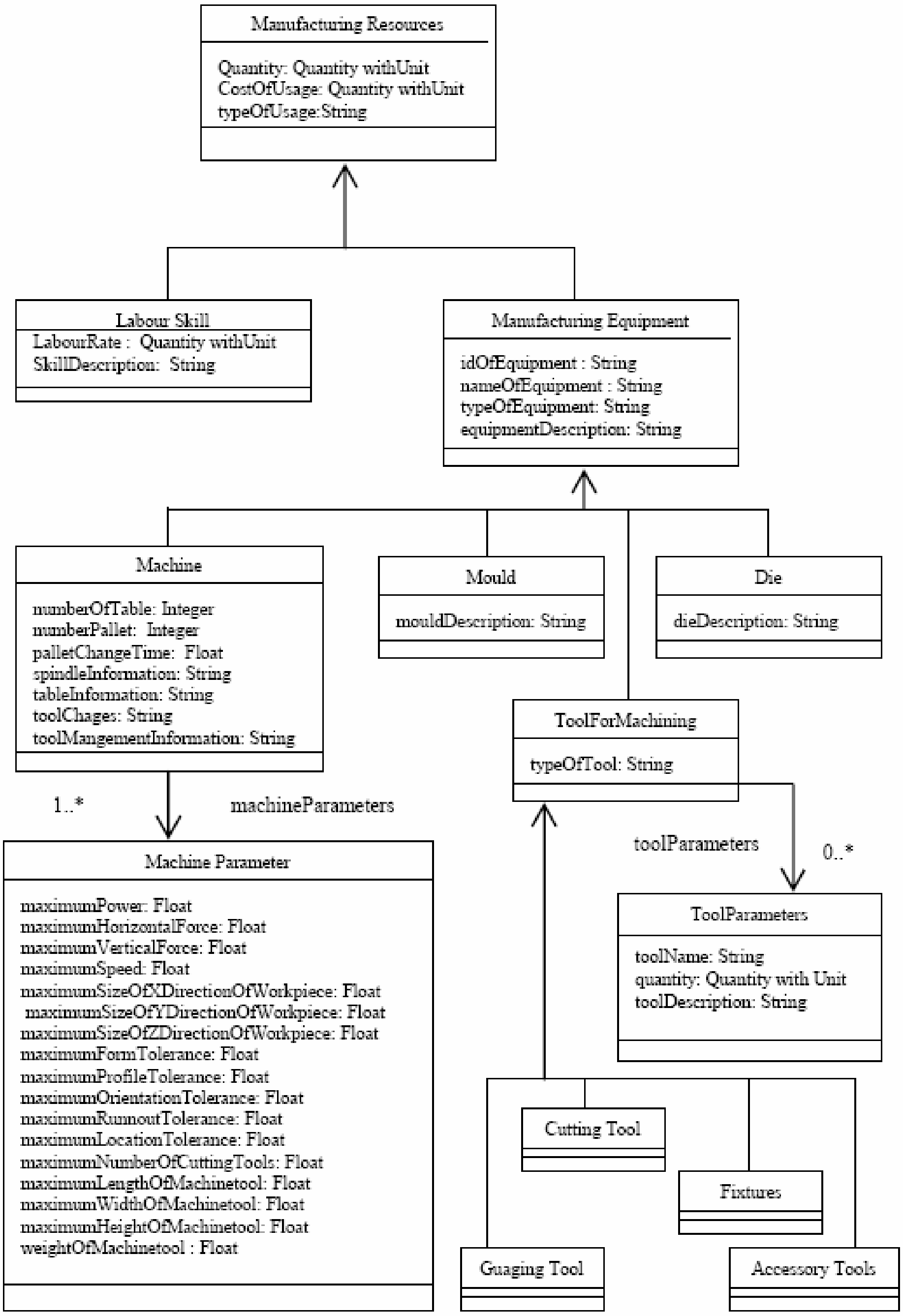


Figure 6.21 Manufacturing Resource Class Diagram

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.

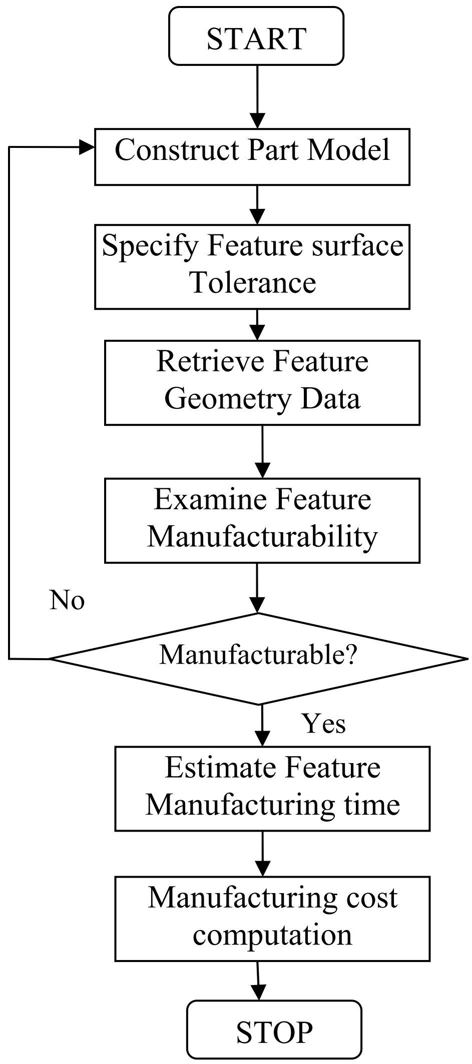


Figure 6.22 Flowchart of the Cost Analysis Process

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.

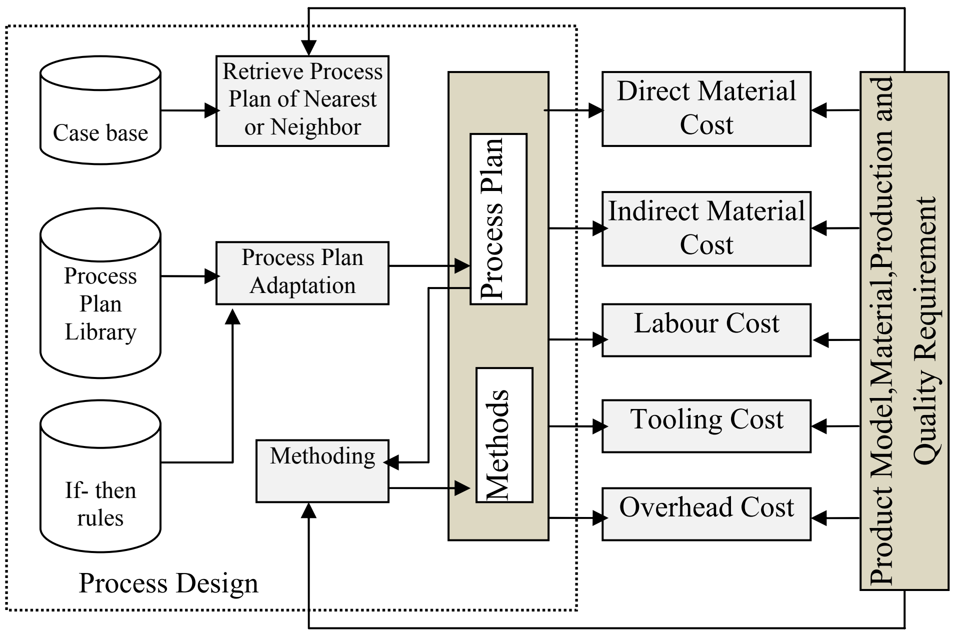


Figure 6.23 Cost Estimation Systems – Overall Architecture

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.

Chapter 7: System Implementation Case Study

IPPPIS implementation in a machine tool manufacturing company is presented as a case study in this chapter. Overview of the machine tool industry in international context with its various components, such as, market situation, classification of machine tool industry, export/import scenario, is presented in the first part. Problem areas in the industry, which requires system improvement, were analysed. Case study is then presented with details of the conventional method followed for the process planning and product development. How machine tool manufacturing organization is benefited to achieve objectives on lean and agile manufacturing, by the integration of product and process models used in the IPPPIS is explained. Benefits derived by the way of CE with the IPPPIS implementation for new product development is given at the end part of this chapter.

7.1 Overview of Machine Tool Industry

The machine tools industry can be broadly classified into metal-cutting and metal-forming tools, based on the type of operation. Metal cutting accounts for 87 per cent of the total output of machine tools in India. Key metal cutting tools include turning centres, machining centres and grinding centres, which account for nearly two-thirds of the total metal-cutting produce. Based on technology, machine tools can be classified into CNC (Computerised Numerically Controlled) and Conventional tools. CNC machine tools, which are highly productive and cost effective, comprise nearly 70 per cent of machine tools. Of these, CNC turning centres, machining centres and grinding centres are the biggest segments, accounting for nearly 81 per cent of the total [99].

Efforts within the industry are now underway to improve the features of CNC machines, and provide further value additions at lower costs, to meet specific requirements of users. In keeping with the current trends, and emerging demand, the CNC segment could be the driver of growth for the machine tools industry in India. The Indian machine tools industry is now recognized as a provider of low-cost high quality lean manufacturing solutions. It is a well-known and often repeated fact that the machine tools industry forms the pillar for the competitiveness of the entire manufacturing sector since machine tools produce capital goods, which in turn produce the manufactured goods [100].

In India, indigenous machine tools have the highest impact on capital output ratios. Machine tools share of Rs.2,500 crore truly supports the advancement of the country's engineering sector output which is estimated to be worth over Rs.1,50,000 crore. In India there are about 450 manufacturers manufacturing complete machines, or their components. There are around 150 units in the organized sector. Almost 73 percent of the total machine tools production in India is contributed by 10 major companies in this industry. The industry has an installed capacity of over Rs.10 billion and employs a workforce directly or indirectly totalling 65,000 skilled and unskilled persons. The government-owned Hindustan Machine Tools Limited (HMT) alone accounts for nearly 32 per cent of machine tools manufactured in India.

7.1.1 Market Situation and Demand in India

In India, the vehicle industry is estimated to invest Rs.25,000 to 30,000 crores in the next 4-5 years in capacity building. The auto component industry is believed to invest Rs.2000 crores yearly since auto component exports are expected to grow to US$ 20 to 22 billion by 2015, a growth rate of 33.45 % CAGR. The engineering industry are projected to invest a total of Rs.2,500 crores in the next two years due to the investment boom in the construction, mining, power, steel and refining sectors.

Ordnance Factories are another major user of machine tools. Defence production is highly specialized, complex and poses unique challenges. Products have to be reliable and consistent in quality and hence the machines producing them need to be of very high technology and accuracy. The technologies and machines being planned for procurement are mostly flexible so as to cater to a wide range of products. During the remaining 10th Plan period, an investment of Rs.560 crores is envisaged for the modernization plan of the Ordnance Factories. The aviation industry in India is growing at a very high rate with the new entrants coming in with purchase of one aircraft per month. The international scenario is also equally optimistic.

7.1.2 Problem Areas Requiring System Improvement

In the survey as given in Figure 7.1, it was observed that 93 percent of the companies have their own design and engineering set up which is a significantly high percentage compared to the other sectors. In fact, the

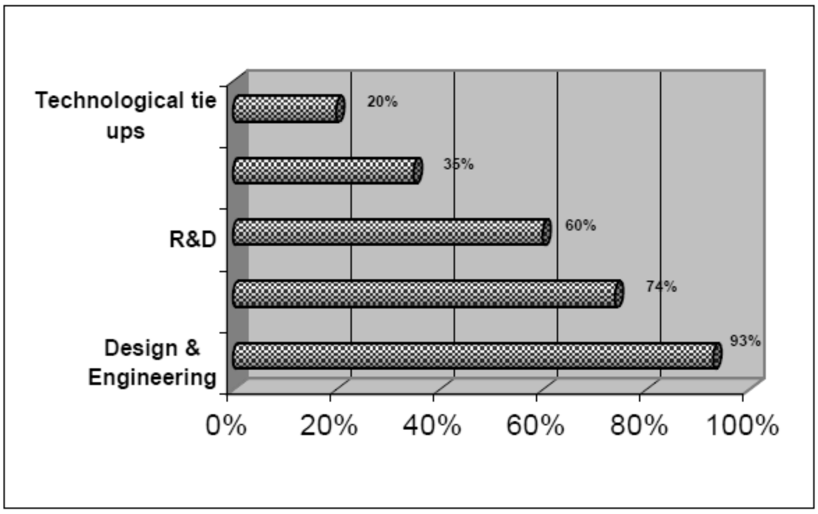


Figure 7.1 Design and Engineering Survey Details [116]

Indian machine tools industry can position itself as the "design lab of the world" with detailed designs being outsourced from India as a diversification strategy by the industry as a whole. Design tends to be market driven rather than technology driven, with technology providing the capability to meet new market needs.

