Chapter 2: Literature Review

This chapter gives review of the literature related to concurrent product and process design and related research areas and come out with the gaps and formulation of the objectives of this research. Integrated product design and concurrent engineering is discussed in the first part. Integrated information system, knowledge based engineering system, which can be useful concepts that help integrated product development is reviewed in detail in the next sections. The manufacturing domain knowledge to be built into the system through its various components, such as, manufacturing information model, manufacturing resource model, process plan model, manufacturing activity model, manufacturing cost model are then reviewed. The modeling of these components was done through the information modeling technologies and databases, is reviewed in the last section of this chapter.

2.1 Overview of the Information System for Product and Process Planning

Since the beginning of the 1990s, business world has been talking about knowledge management. Recent advances in information technology have had a profound impact on knowledge management. Now the challenge for companies is not simply to have a sophisticated information technology system, but more importantly to discover how to employ such resources for enabling knowledge creation and exchange among people in organizations. Two important areas have accelerated the emergence of modern knowledge management systems: network technologies and local databases. The rise of networking of computers has made it possible to codify, store and share certain kinds of knowledge easier and cheaper than ever before [22].

2.1.1 Integrated Information Systems

Knowledge is the most valuable asset of an organization. Decisions are made based on a combination of judgment and knowledge from various
domains. Decision support, knowledge management, and processing are interdependent activities in many organizations. Ideally, all relevant knowledge should be available before making a decision. The knowledge extracted from databases can be integrated with existing expert systems. Grabot et. al. [22] used fuzzy logic to compliment the decision-support system to modify schedules. Koonce et al. [23] applied data mining to assist engineers in understanding the behavior of industrial data. They developed a software tool called DBMine using Bacons algorithm, decision trees, and DB learn. They applied the tool to find patterns in job shop scheduling sequences generated by a genetic algorithm [24]. Caskey [25] developed a general environment for providing the right knowledge at the right time. He used GAs and neural networks in identifying the structure of the data. The knowledge extracted was in the form of “actual control applied - performance obtained” and the knowledge generated could be used to increase the accuracy of the system or validate the performance model. Kusiak applied data mining to support decision-making processes [26]. Different data-mining algorithms were used to generate rules for a manufacturing system.

In recent years, information retrieval techniques coupled with workflow management systems have been used in the KM domain to support proactive delivery of task-specific knowledge according to the context of tasks within a process [14]. They provide an appropriate perspective for designing task-based knowledge support. However, they focus on specifying the process context of a task to support context-aware or process-aware knowledge retrieval, ignoring the embedding of the intelligence into OM. The integration of knowledge management and intelligent tutoring systems could be the answer to creating, organizing, retrieving, and effectively exploiting the knowledge residing in the OM to achieve corporate competence development and training.
2.1.2 Concurrent Engineering

Concurrent engineering has received considerable research attention over the past two decades as industry strives to shorten design cycles. As researchers have sought to understand and extend concurrent engineering, it has presently come to be thought of as an umbrella spanning all of the processes related to a particular product, beginning with initial concept generation, to detailed design and analysis, process planning, manufacturing, and so on. Concurrent engineering is not a new concept. It gained popularity in industry briefly after World War II, but due to technology limitations, was later replaced by a departmentalization scheme, often referred to as the “over the wall” approach [13]. This created a sequential design scheme that lengthened design time.

Jiang et al. [27] present an integrated concurrent engineering approach to the design of complex components. As a case study, they attempt to integrate the solid modeling of a scroll compressor with associated downstream applications such as FMEA, CAM, and CAPP.

Hoffman et al. [28] built upon Bailey’s concept of the IMM and developed architecture to manage a product master model. In their view, the CAD model and all downstream applications are clients of the master model, which is essentially a database containing all the product information. In their work, all the attributes associated with the product data model were defined in the respective downstream application, where they had scope. This research differs in that all the desired attributes are assigned initially in the CAD environment, and stored in an external database for application in downstream applications.

IPPD is an expansion of concurrent engineering utilizing a systematic approach to the integrated, concurrent development of a product and its
associated manufacturing and sustainment processes to satisfy customer needs [29].