Due to the fragmented nature of the industry and the small size of the players, most of them have not implemented any of the latest soft technologies like six sigma, kaizen, lean manufacturing, TPM, CE, etc. and in fact, many of them are unaware of the benefits provided by these. 33 percent of the companies surveyed have undergone a business process reengineering in the past three years to make themselves more competitive in the face of increasing international competition. 26 percent of the companies underwent downsizing to enhance cost competitiveness [100].

Due to the sudden increase of investments in the automobile, defence and engineering sector in the last one year or two, the industry is just out of the recessionary phase and has been unable to cope up with the demand surge since no additional capacity had been added. On an average, companies have reported that 60 percent of the orders are delivered on or before time and another 25 percent within one month of the delivery due date. The sector needs to upgrade its manufacturing technology and business processes to improve its productivity and also educate itself on the planning process to tackle the delays in delivery either by subcontractors, or by the companies themselves.

The business cycle in machine tool manufacturing closely follows the general economic cycle and has therefore always been subject to cyclical fluctuations. Businesses need to compete efficiently and quickly respond to market needs and niches. There is no doubt that the machine tool manufacturers are confronted with challenges and looking to implement improvements in their key activities or processes to cope with the market fluctuations and increasing customer requirements. With the buoyant, domestic and international, demand the efforts are required on the part of the Indian machine tools industry to improve technology, quality and performance and at the same time to reduce cost. There is no doubt, that with a little effort, this sector can emerge as one of the front runners in increasing value addition in the country, since the value addition by this industry is currently one of the highest in the capital goods industry. The Indian machine tools industry has to reinvent itself in terms of its product range technology and enhanced quality as well as cost competitiveness [101].

Agile manufacturing organizations produce high quality products, at a competitive cost that are flexible enough to be mass customised. These products are produced in a short lead-time by a manufacturing system that is intimately integrated with design of the product and manufacturing process design. The focus in this study is to integrate the manufacturing process design with product design while designing the product, so that the operation of the manufacturing process can be more agile. Shorter cycle times increase flexibility and responsiveness while reducing their costs [102].

7.2 Case Study

A CE implementation study was carried out in a machine tool manufacturing company, producing a wide range of machines tools. The products range from conventional lathe (which is having all India market.shares of 90%) and CNC turning center ((which is having all India market share of 30%) [103]. The products are falling under standard products as well as make to order category. Top-level diagram of the activities in the factory is given in Figure.7.2.

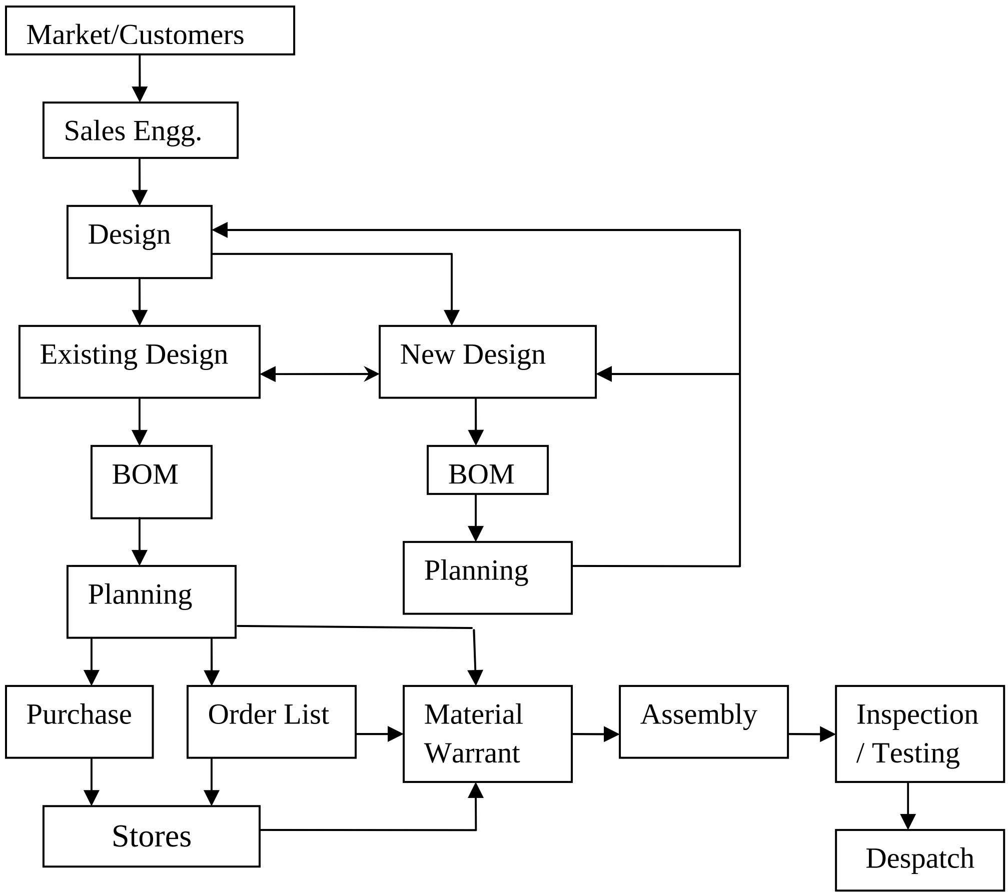


Figure 7.2 Top-level Diagram of Manufacturing Firm (Manufacturing Firm with Standard Products/ Make to Order)

An analysis of orders executed over a period of three years showed that out of a total 60 projects executed per year, 40 projects had serious problems.To visually display the many potential root causes of the problems that are studied, the same is represented as a fishbone chart as shown in Figure 7.3.

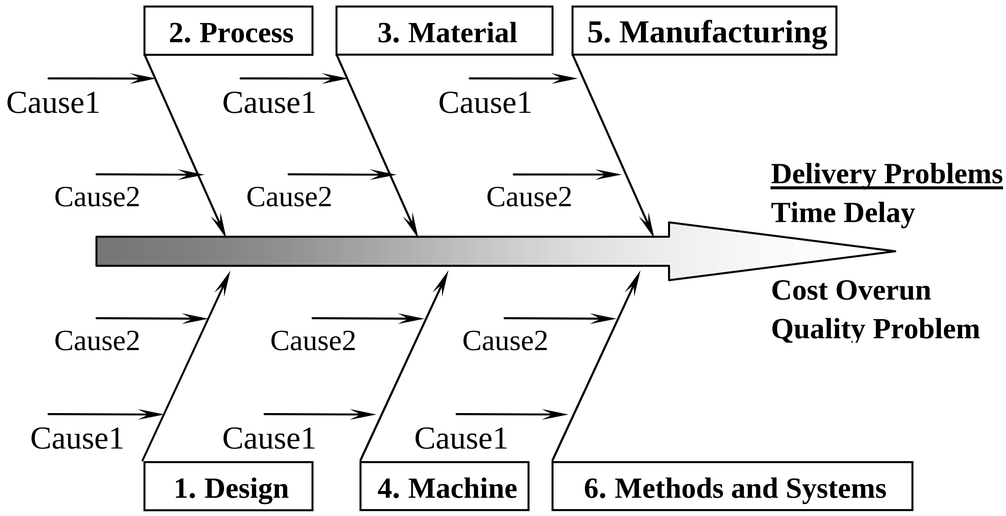


Figure 7.3 Causes for Poor Performance of Machine Tool Factory [Fishbone Chart]

1. Poor performance of machine tool factory-Design

1.1. Poor design
1.2. Design / Engineering changes
1.3. Over design
1.4. Lack of information related to design / process / material
1.5. Lack of information from customer
1.6. Lack of standardisation and rationalisation
1.7. Increased number of components
1.8. Unnecessary Quality specifications, which will increase the cost of the product
1.9. Time control over the product development is poor.
1.10. Reuse level of the existing components are minimal.
1.11. Cost Optimization is poor.
1.12. Reconciliation of conflicting requirements in product development is poor.
1.13. Spending too much development time

2. Poor performance of machine tool factory- Process

2.1. High demand on the skilled planner
2.2. Time taken for the process planning is more
2.3. Increase in the process planning cost
2.4. Manufacturing costs increase due to wrong costly process, lack of information etc

2.5.Non-consistent plans

2.6.Accuracy level of the plan is low

2.7.Unnecessary process and reduction in productivity

2.8.Cost estimating procedures and calculation errors more

2.9.Ability to introduce new manufacturing technology and update process plans is less.

2.10. Lack of planning capability

3. Poor performance of machine tool factory- Material

3.1. Usage of Costly material

3.2. Nonavailable material

3.3. Scrap / Rework

3.4. Material Shortage

4. Poor performance of machine tool factory- Machine

4.1. Process Capability related issues

4.2. Over Loading

4.3. Under utilisation (Idle Time)

4.4. Under utilisation of Costly machines

4.6. Resource Constraints with reference to volume

5. Poor performance of machine tool factory- Manufacture

5.1. Frequent design changes make manufacturing system complex.

5.2. Customer specific tooling

5.3. Customer Orders are highly fluctuating and varying

5.4. Increased number of product variants leads to set up change over/ process resetting

5.5. Scrap and rework related problems /Negligence of operator

5.6. Increased number of parts increases the inventory

5.7. Problem during product introduction Tooling/Work Holding/Special Tools

5.8. Non-value added waiting time / unnecessary movement of material / under utilisation of people.

5.9. Cutter modifications

5.10. Changing production plan

5.11. Less order quantities

5.12. Tooling set-up and reprogramming

5.13. Ineffective machine, equipment

6. Poor performance of machine tool factory- Methods and Systems

6.1. Long Lead time to produce a machine tool

6.2. Slow response to Engineering changes

6.3. Information flow is not smooth

6.4. Accuracy of information is low / Lack of information

6.5 Customer Orders are highly fluctuating and varying make the system complex

6.6 Non-consistent plans increase the complexity.

6.7. Increased number of parts increases the systemic complexity.

6.8. Increased number of product variants increases the systemic complexity.

6.9. Systemic complexities of the batch production are more.

6.10. Unnecessary accuracy level increases the complexity of methods.

6.11. Changing specifications or models

6.12. Poor use of technology and information technology

6.13. Poor information sharing

6.14. Poor responsiveness

6.15. Better allocation

Table 7.1 shows the causes for the poor performance of the projects.

A pareto analysis was carried out to identify the vital problems (Figure 7.4).

Table 7.1 Causes for Poor Performance of Projects

Sl. No	Problem Areas	Average Three Years	Cum. Fre-quency
1	Cost/Time over run due to 1.1. Productivity related problem by improper information flow/ poor information sharing/poor response 1.2. Manufacturing costs increase due to non-optimum process, incorrect information 1.3. Visibility and standardisation related problems 1.4. Rationalization, allocation, planning related problems 1.5. Non-effectiveness of supporting activities 1.6. Poor responsiveness due to complexity and non standardisation	33	33

	1.7. Poor common under standing of procedures 1.8. Poor problem identifying 1.9. Non effectiveness in collecting and evaluating the production information 1.10.Poor ability in making decisions of all level of Employees 1.11. Poor capability of planning team 1.12. Poor decision making by planning and design 1.13. Learning time is more		
2	Development time/cost increase due to 2.1. increase in design/engineering changes 2.2. Poor design 2.3. Poor design optimization 2.4. Poor knowledge base related to design /process/ material 2.5. Increased number of parts due to poor rationalization 2.6.Increased number of new parts and hence more design effort and time 2.7. Poor standardisation	25	58
3	Cost/Time increase due to manufacturing related problems 3.1.Poor plant and resource utilisation 3.2. Products diversification is difficult 3.3. Poor response by Manufacturing to market changes 3.4. Late delivery of products by the plant 3.5. High inventory costs 3.6. Machine and equipment cost is more 3.7. Labour and employee cost is more 3.8. Idle time is more	21	79
4	Waste of time/money reduced due to 4.1 Set up change over/ process resetting 4.2 Unnecessary motion 4.3 Unnecessary process 4.4 Scrap/ Rework 4.5 Inventory 4.6 Under utilisation of people 4.7 Other non value added waiting time 4.8 Tooling/Work Holding/Special Tools 4.9 Poor Material availability, improper material usage	12	91
5	Unnecessary Quality/ accuracy/ precision beyond the customer need, Unnecessary tooling etc.	4	95
6	Poor ability to manage new product development	3	98

7	Lack of information from customer/Poor customer service	1	99
8	Others - modification of cutters - negligence of operator - lack of support/information from related departments - social factors - etc.	1	100

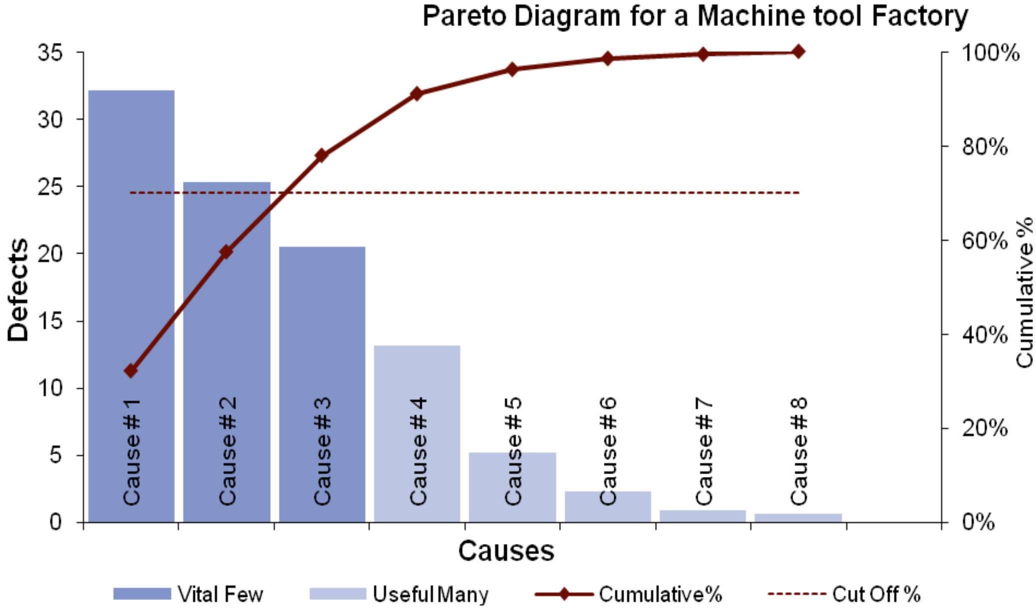


Figure 7.4 Pareto Analysis - Machine Tool Factory

7.3 Conventional Process Planning System and Product Development

Traditional Process Planning Approach is as explained below:

- Process planning comprises many activities amongst which are the specification and interpretation of the part data, the process selection, the resource selection (machines, tools, fixtures, etc.) and the operation sequencing.
- In traditional (manual) process planning, these tasks are carried out by the human process planner in a more or less arbitrary order.

- Product designer may not be knowledgeable of the interrelationships among materials, design and manufacturing as well as overall economics of the operations.

Traditionally, when designing a new product, a team of designers usually participate in what is known as a product development cycle. In general terms, the first stage in designing a new product is that of concept design, in which overall needs and aims are addressed.

Next is the initial design stage. The initial design stage comprises steps of designing the part, then choosing the materials and determining the process to make the part, then designing the tool to make the part. For example, if the part is to be a computer keyboard, first a part engineer determines the size and shape of the keyboard (i.e., the part). Next, when the part has been designed, a second engineer determines the design of the tool that can be used to make the keyboard. Separately, a process engineer determines the materials and process to make the part, for example, whether the part is to be made of plastic; metal or some other material; the properties of the material; the process to be used to make the keyboard (e.g., casting, injection molding, forming, etc.); what are the process parameters; and the rate of production of the process.

The next stage, after making the prototyping of the part, revisions on the design is made. The above steps of part, tool and process design are repeated until part is produced satisfactory, to both design and cost of production. Traditionally, each of the above steps is carried out sequentially, usually by different people. One person may design the part, another the tool, and a third the process. Collaboration between these designers is usually minimal. Where many revisions have to be made, numerous iterations are needed and a long period of time passes until a satisfactory part is produced.

Basic Factors Affecting Process Design are:

- Volume or quantity of product to be manufactured based on sales forecast
- The required quality of the product
- The equipment that is available or that can be procured for the product manufacture

Components of Process Planning are as given below:

- Selection of machining operations
- Sequencing of machining operations
- Selection of cutting tools
- Determining the setup requirements
- Calculation of cutting parameters
- Tool path planning and generation of NC/CNC programs
- Design of Jigs/Fixtures

Requirements for Process Planner as given below:

- Must be able to analyze and understand part requirements
- Have extensive knowledge of machine tools, cutting tools and their capabilities
- Understand the interactions between the part, manufacturing, quality and cost

A Rough Process Plan is shown in Figure 7.5.

Route Sheet		by: T.T. Pullan
Part Number:E80202030 Part Name: Mounting Bracket		
SlNo	Workstation	Time (Min)
1.	Matl Rem	
2.	Mill 02	5
3.	Drill 01	4
4.	Insp	1

Figure 7.5 A Rough Process Plan

A Detailed Process Plan is show in Figure 7.6.

Traditional Process Planning Problems

- Experienced based and performed manually
- Variability in planner's judgment and experience can lead to differences in the of what constitutes best quality
- Problem facing modern industry is the current lack of skilled labor force to produce machined parts as was done in the past
- Chances for the concept of over the wall design
- Hence Computer Integrated Manufacturing and Computer Aided Process Planning

PROCESS PLAN					ACE inc
Part No. S0125-F Part Name: Housing Original: S.D. Smart Date: 1/10/2011 Checked: C.S. Good Date: 2/10/2011				Material: Steel 4340Si Changes… Date:……..	
No	Operation Description	Work station	Setup	Tool	Time (Min)
10	Mill bottom surface1	Mill 01	See attach#1 for illustration	Face mill 6 teeth/ 4" dia	3 setup 5 machining
20	Mill top surface	Mill 01	See attach#1	Face mill 6 teeth/ 4" dia	2 setup 6 machining
30	Drill 4 holes	DRL02	Set on surface1	Twist drill ½" dia 2" long	2 setup 3 machining

Figure 7.6 A Detailed Process Plan

Problem with over the wall design is explained as below:

- Designer is assumed Designers job is to design; somebody else's job is to manufacture.
- No cost optimisation
- No value engineering
- No saving in time/ Delay in delivery.

7.4 Benefits of CE and New Process Planning System in the IPPPIS

Besides the three conventional production modes, mass production, job production, and batch production, a new production mode, mass customization, has been introduced into industries to allow customized products to be made to suit special customer needs while maintaining near mass production efficiency.

Fundamental concern regarding the product design and manufacturing platforms for mass customization is that the company must optimize external variety versus internal complexity that results from product differentiation. External variety comes from customer preferences and is reflected in product design, while internal complexity is associated with a company's process capabilities, especially on the utilization of manufacturing resources. An important step toward establishing manufacturing planning platforms for mass customization is the development of planning methodologies that provide easy access to information in the previous manufacturing plans. Due to the similarity/commonality among production systems or among specific customized products, reuse suggests itself as a natural technique to facilitate increasingly efficient and cost effective product development. That is, a new manufacturing plan that reuses a previous plan at some level or to some extent should be less expensive to develop than a plan that is designed from scratch. By reusing prior plans, an engineer can save design time and cost by leveraging off previously worked-out solutions.

Table 7.2 shows the major characteristics of the above production modes. In this, batch production mode represents the most suitable model for the machine tool factory considered for the case study. Currently, most of the research focuses on job and batch production, with aim to produce customized parts while trying to maintain minimum manufacturing cost by using of standard cutters, fixtures and machine tools.

The basic tasks of CAPP for metal removal include the following steps:

- Design analysis and interpretation
- Process selection
- Tolerance analysis
- Operation sequencing
- Cutting tools, fixtures, and machine tool specification
- Cutting parameters determination

Table 7.2 Characteristics of Manufacturing Planning in Different Production Modes

	Job production	Batch production	Mass production	Mass customization
Volume	<100/year	100- 5000/year	>5000/year	100- 8000/year
Product variety	Large	Medium (Parts are grouped into families)	Small	Large (Parts are grouped into families to reduce the variety)
Machine tool	General machines	General or special machines	Special machines	CNC machines
Machine layout	Function based layout	Manufacturing cells cells	Transfer lines	CNC machines or Manufacturing cells
Fixture	General fixtures or modular fixtures	Dedicated fixtures	Dedicated fixtures	Dedicated fixtures for part families
Cutter	General cutters	General or special cutters	Special cutters	Special cutter designed to machine multiple surfaces
Product repeat rate	Little	By batch	Continuous production	By batch
Productivity	Low	Medium	High	High
Cost per part	High	Medium	Low	Low (approaches to mass production cost)
Cycle time	Long	Medium	Short	Short
Turnaround time	Short	Medium	Long	Short

7.4.1 Tasks of Manufacturing Plan Generation

It is known that in overall cycle time, non-cutting time, including cutter change time, cutter rapid traverse time, and machine tool table index time, takes important portion. In the CAMP, in order to improve productivity and reduce cycle time, manufacturing plan generation includes the following steps, in which machine-level decision-making strategies that abstracted from BOP is applied to achieve optimal cycle time.

1. Machine Tool Selection

Candidate machine tools are those that fulfilled the entire requirement for machine tool capabilities from setup planning, including the number of axis of machine tools.

2. Tooling and Fixture Selection

The initial solution of conceptual fixture design is derived from machine-level BOP, which includes machine tool selection, fixture base selection, and part layout on fixture bases. The part layout in BOP is based on previous detail fixture design, which determines the fixture structure and fixture components. In the meantime, necessary verifications of fixture performance are needed in detailed fixture design, such as interference free, chip shedding to avoid chip accumulation, locating accuracy, stability problems, clamping sequence, error proofing, and ergonomic issues.

3. Global Process Sequence and Tool Path Generation

In order to reduce the non-cutting time on each part, the processes that use the same cutters are to be carried out sequentially. Hence, a sequence is needed for all the manufacturing processes on the multi-part fixtures. A corresponding tool path is generated without interference with fixture components, machine tools, etc.

4. Cycle Time Calculation

Cycle time is the critical factor in choosing the optimal manufacturing plan in mass customization. Hence, the estimation of cycle time is indispensable for manufacturing plan generation.

Figure 7.7.gives the details of the Conventional Process Planning Procedure. Hierarchy of the feature-based model is shown in Figure 7.8.

Reasons for Adopting the Concurrent Engineering are as given below:

- 70 to 80 % of the cost of product development and manufacture is determined at the initial design stages.
- Minimise product design and engineering changes Time and Cost
- Reduce Time to market .i.e., Agile to market condition
- Encourage the Design for Manufacture
- Interrelationships among design and manufacturing as well as overall economics of the operations, which leads to Lean manufacturing.

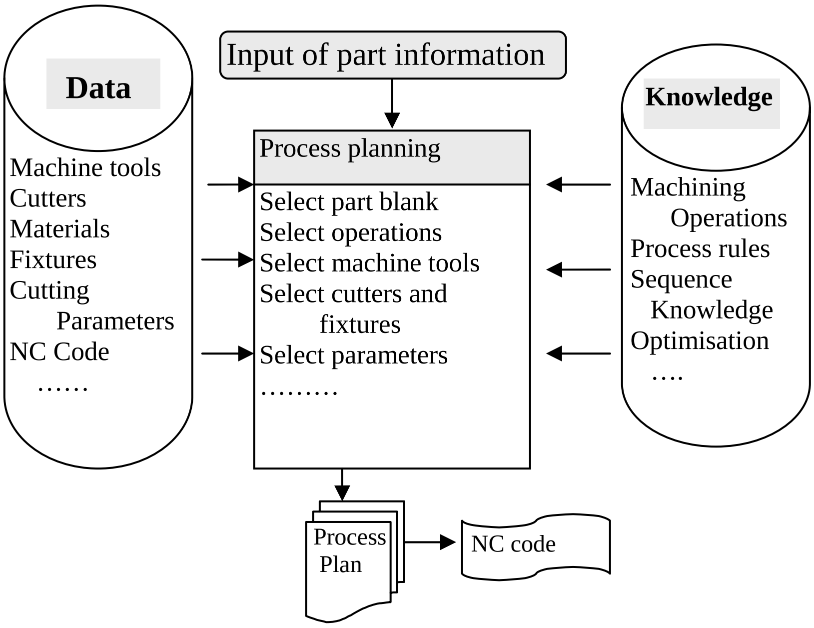


Figure 7.7 Conventional Process Planning Procedure

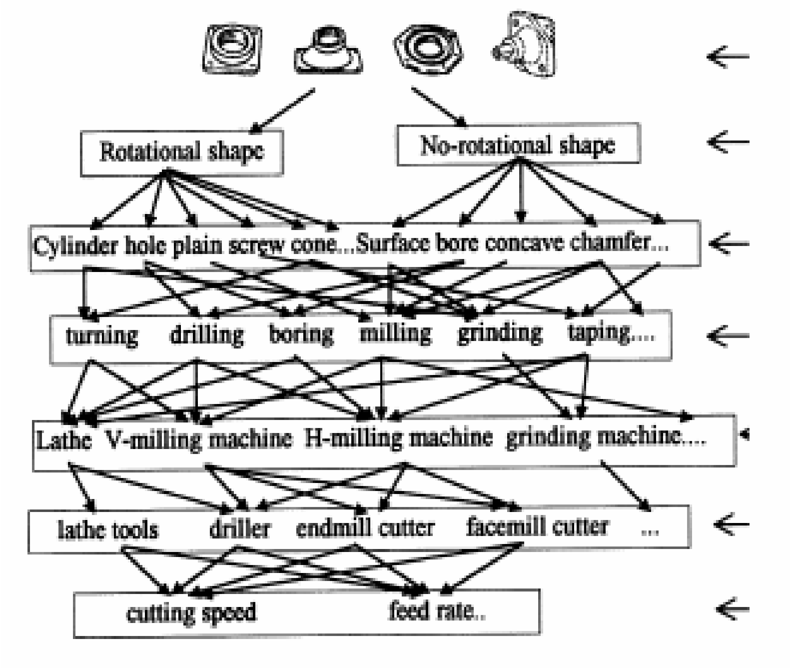


Figure 7.8 Hierarchy of the Feature-Based Model [119]

Concurrent Engineering is explained as:

- Product designer must be knowledgeable of the interrelationships among materials, design and manufacturing as well as overall economics of the operations
- Concurrent engineering is a systematic approach integrating the design and manufacturing of product.