2.1.3. Knowledge-Based Engineering in Engineering Design

Artificial intelligence and, in particular, knowledge-based engineering systems provide capability to define rules for effective product and process design in an integrated manner. Design rules can include producibility guidance to effectively-mesh the product design with the company's process capabilities. This configuration guidance can be extended to help design products as per order from basic, pre-designed product modules quickly and inexpensively [15]. Many CAPP systems were implemented using AI techniques, usually referred to as either "knowledge-based" systems or "expert" systems [30].

Engineering design is a multidisciplinary, multidimensional, and non-linear decision-making process where parameters, actions, and components are selected. This selection is often based on historical data, information, and knowledge. It is therefore a prime area for data mining applications and only a few papers have reported applications of data mining in engineering design. This has been an area of increased research interests in recent years. Recently published papers synergies the relation between design and manufacturing. The importance of considering how a product should be manufactured during the design stage and the constraints imposed on design by particular manufacturing processes and technologies have been accepted for many years. There is indeed great potential for data mined knowledge to integrate manufacturing, product characteristics, and the engineering design processes [24]. Kusiak et al. [31] proposed a rough-set theory approach to predict product cost. Ishino and Jin [32] used data mining for knowledge acquisition in design from the data obtained through observing design activities using a CAD system. Romanowski and Nagi [33] applied a data mining approach for forming generic bills of materials (GBOMS), entities
that represent the different variants in a product family and facilitate the search for similar designs and the configuration of new variants.

2.1.4. Integrated Product Design

Approaches of integrated design are also presented which specify knowledge integration and aim at taking into account all events, which must appear early or late in the product life cycle. DFX, is seen as assessing and integrating “X-field” information, is linked to CE and therefore can no longer be treated independently [3]. An efficient CAPP system has a key role to integrate the design and manufacturing or assembly systems properly considering available resources and design constraints. It has been found that 15% of the process planner’s time is spent on technical decision making while remaining time is spent equally between gathering data, calculating and the preparation of documentation [34]. Investigation shows that an efficient CAPP system could result in a total reduction of the manufacturing cost by up to 30% and time in the manufacturing cycle and the total engineering time could also be reduced by up to 50% [35].

Despite the early recognition of possibility of extracting operations and processing sequences from the part geometry as described in CAD, computer aided process planning has not been addressed broadly until 1970s. In 1976 two CAPP systems (CAPP and MIPLAN) were developed. Subsequently a generative system for detailed process selection titled APPAS was presented [35]. Since then CAPP has begun to be widely addressed. Process planning is that facet of manufacturing engineering, which covers the translation of engineering design data into the most efficient method of part manufacturing. The society of manufacturing engineers defines process planning as “the systematic determination of methods by which a product is to be manufactured, economically and competitively”.

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Collaborative product development increases efficiency, reliability, and innovation by ensuring the right knowledge is available at the right time. It avoids backtracking and rework due to miscommunication, and delays due to unnecessary dependencies between designers. Integrated and concurrent design enables engineers to interact and reach agreement by sharing product information and knowledge. This reduces the cost of design, increases reliability, opens opportunities for innovation, and provides stronger competition in the international marketplace [35].

Information modeling of conceptual design integrated with process planning in the context of design for manufacture is outlined by Feng and Song [36]. An object-oriented model for concurrent optimization of the design and manufacturing stages of product development given by Lamghabbar et al. [4]. Design for manufacturing concepts and its new directions, which have to be considered during design, are discussed by Jeffrey et al. [37]. It is important to model and estimate the costs to guide designers to make some decisions to lower product costs. Charles et al. gives model in three-dimensional concurrent engineering using goal-programming approach for cost management [7]. Mountney et al. [38] and Ling et al. [12] gave a knowledge system model to support manufacturing knowledge during preliminary design. Manufacturing knowledge verification in design support systems is outlined by Cochrane et al. and Irani et al. [39, 40]. Xu et al. [20] outlines an integrated information system using concurrent engineering for product design. Shukor and Axinte [41] have made an analysis of manufacturability analysis systems developed to allow the evaluation of various manufacturability aspects during the design stage and consequently to reduce the costs and time to market of the designed products.