Concurrent Design will have some of the Specific Advantages by the way of:

- Design permits production in the most efficient manner.
- Most economical process to produce the required quality, strength, tolerance, etc..
- Standard machines and cutting tools can be used.

The IPPPIS will Provide:

- Product Designer with more insight into most economical process to produce the required quality, strength, tolerance, etc..

- Designer can select design features in initial stage of design in such a way that Standard machines and tools can be used.
- Process planner has an interface or editor for each process planning activity, allowing the systematic, interactive construction of the process plan.
- Similar to the expert systems approach, this will provide reasoning mechanisms and knowledge sources. The kernel should have several knowledge sources (e.g. one for process selection, one for tool selection, etc.,) which can be consulted in an any order to perform some specific planning task.

The methodology for development of the proposed CAPP in IPPPIS is given in Figure 5.1 in chapter 5.

7.4.2 Information Modelling Technologies

Information models are data structures that represent information contents. A large amount of information in manufacturing planning needs to be computerised so that CAPP systems can manipulate them. All this information is identified and represented by information models. There are basically four categories of information in the CAPP:

Design Information

Design information is the input of CAPP. Generally, part information, including part geometry information, tolerance information, functional information, and production information (production volume, material), are analyzed and represented in CAPP systems.

Manufacturing Resource Information

Manufacturing resources may include cutting tools, machine tools, fixtures, and inspection tools. Some of them are standard tools and readily available. Others are designed specifically for particular processes used in manufacturing plans.

Manufacturing Knowledge

Manufacturing knowledge is the constraint to help engineers make the right decisions. It is composed of general manufacturing rules and best practice knowledge that is summarised by manufacturing industries.

Information Generated by CAPP Systems

The result generated by CAPP systems also needs to be described by information models. This consists of process information; including the utilization of manufacturing resources and process parameters; setup information, and manufacturing planning information.

Methodology of CAPP is explained with figures in chapter 5 section 5.5.

7.5 Architecture of the IPPPIS

The architecture of the CAPP system that supports the methodology put forward is given in Figure 7.9. From an information point of view, it has been designed with the aim of giving the CAPP system autonomy from the manufacturing environment.

The architecture takes into account an internal database in which specific information structures for CAPP are established. This idea was used in previous studies. However, it has increasing advantages when used with information systems able to represent the product, the production resources and the process plan in a general and flexible way. This enables the application domain (parts and production resources) to be represented in a way that is both general and tailored to the needs of the CAPP.

The internal data and knowledge bases act as a shield to make the CAPP system independent from its production environment. Furthermore, if the information systems can represent any part and any type of production resources, the responsibility for generality will then fall on the planning methodology and the functions it develops. These must deal with and process data.

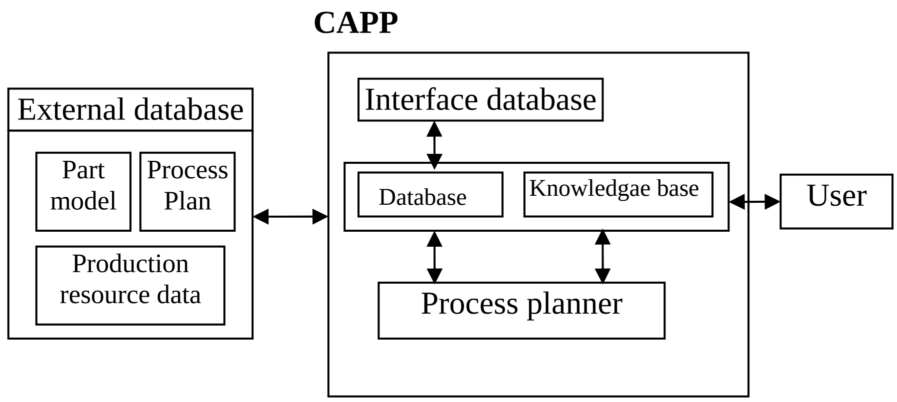


Figure 7.9 Architecture of the CAPP

7.5.1 Functional Structure

Having described the planning methodology and system architecture, we will now look at the functional structure of the system. The functional structure defines the different functions developed by each of the tasks involved in process planning, and the exchange of information between the various functions. The information structure and function structure have mutual influence. This is because the information structures represent the communication link between these functions. As a result, when considering the functional structure, at the same time we have to also bear in mind the information structure.

7.5.1.2 Information structures

The information model to implement this methodology was made up of models that will now be outlined. Their main characteristic is generality for resource representation. It consists of a model representing the part, models for production resources and their capacities, and a model providing support for the representation of alternatives at phase level.

***** *Description of machining features*: - This model establishes a representation of the part based on machining features. Each machining feature is represented by a group of properties that characterize it regardless of the part and the rest of the features. This enables an individualized assignment of resources at phase level (processes, operations and machines). The description takes into account the following data:

**Description of process and operation capacities:* - Information structure that gives a general description of the process capacities and their operations.

The model describes the following:

* Capacity for qualities, hardness, etc.
* Description of tools applicable.
* Data for modeling the time and cost of the process and its operations.

* *Description of machine capacities.*

**Description of alternatives for processes, operations and machines:* - This information model allows various production resource alternatives to be represented for the manufacturing of a part. As shown in Figure 5.5 of chapter 5, section 5.5, the model represents, in hierarchical order, the alternatives at the machining feature, the operation, the process and the machine group levels. It uses general information structures to describe the operations qualitatively and the process and machine groups quantitatively.

7.5.1.3 Functional structure is explained with figure in section 5.5 of chapter 5.

7.6 Information Content in the System Developed

Concurrent Product and Process Design in shown with the help of a flow diagram for better understanding in Figure 5.4 in chapter 5. The characteristics of the IPPPIS can be summarized as generating manufacturing plans quickly in accordance with part changes based on best of practice of part families. The architecture of the IPPPIS for mass customisation includes feature-based part information modelling, setup planning, conceptual fixture design and manufacturing plan generation.

A systematic information modelling technology was used to represent the information relationships and associativities from the system perspective. The OSA approach was used as the primary tool to describe the static and dynamic characteristics of information. Therefore, the information associativities within the IPPPIS between part design and manufacturing planning can be properly described, so can the information in BOP of part families. A three-level decision-making mechanism was used by making use of the systematic information modelling technology. At the feature-level, the combined features and their manufacturing strategies were defined based on part families.

First, feature-based part information modelling was studied, based on the BOP of part families. In the IPPPIS, parts are grouped into part families. The parts in the same family may have similar manufacturing plans, which are composed of sequences of processes and the manufacturing resources used to carry out these processes. In the research, the definition of feature is extended to include combined features, which are associated with particular processes that are pre-defined by specific part families.

Figure 6.13 in chapter 6, section 6.3 shows the diagram of IPPPIS architecture. The software contains function modules: (1) The part information modelling module extracts part information; recognizes manufacturing features; and associates them with predefined manufacturing strategies; the module then organize feature based part information (2) The setup planning module can generate setup plans based on BOP (3) The conceptual fixture design module (4) The manufacturing plan generation. Manufacturing plan generation is a special step for mass customization. Part layout on fixture bases, global process and tool path generation, and cycle time calculation are discussed at this stage based on the machine-level decision-making strategies. Cycle time was used as the criterion to evaluate the manufacturing plans.

The Manufacturing knowledge and BOP are stored in relational databases and knowledge bases. Figure 5.4 in chapter 5, section 5.5, shows the overview of database relationships, in which part type, feature type, process type and manufacturing resource type are stored. However, this kind of databases is not suitable for storing the knowledge that is specified by BOP because this knowledge is associated with specified manufacturing industry environments and does not have a unified format.

7.7 Use of Information Model for Lean Manufacturing

Lean manufacturing means eliminating wastes by identifying non-value added activities thorough out the supply chain. The five fundamental Lean principles are: to specify value from the point of view of customer, identify the value stream, make the identified value flow, set the pull system which means only make as needed; and finally perfection in producing what the customer wants and by when it is required in the right quantity with minimum waste [104].

Toyota Production System (TPS), which is known as Lean manufacturing by in their book “The Machine That Changed the World” has influenced the manufacturing, practices around the world [105]. The fundamental of TPS is to eliminate wastes and produce only the items needed at the required time and in the required quantities. Principles of lean are universal as they are broadly accepted by many manufacturing operations and have been applied successfully across many disciplines. It has become an integrated system composed of highly inter-related elements and a wide variety of management practices including just in time, quality system, work teams, cellular manufacturing, etc.

The available models are not fully integrated with each other or with another information model. Some issues addressed by the IPPPIS model developed to make the organization more responsive to change and minimise the waste, to make them as lean enterprise are as follows:

- Assure seamless information flow by enabling practices like link databases for key functions throughout the value chain; minimize documentation while ensuring necessary data traceability and availability.
- Implement integrated product and process development. Most published process plan models form detailed process planning, not the preliminary process planning in the early product assesment stage, is extended to the manufacturing information hierarchical structure.
- The type of methods used for manufacturing cost and time estimation is integrated into the manufacturing process model.

7.7.1 Lean Manufacturing through Cellular Manufacturing

Customers demand variety and customization as well as specific quantities delivered at specific times; a lean producer must remain flexible enough to serve its customers' needs. CM allows companies to provide their customers with the right product at the right time. It does this by grouping similar products into families that can be processed on the same equipment in the same sequence.

The benefits of CM such as faster throughput times, improved product quality, lower Work- In-Process (WIP) levels and reduced set-up times, were achieved through the model built in the IPPPIS. These gains are achieved because the batch sizes can be significantly reduced. As set-up times decrease through the use common tools or the collaboration of cell workers during set-up times, batch size can be reduced. The shorter the set-up time the smaller the batch size, and as a goal, a batch size of one is feasible when set-up time is zero. Within a cell, small batch sizes do not travel very far as machines are collocated, resulting in less work-inprogress, shorter lead times and much less complexity in production scheduling and shop floor control.

CM offers an opportunity to combine the efficiency of product flow layouts with the flexibility of functional layouts. In CM, products with similar process requirements are placed into families and manufactured in a cell consisting of functionally dissimilar machines dedicated to the production of one or more part families [106]. By grouping similar products into families, the volume increases justifying the dedication of equipment. However, since this volume is justified by process and product similarity, CM warrants much more flexibility than a pure product-flow layout. In terms of the product-process matrix, CM allows movement down the vertical axis, i.e., it allows increasing the continuity of the manufacturing process flow without demanding that the products be made in large volumes. This is further explained in section below:

7.7.1.1. Benefits by Machine Grouping

Machines can be grouped depending upon the feature-manufacturing requirement. Further machine groups are selected as per the design features, which will lead the system to rationalisation and standardisation of design and process. Figure 7.8, Figure 7.9 and Figure 7.10 explain this.

Some other benefits of the CE implementation revealed by the case study are as given below:

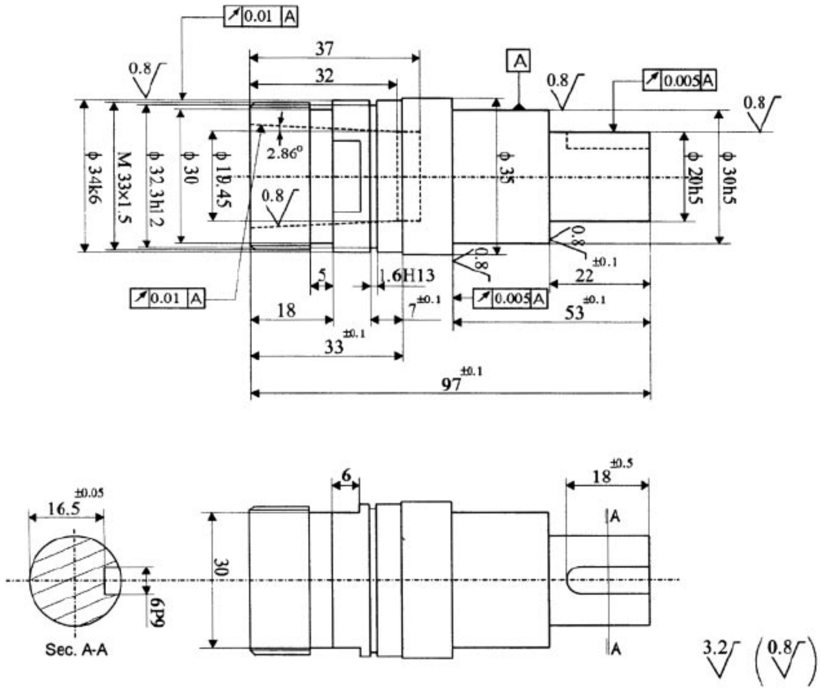


Figure 7.8 Technical drawing of the part [56]

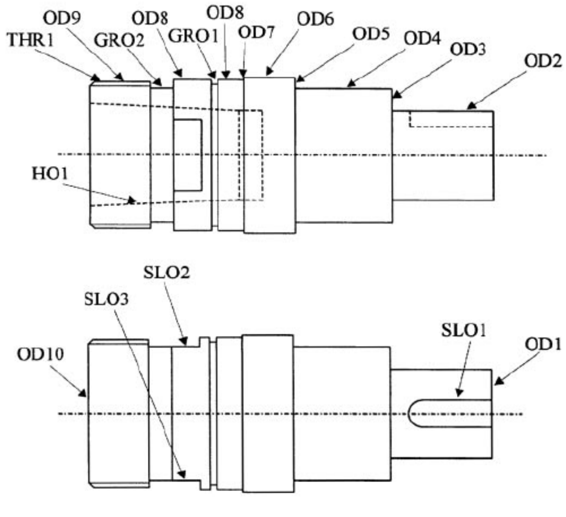


Figure 7.9 Machined Features Used in the Definition of the Part [56]

FEATURES	OPERATIONS	PROCESS MACHINE GROUPS	PROCESS MACHINE GROUPS
OD1 OD3 OD6 OD7 OD9 OD10	Rough	Turning	G1 G8 G10 G14
		Broaching	G13
		Grinding	G6 G7
		Milling	G2 G5 G12 G15
	Finish	Turning	G10 G14
		Broaching	G13
		Grinding	G6 G7
		Milling	G11 G16
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16
SLO1 SLO2	Rough	Slotting	G2 G5 G12 G15
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16
HO1	Rough	Milling	G2 G5 G12 G15
		Turning	G11 G8 G10 G14
	Finish	Grinding	G6 G7
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16
GRO1 GRO2	Rough	Milling	G2 G5 G12 G15
		Turning	G1 G8 G10 G14
		Broaching	G13
	Finish	Grooving	G10 G14
		Broaching	G13
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16
THR1	Rough	Threading	G1 G8 G10 G14
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16
OD2 OD4 OD5 OD8	Rough	Turning	G1 G8 G10 G14
		Milling	G2 G5 G12 G15
		Broaching	G13
		Grinding	G6 G7
	Finish	Grinding	G6 G7
	Surface hardening	Carburizing	G11G16
	Quench	Quench	G11 G16

Figure 7.10 Alternatives for Processes Operations and Machine Groups [56]

7.8 Use of Information Model for Agile Manufacturing

In today's industry, a manufacturing system is required to be able to produce products efficiently and to respond rapidly to changing market needs. In order to meet these requirements, the agile manufacturing paradigm has emerged as an important concept in the development of manufacturing systems. AM synonymous with responsive manufacturing in a broad sense that is defined as the capability of surviving and prospering in a rapidly, continuously and unpredictably changing environment, by responding quickly and effectively and by taking a customer's views into account [107]. Information technology, virtual manufacturing, concurrent engineering, standard of the exchange of product model data (STEP), web-based engineering, design engineering and rapid prototyping are some of the enablers for AM [5]. Among these, CE is a systematic approach to the integrated, concurrent design of product and their related processes, including manufacture and support. It is a useful and beneficial approach to reduce the development time and manufacturing cost while simultaneously improving the quality of a product to respond better to the customer expectations.

In an effort to help designers better assess the downstream life cycle impacts of their design choices, manufacturing companies and researchers have developed many design decision support tools referred to as Design for X (DFX) methodologies. This research is based on concurrent engineering framework using effective application of information technology. A model has been developed using object oriented technology, and cellular manufacturing concept for collaborative design and manufacturing of machine tool.

7.9 A Framework for Agile Manufacturing System for Machine Tool Industry

There are several tools and methods that have been proposed to develop an agile manufacturing system [108]. For modelling the agile manufacturing system, we have to clarify what a manufacturing environment and a system commonly mean. Manufacturing environments are product-dependent. They are somewhat like natural phenomena, which evolve due to various forces that work in the market place. Attributes defining manufacturing environments include.

1. *Product characteristics*: - Features and functions of the product.
2. *Product variety*: - Different types of products the company should produce.
3. *Lead-time*: - Period of time until the product enters the market.
4. *Product life cycle (PLC):-* Length (or number of periods) and quantity a product is in demand over its life-cycle.

Such attributes are the defining factors of traditional and agile manufacturing environments. The means by which the company selects to deal with attributes of an environment and attempts to control the situation is referred to as a manufacturing system.

The business cycle in machine tool manufacturing closely follows the general economic cycle and has therefore always been subject to cyclical fluctuations. Businesses need to compete efficiently and quickly respond to market needs and niches. There is no doubt that the machine tool manufacturers are confronted with challenges and looking to implement improvements in their key activities or processes to cope with the market fluctuations and increasing customer requirements. Applying agile manufacturing philosophy is one of the most important concepts that help businesses to compete. On analysis of the difficulties experienced by the Indian machine tool industries to address the customer demand, the following reasons are indicated as some of the obstacles.

- Lower volume of demand
- Decreasing volumes for identical products
- Increasing product variety.
- Decreasing concept-to-market and, thus, the introduction time between new products.
- The customer orders are highly fluctuating/varying

- Customer-specific tooling
- Long lead time to produce a machine tool
- Frequent changes in design
- Resource constraints with reference to volume

The above factors may have a significant influence on day-to-day operational strategy variation. Many industrial studies conducted have revealed that most of the machine tool manufacturing activities are highly influenced by the customers. To cope with such characteristics, the concept of agile manufacturing comes into play. Agile manufacturing environments differ from traditional manufacturing environments in the fact that product life cycles are becoming shorter while the quest for higher qualities are becoming more consequential, and products are becoming increasingly diversified and global[109].

The agile manufacturing system should be able to produce a variety of components at low cost and in a short time period. The design rule reduces manufacturing lead times in consecutive changes of product models. Managing change in a manufacturing environment requires a more systematic method of concurrently designing both the product and the downstream processes for production and support. Agile manufacturing requires a rapid product design system with the objective of switching over to new products as quickly as possible. It is then essential to the employment of CE during (when realizing) new product development (NPD), which can be called concurrent new product development for AM, which is built in the IPPPIS.

7.10 Integration of Product Models and Process Models for Agile manufacturing in the IPPPIS

The relations between the product model and process model were analysed from the viewpoint of integration, and the coupling mechanism of models was also established in the developed IPPPIS. The logicality of the development process and the completeness of product model information were emphasized. Therefore, it can promote the development process evolvement efficiently and make the product development process optimal.

7.10.1 The Relations Between Product Model and Process Model

Product model describes the product information and the relations among information. It is the digital and abstract definition of a realistic product. In general, product model data is determined by its structure and its content. The structure is dependent on the nature of the product and the tools used to model the information as well as to build the necessary schemes for the database. The content is dependent on the particular product. Process model is the abstract description of the product development process, and it can be used to analyze, optimize, and establish the activity process of product development and to assist the management and monitoring of the whole process.

Product development process modeling, in its complete sense, consists of two interrelated aspects: product model and process model. Product models are referred to product model databases and their associated management and access algorithms. Process models are also commonly referred to product development workflow or product modeling processes. The basic requirement of integrated product and process development is that both the product model and the process model are integrated in one model frame. That is to say, it should realize the integration of the two models, i.e., coupling. The validity of coupling will determine the quality of product development.

7.10.2 Development Mode Based on Model Integration

There are three different development modes as shown in Figure 7.11.

1. The product model is the main line of product development. In this mode, product model is static, and process model is dynamic. The

product model is the kernel of the development process. The process model is improved (or reorganized) continuously to adapt to the product model, by which the product development is completed.

2. The process model is the main line of product development. In this mode, the process model is static, and product model is dynamic. The process model is the kernel of the development process. The product model is modified based on the development environment to adapt to the process model.
3. Integrated development mode. In this development mode, the product model main line and process model main line are integrated. Based on the practical development environment, both the product model and process model were modified synchronously to adapt to each other. This modification is dynamic and mutual. The state of product model information and process model information change simultaneously.

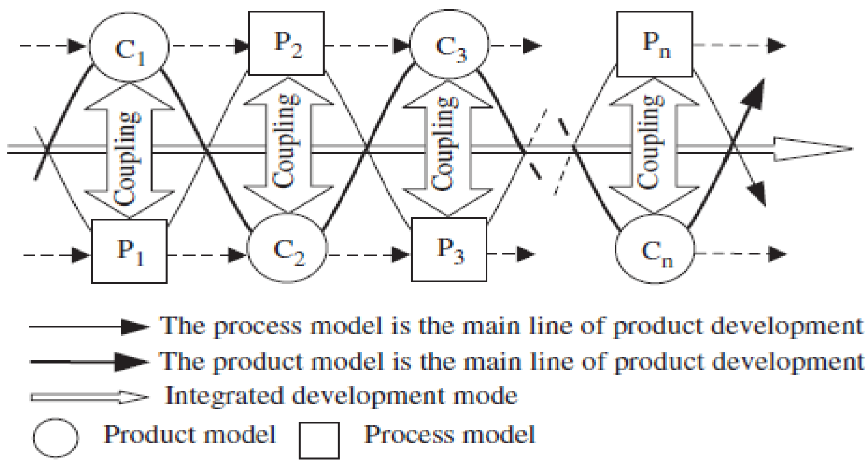


Figure 7.11 Development Mode Based on Model Integration.

Benefits using IPPPIS, which gives agility in the system was explained in subsequent section:

7.10.3 The Benefits Obtained by Agility as Time Saving

The benefits obtained by the way of time saving by the integrated product design and manufacturing cycles in a systematic way is as described in Table 7.3. This demonstrates the ability of the IPPPIS to make swift, cost effective progression of new product from raw material concept to final product.

Table 7.3 Benefit / Time Saving in the Process Plan Generation Using IPPPIS

Time in Hours

Sl. No	Activity Details	Time Taken by Traditional Method	Time Taken with IPPPIS
1	Determination of raw material	2	0.5
2	Selection of the possible process and operations	4	1
3	Compatibilize operation alternatives	3.5	0.75
4	Select capable machines	2.5	0.75
5	Cost estimation	4	1
6	Select the machine sequencing	4	1
7	Assignmnet of fixtures	2.5	0.75
8	Assignment of tools and work condition	3.5	1
9	Write results/process plan	4	1
	Total Time	**30**	**7.75**

7.11 Other Benefits Obtained from the *IPPPIS*

We have seen some of the benefits manufacturing organisation is having by becoming lean and agile with the help of IPPPIS. Some of the other benefits that were observed are as given below:

7.11.1 Benefits by Faster Cost Estimation for Machined Parts

For some manufacturing domains such as machining, cost estimate depends on the geometric details of the object and automated procedures are not available for doing accurate cost estimation. Currently in such cases, humans perform cost estimation. In the internet era, where designers solicit many quotes to make a decision, manual cost estimation is not economical. Cost of manufacturing a new part can be quickly estimated by finding previously manufactured parts that are similar in shape to the new part.

If a sufficiently similar part can be found in the database of previously manufactured objects, then the cost of the new part can be estimated by suitably modifying the actual cost of the previously manufactured similar part. Figure 7.12 shows a new part and a previously manufactured similar part that can be used to provide cost estimate for the new part.