2.2 Manufacturing Information Modeling

Knowledge is the most valuable asset of a manufacturing enterprise, as it enables a business to differentiate itself from competitors to compete
efficiently and effectively to the best of its ability. Knowledge exists in all business functions including purchasing, marketing, design, production, maintenance and distribution. But knowledge can be notoriously difficult to identify, capture, and manage. Knowledge can be as simple as knowing who is best to contact if particular materials are running short, or can be as complex as mathematical formulas relating process variables to finished product dimensions. Harding et al. [24] reviewed two models of knowledge. The first model follows a conventional hierarchy and transformation of data into information and knowledge with a spiral and recursive way of generating knowledge. The second model presents a reverse hierarchy where knowledge may appear before data and information processing. Knowledge discovery, knowledge management, and knowledge engineering are currently topics of importance to researchers manufacturing. Database technology is central to all these knowledge-based research topics [24].

In design, a product model is being developed in ISO 10303 (informally known as the Standard for Exchange of Product data - STEP) [42]. To achieve software interoperability, information models are necessary and critical to specify common terms and programming interfaces. STEP includes representations of geometry, topology, dimension, tolerance, and feature material, product configuration, and so on.

The seamless integration of preliminary design and preliminary process planning can be established by an open, neutral manufacturing process object model using object-oriented technology [4]. This model supports the representation of manufacturing activities, resources, cost, and time. The ISO 16100 Part 2 (Industrial automation systems & integration – Manufacturing software capability profiling – Information model for interoperability) working draft has been developed based on this model. To achieve software interoperability, information models are necessary and critical to specify common terms and programming interfaces.
Manufacturing information modeling efforts have been focused on manufacturing resource capability modelling, process plan modelling, and manufacturing cost modelling. Several manufacturing models have been developed, but they have not been standardized.

2.2.1 Manufacturing Resource Modeling

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. Evaluation of a candidate manufacturing resource’s capabilities has become one of the critical factors in reducing manufacturing costs in mass customization.

Manufacturing resource information model is often used in resource selection and process capability evaluation. A manufacturing resource capability model represents information on the function and characteristics of resources that contribute to process capability. Several manufacturing resource capability models have been developed. Manufacturing information model supports the product realization process. It only focuses on the information on design for manufacturability at factory level. Two manufacturing capability models to support concurrent engineering are capable of representing the resource capability on the workstation level [43, 44]. A product and manufacturing capability model for CAD/CAPP integration focusing on information about machine tools, machining processes, operations and cutting tools is also available [45]. A model of manufacturing resource information focusing on milling and turning machine tools, cutting tools appropriate to the processes of milling, drilling, and so on is also reported [45]. An object-oriented manufacturing resource modelling for process planning including shape capability, dimension and precision capability, surface finish capability, and position and orientation capability is presented in the reference cited [47]. These models provide a
foundation for developing the manufacturing process information model dealt within this thesis.

Most of the research have paid attention to the management of manufacturing resources and implemented it using Relational Database Management Systems (RDBMS), which is very weak in describing manufacturing resource capabilities [48]. Several O-O manufacturing resource models have been designed to express the relationships between manufacturing resource capabilities and feature attribute. However, a widely accepted model and methodology is still to come.

2.2.2. Design for Manufacture

Design for manufacture (DFM) is a product design approach that takes into account design goals and manufacturing information as soon as possible in product definition. Many studies deal with presentation and implementation of the following DFM concepts [3, 49]:

- Presentation of DFM concepts and tools
- Analysis of manufacturability and providing solutions to improve design
- Manufacturing processes selection based on processes classification and attributes comparison.
- Specification of appropriate method and techniques of materials and processes selection
- Specification of techniques that will reduce cost and ease handling of components
- Providing some fundamental rules of design, that gives the “best” solutions from manufacturing point of view.

Papers referred above focus on a methodology and a product model that simultaneously manage manufacturability analysis (processes selection) and synthesis (constraints integration), to let the product definition (including 3D modeling) progressively emerge. It takes place earlier during the product definition process (in the conceptual and embodiment design stages). The
methodology is defined by a set of activities whereby input/output is the modeled product data.

In the area of design and manufacturing interface, many studies are focused on CAD-CAM integration. They provide solutions for exchanging data based on standards (e.g. STEP-AP203). This standard is not currently able to define expert’s concepts but only handles features. Moreover, STEP standards cannot be changed easily, and it is difficult to dynamically add new concepts concerning product modeling. STEP was developed for representing product data for data exchange throughout a product’s design, analysis, and manufacture cycles (ISO/DIS 10303-1 1993) [50]. Sean et al. in their paper have tried to establish a methodology, specifically for the verification of manufacturing knowledge in design support systems [51].