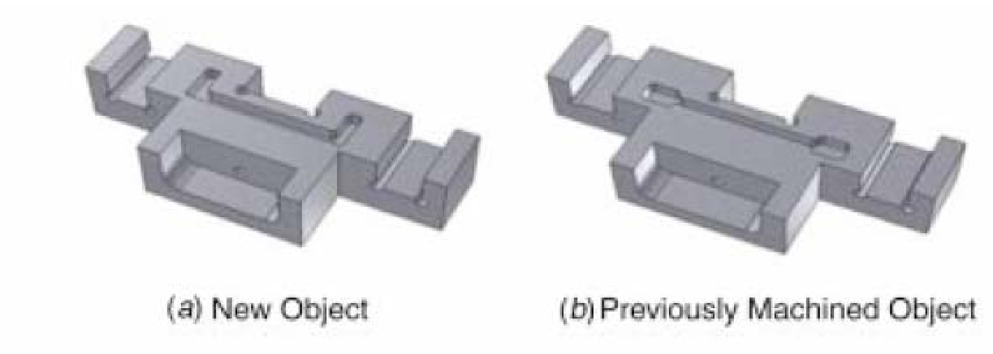


Figure 7.12 An Example of Using a Similar Part for Cost Estimation

7.11.2 Benefits by Part Family Formation

In many manufacturing domains such as sheet metal bending, machine tools can be setup to produce more than one type of part without requiring a setup or tool change [3, 76]. However, parts need to be shape compatible in order for them to share common tools and setups. Therefore, in order to find common tools and setups, geometrically similar and therefore compatible parts need to be grouped into families. Shared tools and setups can be used to manufacture objects in the same family and therefore result in significant cost savings.

7.11.3 Benefits by Reduction in Part Proliferations

Reusing design/manufacturing information stored would result in a faster and more efficient design process. While designing a new part the designer can refer to existing designs and utilize the components used previously. Let us consider the design of the shaft of a turbine engine. Usually the designer has two options. The first option is to design the shaft from scratch and go through the process and manufacturing planning. The second option is to refer to the database of existing designs and select an existing shaft and either use it as it is or make minor modifications to it (e.g., drill a few holes or cut a few slots). The process of creating a preliminary concept of the shaft and selecting a shaft similar to the proposed concept is illustrated in Figure 7.13.

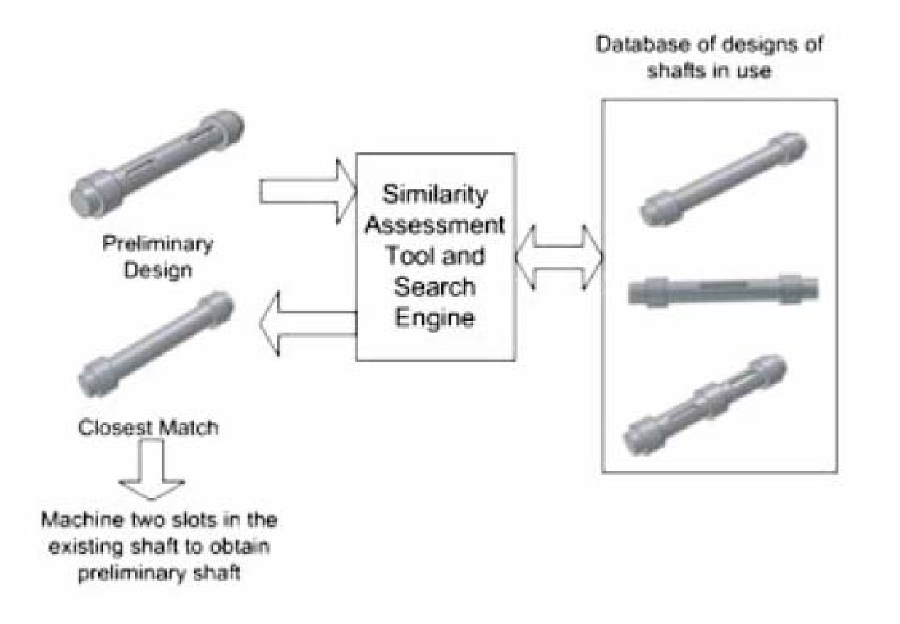


Figure 7.13 An Example of Using an Existing Shaft for Reducing Part Proliferation

With more and more 3D models being added to databases, a need to organize and index databases of 3D models. This will provide a systematic and efficient way of retrieving similar models from the database. Group Technology has traditionally been used to categorize parts having similarities in design and manufacturing. Group Technology (GT) involves classifying similar products into groups in order to achieve economies of scale normally associated with high-volume production. In order to implement GT, one must have a concise coding scheme for describing products and a method for grouping (or classifying) similar product, such as the popular Opitz, DCLASS, and MICLASS schemes. In each case, the basic idea is for the users to use various tables and rules to capture critical design and manufacturing attributes of a part in an alphanumeric string, or GT code, which is assigned to that part. However, as the classification is done manually, it is subject to individual interpretation. It has been shown that human perception of similarity is subjective. Thus, there are possibilities of errors in such classifications.

7.11.4 Benefits from Intangible Factors

- Improved communications through common vocabulary
- Increased capacity of existing equipment
- Increased process planning productivity
- Individual expertise knowledge capture
- Improved responsiveness to customers
- Reduced throughput time
- Standardization in process plans, designs, terminology
- Increased process plan and estimate accuracy
- Reduced time for engineering changes
- Reduced cost of quality
- Reduced raw material requirements for tooling
- Increased productivity on a plant-wide basis
- Reduction in setup times

7.12 Implementation Example

Initial Implementation and Model Testing

A ball screw assembly was used in testing the object model and pilot implementation of a preliminary process planning system. The reason for choosing ball screw assembly is that they are widely used in the mechanical and automotive industries. The manufacturing processing information of output housing components of a ball screw assembly is used as an example. Figure 7.14 shows a bearing housing component. The object model has been tested by populating the manufacturing information into the model. In addition, the model was used as the basis for implementing a preliminary process planning system.

Initial Implementation

As shown in Figure 7.15, an integrated knowledge based IPPPIS has been implemented using a relational database management system Oracle 9i that supports the Structured Query Language (SQL). The information about an artifact design, processes, resources, time, and cost structure is stored in the database. The preliminary process planning system starts with reading the artifact information from the artefact database, including artifact name, main shape, shape complexity, symmetry, secondary positive features, secondary negative features, material, maximum size, tolerance, surface condition, and production volume. Then, the selection of primary manufacturing processes follows. This system automatically selects candidate primary manufacturing processes based on manufacturing knowledge. Next was the selection of manufacturing resource (machine, fixtures and tool for machining), estimating manufacturing time and cost, and then selection of the best manufacturing processes according to estimated manufacturing cost.

Figure 7.16 shows the Artifact information interface and code generation screen. Different weightages can be given for the different features by assigning different weights between 0-100 through the screen as shown in

Figure 7.17. If the user is not assigning any weights, the system will automatically take the pre-assigned weights.

Depending upon the weightages given, the components with similar features will be retrieved from the relational database depending upon the score secured in comparison with the existing components in the database. Figure 7.18 shows the nearest scores secured by different items in comparison with sample items housing.

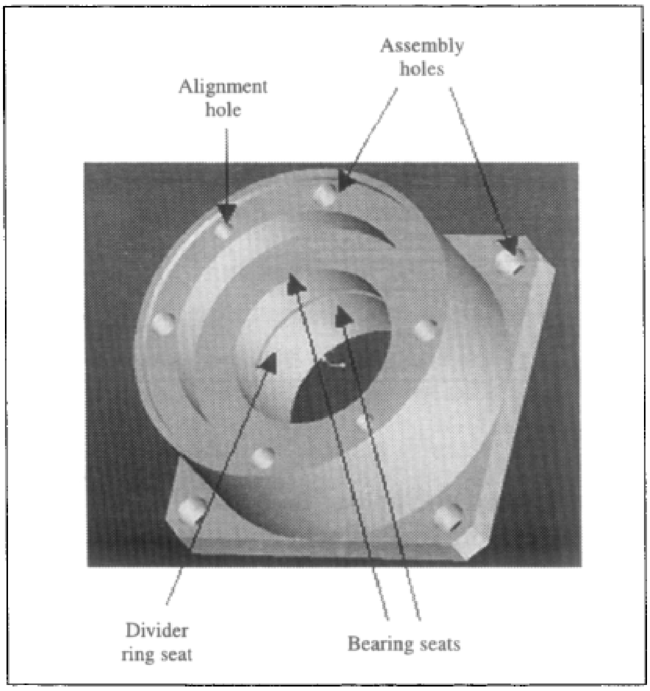


Figure 7.14 Bearing Housing

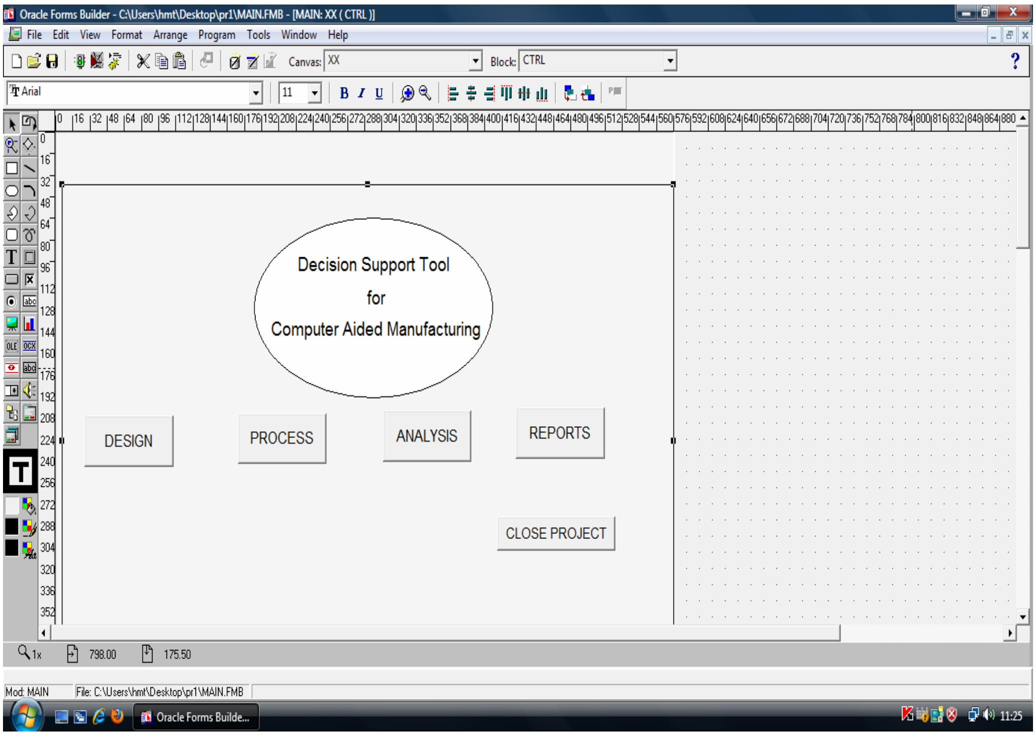


Figure 7.15 Interface of Integrated Knowledge Based IPPPIS

The information of an artifact design can be directly read from an artifact database. Figure 7.19 shows the result of selecting manufacturing process plan based on manufacturing knowledge for the housing component.

Figure 7.20 shows that the manufacturing costs incurred in different processing step. The optimization can be done on the proposed process plan by using the alternate processes.

Other screens developed as a part of the system is given as Appendix-10 with its functions explained below with each screen

The structure of the information is stored in a relational database, for the developed system is shown as Appendix-11.

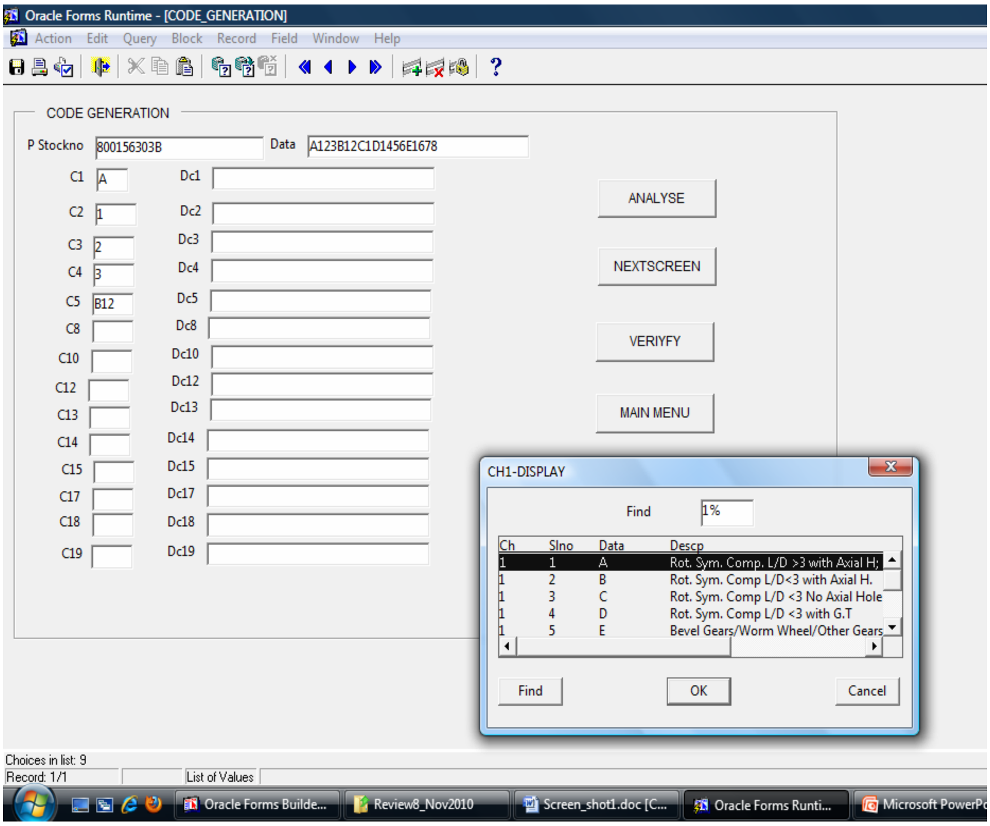


Figure 7.16 Code Generation Screen

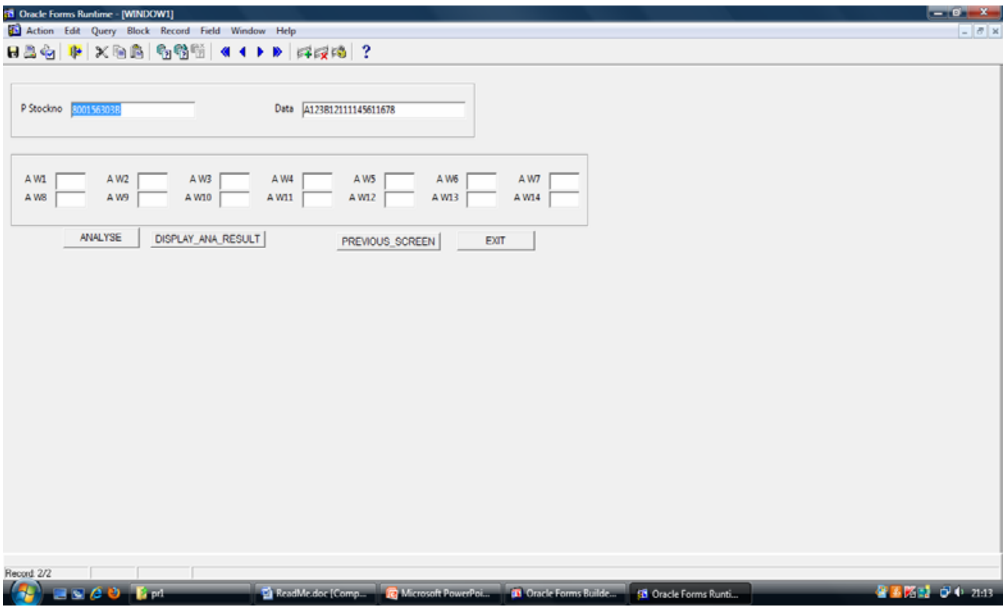


Figure 7.17 Screens for Weightage for Different Attributes

```
set pages 65
set newpage 0
ttit "SEQUENCE MATCHING WITH SCORE SAMPLE ITEM-A123B12C1D1456E1678"
select p_stockno,substr(data,1,20) ,seq,score
from temp2proj1
order by -score
/

Mon Nov 29                                                      page    1
        SEQUENCE MATCHING WITH SCORE SAMPLE ITEM-A123B12C1D1456E1678

P_STOCKNO       SUBSTR(DATA,1,20)    SEQ                      SCORE
--------------- -------------------- ------------------ ----------
800156303B      A123B12C1D1456E1678  11111111111111            100
820744023C      B123B12C1D1456E1678  01111111111111             90
800133011B      D123B12C1D1456E1678  01111111111111             90
802056203A      E123B12C1D1456E1678  01111111111111             90
802031113A      C123B12C1D1456E1678  01111111111111             90
827323303E      A123B23C2D1456E1678  11110001111111             83
828131011K      D123B23C2D1456E1678  01110001111111             73
820044012C      B123B23C2D2456E1678  01110000111111             66
830037152B      E123B23C2D2456E1678  01110000111111             66
845510103A      C123B23C2D2456E2678  01110000111011             61

10 rows selected.
```

Figure 7.18 Nearest Scores Secured by Different Items in Comparison with Sample

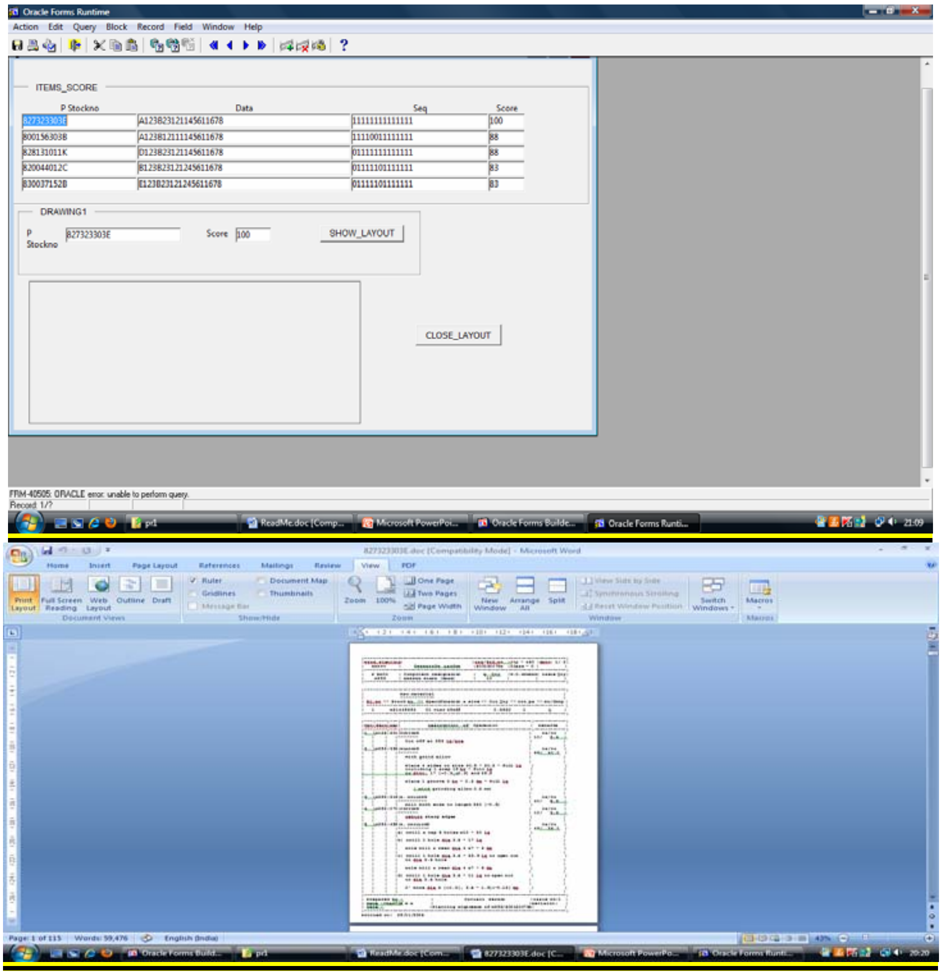


Figure 7.19 Selecting Manufacturing Process Plan

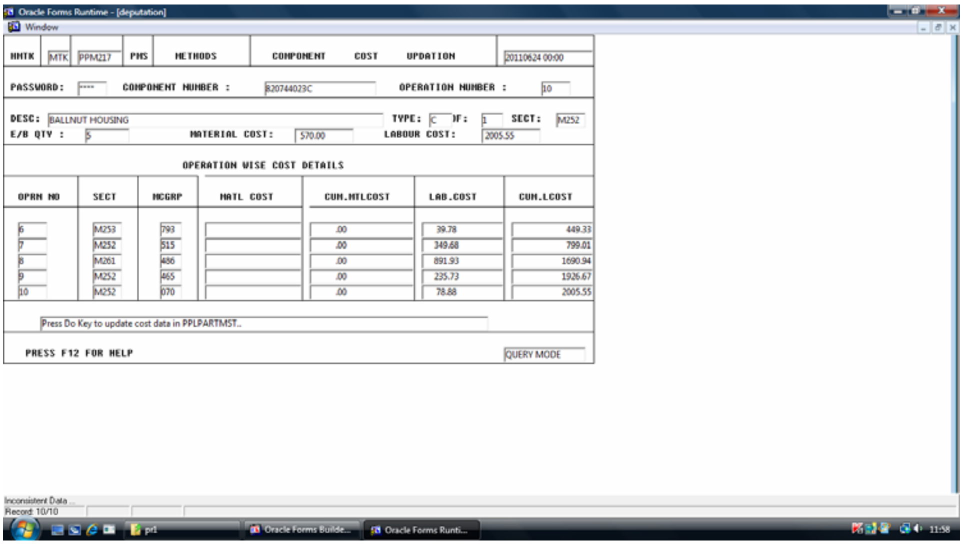


Figure 7.20 Screen Showing Manufacturing Costs Incurred in Different Processing Step

7.13 Conclusion of the Case Study - Benefits of Concurrent Engineering Implementation

It is seen that the conventional design process followed in the company was taking too much time. Time overrun was the primary culprit, cost overrun and quality problems were also found. Since manufacturing time could not be reduced much without major capital investment, it was decided to give a try to reduced time for design. CE is an accepted method to reduce time taken for the design process and system complexities. CE practices such as design for manufacture and feature based CAPP were introduced and practiced for two years. An audit was then undertaken to evaluate the monetary gains from CE implementation.

Some of the benefits of the CE implementation revealed by the case study are as given below:

1. Machines can be grouped depending upon the feature-manufacturing requirement. Further machine groups are selected as per the design features, which will lead the system to rationalisation and

standardisation of design and process. This is explained in section 7.7 , with Figure 7.8, Figure 7.9 and Figure 7.10 of this chapter.

2. Reduction in the number of components for new machines. This is achieved by reuse of the existing components. This will benefit organisation directly by the way of reduction in design and development time and cost of machines. This will further benefit the organisation by reducing inventory, reducing systemic complexities etc.

The direct cost benefit derived by reduction in the number of manufacturing components is explained with Table 7.4, Table 7.5 and Table 7.6.

Table 7.4 gives details of the machines considered for the case study with Manufacturing Items produced in-house.

Table 7.5 gives Cost details of the components manufactured in the machine tool factory considered in the case study.

Table 7.6 gives the details of direct saving in manufacturing cost incurred by reducing the number of manufactured components.

Table 7.4 Machines Considered for the Study with Manufacturing Items Details

Machine Details	Machine/yr	Total Number of Manu. Items	Number of Manu. Items per Std Machine	NEWITEMS
Conventional Lathe	260	1003	499	50
CNC Lathe 1	20	652	445	45
CNC Lathe 2	8	167	334	33
CNC Lathe3	10	1648	334	33
CNC Lathe 4	25	925	285	29
CNC Lathe 5	15	925	257	26
CNC Lathe 6	15	2074	366	37
CNC Lathe 7	10	663	384	38
CNC Lathe 8	15	2774	523	52
CNC Lathe 9	5	155	251	25

Table 7.5 Material and Labour Cost Details of the Components Manufactured

Machine Details	Total Number of Manu. Items	Number of Manu. Items per Std Machine	Material total value	Labour total value	Material average value	Labour Average value
Conventional Lathe	1003	499	1,90,399	3,01,605	382	604
CNC Lathe 1	652	445	3,12,924	3,26,184	703	733
CNC Lathe 2	167	334	3,00,087	3,66,588	898	1098
CNC Lathe3	1648	334	2,46,279	3,06,815	737	919
CNC Lathe 4	925	285	1,73,643	3,03,776	609	1066
CNC Lathe 5	925	257	2,71,079	3,52,193	1055	1370
CNC Lathe 6	2074	366	4,57,659	5,34,116	1250	1459
CNC Lathe 7	663	384	4,79,658	5,61,349	1249	1462
CNC Lathe 8	2774	523	9,27,735	10,77,061	1774	2059
CNC Lathe 9	155	251	5,71,253	4,40,814	2276	1756

Table 7.6 Details of Saving in Manufacturing Cost Incurred by Reducing the Number of Manufactured Components

Val in Rs

			Before the CE		After the CE Tool Implementation		Savings		
MACHINE DETAILS	Machines/yr	No. of Manu. Components for Std Machine	No. of Manu. New Comp. for Std Machine	Cost incurred by the New Comp./Machine	No. of Manu. New Comp. for Std Machine	Cost incurred by the New Comp./Machine	Saving per Machine	No of Machines/yr	Savings per yr
Conv. Lathe1	260	499	50	49,200	40	39,439	9,761	260	2,537,892
CNC Lathe1	20	445	45	63,911	35	50,267	13,644	20	272,878
CNC Lathe2	8	334	33	66,668	22	43,913	22,755	8	182,040
CNC Lathe3	10	334	33	55,309	23	38087	17,222	10	172,220
CNC Lathe4	25	285	29	47,742	20	33,503	14,239	25	355,971
CNC Lathe5	15	257	26	62,327	19	46,078	16,249	15	243,730
CNC Lathe6	15	366	37	99,178	28	75,874	23,304	15	349,562
CNC Lathe7	10	384	38	104,101	29	78,618	25,483	10	254,831
CNC Lathe8	15	523	52	200,480	41	157,164	43,316	15	649,739
CNC Lathe9	5	251	25	101,207	18	72,579	28,628	5	143,141
								GRANT TOTAL	**5,162,004**

A summary of the monetary benefits are shown in Table 7.7.