2.2.3. Process Plan Modelling

Process plan modelling is 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. A Language for Process Specification (ALPS) has been designed as a data model to support the description of process plans used in the discrete manufacturing industry. The design goals of ALPS include the support for decomposition, parallel tasks, synchronization of tasks, alternative tasks, sequences, resource allocations, critical task sequences, and information manipulation operations. This model is an entity-relationship model. However, the model is not object oriented. STEP AP213 is an application protocol (AP) within STEP that speeds the exchange, archiving, and sharing of numerical control (NC) process plans for machined parts. The model supports sequential entities. It does not support parallel or concurrent ties. It also does not support manufacturing cost and time information exchange.
2.2.4 Manufacturing Cost Modelling

Production costs are primarily committed early in design stage. It is important to model and estimate the costs to guide designers to make decisions to lower product costs. There are three cost-estimating methods used in industry: the metric-based approach, feature-based approach, and activity based approach [49, 52]. Activity-based cost (ABC) estimation is based on the costs of all manufacturing activities. ABC guides process planners to lower manufacturing cost, by controlling and reducing manufacturing related activity, through identifying non-value-adding activities. The integration of cost models with manufacturing resource capability models and process planning models has to be further developed to an integrated model to enable software interoperation.

A number of cost estimation approaches are available today for estimating product cost at design stage [10]. A few researchers have focused on cost estimation of a particular operation or domain such as sheet metal working, hole making, and injection moulding. The castability analysis and cost estimation system for permanent mould cast components was done. However, very little work has been reported on cost estimation of sand casting that accounts for over 75% of casting production. The major cost elements of a casting such as material, tooling, labour, energy and overheads have been identified by early researchers.

To summarize, early cost estimation enables assessing various design alternatives to arrive at the most economical one. Since the total cost depends on the tooling and process parameters also, the cost model must consider these too. Yet, it must be easy-to-use by product designers with limited knowledge of downstream activities. While a number of cost models based on analogical, analytical, feature-based and parametric methods have been evolved, and used for early cost estimation of machined, moulded and sheet metal parts, there is very little published literature on early cost
estimation of castings.

2.3 Feature Technology and Feature Manufacturing Strategies

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 but this result in a number of different product models being stored. In other cases where features have been used during the concept (pre-geometry) stage, the definition of a feature has shifted to that of a carrier of information relative to a life cycle phase, rather than the traditional form feature view.

Features have certainly proven to be useful as part of the product structure, usually in representing manufacturing features. In one example of such a system, a product model and a manufacturing model were developed to support concurrent engineering [12]. The models were linked by their resources and processes and the manufacturing strategy at feature level was made. This created a flexible method of linking manufacturing features to a method of manufacture. In another example, a multi-level knowledge model was used for design and manufacturing knowledge management based on the product structure.

Other examples have sought to include some assessment of manufacturability in the system, such as a feature-based information system created to assess manufacturability during the early design stages, on an
operation-by-operation basis. Specific operations from the process model linked into the product model at component and feature levels. The database functionality includes assessment of manufacturing processes, costs and capability. Being feature-based, the latter two systems rely on a certain maturity of geometric definition before a manufacturing analysis can be carried out. Techniques such as multi-feature view mapping, where features from one domain are translated into a second domain have been developed to overcome this problem but results in a number of different product models being stored.

Part information includes geometry information and design specification information (tolerance, surface finish, etc.), which either come directly from part CAD models or neutral files (STEP, IGES, etc.) generated by CAD packages. In variant CAPP, part information is represented by GT codes. There are some commercially available coding systems in the marketplace [48]. In generative CAPP, a comprehensive description of part CAD models and design information is needed. Feature technology is well accepted as a successful tool to represent part information [53]. There have been two main methods of representing features: the superficial approach, in which features are defined as sets of surfaces having topological relationships; and the volume approach, in which volumes are used to define features [52]. By the use of graph theory, part information can be represented by a FTG, in which parts are composed of features, and design specifications are described by the relationships between features [47].

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 [48]: (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. Feature manufacturing strategies are represented in two ways. One is by associating
a list of candidate processes to a feature type. The other is by associating features with a process type that can machine these features. Both methods define a strong relationship between features and processes, in which cutters and machine tools are described in detail. Hence, if a new feature type or process type is added, related feature manufacturing strategies should be redefined. Moreover, if cutters or machine tools in a company are changed, all the processes that use these cutters or machine tools have to be updated. This maintenance work is huge and time-consuming. Based on the original definition given by Shah [53] a feature is described “as a semantically endowed object that accompanies product development from the customer request through to product release”. A huge number of product meta-modelling proposals have been based on that concept of feature to define design solution breakdown [3].

Ma and Tong [54] presented a modeling technique based on what they call “associative features.” They used the CAD API to create a knowledge-oriented tool. As a case study, they illustrated their techniques on the design of plastic injection molds. They proposed that CE becomes realistic through use of such modeling techniques as “associative features.” Unified feature based integration of design and process planning was given by Chen et al. [55].

The details of the systems developed from 1989 to 1996 are presented according to their approaches and the programming languages used by Marri et. al. [30]. In this paper, more than 20 CAPP systems have been reviewed and are listed in Table 2.1. Gonzalez and Rosado in their paper described the CAPP information model used in the GF-CAPP system for a general description geared to process planning [56]. This model represented the machined parts from a CAPP perspective and within the work domain of assigning processes, operations and machines. It is a product model for process planning at machine level.
Table 2.1 Details of the CAPP Systems [30]

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<tr>
<th>System</th>
<th>Approach</th>
<th>Programming language</th>
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<td>AFR</td>
<td>Generative</td>
<td>Clipper language compiler with dBASE</td>
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<tr>
<td>ALPS</td>
<td>Generative</td>
<td>Turbo Pascal</td>
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<tr>
<td>AMOPPS</td>
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<td>CADEXCAP</td>
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<td>IKOOPP</td>
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<td>Fortran Auto-Trol series 7000</td>
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<td>KAPLAN</td>
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<td>RDCAPP</td>
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2.4 Information Modeling Technologies

Information models are data structures that represent information contents. A large amount of information in manufacturing planning needs to be computerized so that CAPP systems can process 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 [53].

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• **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 made available 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.

Knowledge in product design is defined by the information put into a context of a particular use scenario in product design [14]. It is information evaluated and organized by the human mind for guiding actions and decisions in product design. Different types of knowledge are recognized in the literature. For example, knowledge can be classified as either explicit or tacit. Explicit knowledge is that which has been codified and expressed in formal language; it can be represented, stored, shared, and effectively applied. Tacit knowledge is difficult to express and cannot be documented in formal language. That is why tacit knowledge management is much more difficult.

Several information models have been provided for representing and storing the above information. Group technology and coding systems were applied to represent part design information by fixed-length codes or flexible-length codes. These codes were used to group parts into part families that link them with standard process plans. Graphs were utilized to describe part and setup planning information [53, 57]. Decision tables and decision trees were used to computerize the decision-making procedures that incorporate
manufacturing knowledge [48]. Relational databases were employed to store part design and manufacturing resource information. The O-O modeling technology has received much more attention since 1990. It is good at representing logic relationships for real-world entities and has excellent flexibility, incremental system development and reusability. O-O technology has been applied in all aspects of CAPP, which include O-O product models [58], O-O databases for machining operations [59], O-O case-based process planning [60], and O-O manufacturing resource modeling [47]. Often represented as class-based UML diagrams, these models enable different domains to be modelled and translated [12].

Yang et al. [61] have carried out a comprehensive review on the recent development of product modeling technology. Four types of product modeling methodologies are discussed in detail. Two object-oriented product-modeling methods: STEP-based product modeling and UML-based product modeling are compared [62, 63]. The paper gives a review on technologies and methodologies for collaborative product development systems. Nategh propose a model for concurrent engineering planning based on forward and backward effects of manufacturing processes [64].

Many authors have reported that, use of ontology’s improves interoperability among different information systems in general. According to Fonseca et al., literature presents many descriptions of ontology-based interoperability, ranging from federated databases with schema integration to the use of object orientation [65]. The author also says that the support and use of multiple ontologys is to be a basic feature of modern information systems if they want to support semantics in the integration of information.