Table 7.7 Benefits of Concurrent Engineering Implementation

Sl. No	Benefits and Metrics Related Design/Process	Cost incurred In INR / year		Benefits in INR	
		Before	After CE	Savings	As %
1	Cost/Time reduction by better production planning control by the way of 1.14. Productivity improvement by proper information flow/ information sharing/better response 1.15. Manufacturing costs decrease due to optimum process, correct information 1.16. Visibility and standardisation of processes 1.17. Rationalization, better allocation, effective planning 1.18. Effectiveness of supporting activities 1.19. Improved responsiveness by reduced complexity and standardisation 1.20. Better common under standing by documented key procedures 1.21. Better in identifying the problems by improved processes 1.22. Effectiveness of collecting and evaluating the production information 1.23. Improved ability in making decisions of all level of employees 1.24. Encourage and promote capability of planning team 1.25. Better decision making by planning and design 1.26. Reduction in learning time	66,03,750	16,87,500	47,16,250	74
2	Development time/cost reduced due to 2.1. decrease in design/engineering changes 2.2. Improved design 2.3. Better design optimization 2.4. knowledge base related to design /process/material 2.5. Reduced number of parts due to rationalization	50,99,000	15,18,750	35,80,250	70

	2.6.Reduced number of new parts and hence less design effort 2.7. Better standardisation				
3	Cost/Time reduction by flexibility in manufacturing 3.1.Better plant and resource utilisation 3.2. Different products can be produced effectively 3.3. Manufacturing can effectively respond to market changes 3.4. Plant can reduce late delivery of products 3.5. Reduction in inventory costs 3.6. Reduction in machine and equipment costs 3.7. Reduction in labour and employee costs 3.8. Reduction in idle time	39,21,500	14,20,500	25,01,000	64
4	Waste of time/money reduced due to 4.1. Decrease in set up change over/ process resetting 4.2. Reduction in unnecessary motion 4.3. Reduction in unnecessary process 4.4. Reduction in Scrap/ Rework 4.5. Reduction in Inventory 4.6. Decrease in Under utilisation of people 4.7. Reduction in other non value added waiting time 4.8. Reduction in Tooling/Work Holding/Special Tools 4.9. Material availability, proper material usage	29,37,500	13,50,000	15,87,500	54
5	Improved Quality - required accuracy, precision as per customer need, testing as per requirement	22,60,000	11,47,500	11,12,500	49
6	Others Benefits				
6a	Improved customer service and reducing the scrap			9,02,500	
6b	Better ability to manage new product development			8,43,750	
	TOTAL			1,52,43,750	

Benefit obtained average per year = 1,52,43,750

Average turn over of the company after CE = 50,50,00,000

Benefit obtained as percentage

of turnover = 1,52,43.750 / 50,50,00,000 X100

= 3.02 %

Profit before CE =2,60,00,000

Average turn over of the company before CE = 45,50,00,000

Profit before CE as Percentage = 2,60,00,000 / 45,50,00,000 X100

= 5.72 %

Profit After CE = 3,50,43,750

Profit after CE as Percentage = 5,10,43,750 / 50,50,00,000 X 100

= 10.1 %

After introducing CE, 10 projects were facing problems problems out of 68 projects executed on an average per year. The company which has made 5.72 percent profit(Rs. 2,60,00,000 /yr) on an average turnover of Rs. 45,50,00,000 is able to increase the profit margin to 10.1 percent profit (Rs. 5,10,43,750/yr) on increased turnover turnover of Rs 50,50,00,000.

7.14 Conclusion

A system implementation case study has been presented in this chapter to demonstrate the benefits a machine tool manufacturing industry had from the concurrent engineering IPPPIS. Overview of the machine tool industry was given in the initial part of this chapter, which gave give structure and current scenario of Indian machine industry. Problem areas, which requires improvement were analysed in detail in the subsequent sections of this chapter. The case study of IPPPIS in the machine tool manufacturing company has shown its implementability. Conventional process planning system and product development followed in the company were discussed along with the general architecture of the IPPPIS used. Information content and new process planning method in the IPPPIS were given detailed along with the benefits that achieved by the system.

Using IPPPIS, information model developed, how the benefits of cellular manufacturing make machine tool manufacturing firms to become lean have been outlined. A framework for agile manufacturing for machine tool industry was also discussed in this chapter. The relation between product model and process model, the model integration are also detailed. The benefits of integrated product and process model in IPPPIS for agile manufacturing were brought out in the last part of this chapter. The details of benefits that can be obtained by use of the IPPPIS by the way of time saving, machine grouping, faster cost estimation, part family formation, reduction in part proliferations by reusing previously designed parts, etc. have been clearly explained.

From the case study it is clear that the IPPPIS is implementable in a machine tool factory and significant saving in cost, time and effort are possible with the CE implementation using the IPPPIS.

Chapter 8: Conclusion, Limitations and Scope for Further Work

8.1 Conclusion

Traditionally when designing a new product, different steps in the initial design stage such as choosing the material, determining the process to make the part, designing the tool to make the part etc., are carried out sequentially by different people or work groups in numerous iterations. This leads to long lead time to come out with satisfactory results in designing the product and process. An IPPPIS have been developed for a machine tool manufacturing firm with integrating domain knowledge of various departments in the manufacturing industry.

This research has presented an integrated manufacturing application framework to link design stage to the other stages in the manufacturing systems, more specifically the manufacturing process design stage. The IPPPIS developed provides a computer-based method for the concurrent design of a part, the tool to make the part design, and finalize the processes to be used in making the part. Using this research, unlike in prior systems, the part design, the tool design and the process design can be carried out concurrently, which will reduce the time and cost of part design significantly.

To enable correct part design, the IPPPIS provides the part designer with all relevant information affecting the part design (such as information about the processes and materials used to make the part) while the part is being designed. With information models and IPPPIS developed in this research, the relevant information supplied to the part designer, the tool designer and the process designer. Designers can share information concurrently using the IPPPIS. Design decisions made by each designer can be included as a factor in the design decisions by other designers. As such, the functions of part designer, tool designer and process designer often merge and overlap when the IPPPIS is used.

Using the above framework a prototype of an IPPPIS has been developed using object-oriented technology. This was done after studying the design process in a lathe manufacturing company and examining all information and factors necessary for modeling manufacturing and process planning used for collaborative design and manufacturing. A systematic information modeling technology was used to represent the information relationships and associations from a system perspective.

For development of the model for collaborative design and manufacturing in a machine tool manufacturing factory, Oracle tools such as Oracle 9i, Forms6i, Report 6i, has been used. The main components of this model are - process-planning model (PPM), manufacturing activity model (MAM), manufacturing resource model (MRM) and manufacturing cost and time model. In order to reduce the turn-around time and improve the response time to customer’s needs, modularity analysis in the design stage can be applied to the manufacturing planning stage to finish total tasks by using interrelated modules.

IPPPIS developed was able to meet the following objectives:

- Integration of part, tool and process design
- Deploying the concept of reuse by designing part-coding mechanism suitable for a machine tool company, this is kept in a part database.
- The reuse of planning methodologies and 'best of practice' (BOP) to reduce engineers’ workload and increase their planning efficiency.
- Design classifying and coding system for tools to keep in a tool database
- Collect and encode available machine data and process that can be carried out on them

This IPPPIS if adapted and implemented will benefit manufacturing units, by giving them an extra edge, in today's cost and time competitive market by:

- Providing a set of feature data records, including shape information, tool information and process information corresponding to the respective primitive object. Each feature data record corresponding to a respective primitive object having a predefined function.
- Concurrently designing a product drawing and a process specification to make the product as a function of the form information, the tool information and the process information in the selected feature data record.
- Automating concurrent engineering, and more particularly, to provide a method for concurrent design of parts, tools and processes, that can quickly and accurately generate feasible manufacturing plans in mass customization situation based on existing BOP. This enhances the production efficiency, eliminates waste and reduces cost of the product by miinimising product variety.
- Providing a process by which a product may be produced with minimum cost, highest quality, highest consistency, while reducing the time to market (Being Agile to market).
- Designer can select design features in initial stage of design in such a way that standard machines and tools can be used (Encourage design for manufacture).
- Improved interrelationships among design and manufacturing as well as overall economics of the operations, which leads to Lean manufacturing.

The workability of this approach was tested in a machine tool manufacturing firm. The case study demonstrates the benefits from such an approach. Furthermore, this model provides software developers with the information foundation for developing new process planning systems so that development time can be significantly reduced.

8.2 Limitations

In this research, the scope of IPPPIS development was for realisation of mass customization and batch production of machine tools. Design of the system was done keeping in mind the organization taken for the case study, which is a machine tool manufacturer, which manufactures lathes. Basing the design on a specific manufacturer and their process could have created a bias in system design, and therefore limited the applicability of the work presented in this thesis.

The process and stages in design though general in most machine tool manufacturing organizations, work allotment to group and work flow could be different in different organizations. This system was developed with, the stages and grouping of work and workflow, of the company studied in the case in mind. Hence, fine-tuning of the IPPPIS may be required to the meet the requirements and work grouping of some other organization.

In this research, object-oriented technology with related tools and databases (free downloadable database software - Oracle 9i) has been used, which has its own advantages and disadvantages. Use of other technologies and tools such as Java, Dot Net etc. were also possible but were not attempted in this work.

The case study and trials were carried out with small parts design section of the machine tool manufacturing company. However, the same can be extended covering broader areas the same has not been done in this study.

8.3 Scope for Further Work

In this research, an integrated manufacturing application framework to link design stage to the other stages in the manufacturing systems has been developed. An IPPPIS has been developed to have a computer-based method for the concurrent design of the part design, the tool design and the process design. Some directions for further work are given below:

- Only the limited aspects of fixture issues were considered here. However, fixture planning and fixture design is indispensable in setup planning which requires more attention. Multi-spindle machine tools are widely used in mass production. They can execute multiple processes at the same time, which can greatly increase productivity and reduce cycle time. The machine tool capability model can be extended to multiple spindle machine tools in future studies.
- In the part coding area, coding was restricted to 19-digit code in the design and process area. This is to reduce the time for coding and overall prototype model development. This can be further extended to more number of digits to enhance the accuracy of the retrieval. Some of the attributes such as tolerance, tools, fixtures, etc., can be elaborated further in this context, according to the requirement of the industry on which it is to apply.
- In this research domain, knowledge in the setup planning and fixture design area is restricted with more focus being given on process and design. This can be further elaborated with details of fixtures design and setup planning depending upon the type of machine tools that are being used, which can be linked with the framework of the IPPPIS developed.

Future research work can be planned for the improvement of the proposed framework, for creation of a model for evaluation of productivity improvements, in order to quantify time and cost reduction. Enhancement of the model through a workflow perspective, using the object-oriented approach used here, will help extending the use of the model for the entire production system.

The recommendations for future work also include:

- Incorporating the supplier’s process capability, in the framework, this will be useful where the processes are off loaded or subcontracted.
- Development of methods to integrate additional organizational strategies and goals (profitability, market share, technological leader, etc.) into design decisions.
- Investigation of the use of Living Systems Analogy (LSA) to model entire organizations at multiple levels of abstraction to facilitate the inclusion of organizational concerns in design decisions.
- Investigation of methods to include organizational goals at other points in the product realization process (in addition to configuration design addressed here).

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