2.5 Database Application for Decision-making

The trend in manufacturing systems is to change from island of automation to enterprise-wise integration, from physical processing workers to
information processing workers, and from management of people/activity to management of information about people/activities [12]. Many companies are going in for computer-integrated manufacturing (CIM) to improve productivity and competitive advantage and to meet survival needs of world-class manufacturing enterprises. Making CIM work effectively calls for a high level of interoperability, integration, and data sharing. Therefore, extensive use of databases and database management systems (DBMS) is necessary.

Today, the relational database model and relational database management system (RDBMS) are the de facto industry standard for organizing and managing data in most CIM environments. Some authors hold that the relational data model is very powerful and serves as a bridge to connect the islands of automation [66, 67, 68]. It is mature and reliable, and it has proven to be a flexible platform for evolution toward new applications, furthermore, relational model is based on the formal mathematical model while the object-oriented model is not. In summary, the relational database provides:

- transaction management for correct, efficient, and concurrent access by multiple users
- access control for limiting data access to authorized users only
- long-term reliable storage of data and recovery from media and system failure
- support for one or more query language for data definition and data manipulation.

The use of databases and statistical techniques are well established in engineering [24]. The first applications of artificial intelligence in engineering in general and in manufacturing in particular were developed in the late 1980s [69]. The scope of these activities, however, has recently changed. The advancements in information technology (IT), data acquisition systems, and storage technology as well as the developments in machine
learning tools have enticed researchers to move forward toward discovering knowledge from databases (KDD). Data from almost all the processes of the organization such as product and process design, material planning and control, assembly, scheduling, maintenance, recycling, etc., are recorded. These data stores therefore offer enormous potential as sources of new knowledge. Making use of the collected data is becoming an issue and data mining is a natural solution for transforming the data into useful knowledge. The extracted knowledge can be used to model, classify, and make predictions for numerous applications.

The idea of finding patterns in manufacturing, design, business, or medical data is not new. Databases have been processed to derive the underlying relationships within the data for many years as evidenced by the developments in statistics. Traditionally, it was the responsibility of analysts, who generally used statistical techniques, but increasingly data mining, which is an emerging area of computational intelligence, is providing new systems, techniques, and theories for the discovery of hidden knowledge in large volumes of data. Data mining is a blend of concepts and algorithms from machine learning, statistics, artificial intelligence, and data management. With the emergence of data mining, researchers and practitioners began applying this technology on data from different areas such as banking, finance, retail, marketing, insurance, fraud detection, science, engineering, etc., to discover any hidden relationships or patterns. Data mining is therefore a rapidly expanding field with growing interests and importance and manufacturing is an application area where it can provide significant competitive advantage. The use of data mining techniques in manufacturing began in the 1990s and it has gradually progressed by receiving attention from the production community [24, 70].

So far, the relational data model and relational database management systems (RDBMS) have been the de facto industry standard for organizing
and managing data in most CIM environments. In recent years, however, numerous authors [66, 67] have pointed out the limitations and inadequacies of using RDBMS for CIM. Most of these authors lean heavily towards object-oriented database systems (OODBMS), which they consider a panacea for implementing CIM.

Overall, most published studies seem to take a rather “either/or” stand with regard to the appropriateness of relational and object-oriented DBMS for CIM applications. In our judgement, however, it is not really a matter of either relational or object-oriented; both have their own advantages and disadvantages. Limitations of relational technology and the potential benefits that object-oriented as an alternative DBMS can provide for CIM implementation are well-documented [69]. This, however, should not be construed to mean that relational technology is inappropriate or inferior to object-oriented for all CIM applications.

Tonshoff and Dittmer [71] state that today substantial heterogeneity exists in data processing in production systems where all data processing systems maintain their own data. CIM implementations are rather bilateral connections of systems instead of genuine integration. Such subsystem-oriented data management creates some apparent problems: data redundancy, data inconsistency, expensive integration of systems, and minimal manufacturing transparency. According to them, a common database can serve as an integration kernel for a CIM concept.

This is further reinforced by Doll and Vonderembse [72], who state that an effective implementation of CIM would require a shared database, a high level of database management capability, and a communications network linking engineering, flexible manufacturing, and business information systems. They provide a comprehensive model and description of the CIM component technologies.
The knowledge used in CAPP 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 CAPP systems, modify the old solution for new parts, and abstract and store the newly generated solutions in CAPP systems. Therefore, the process plan generated is based on existing experience. While rule-based CAPP generates process plans from scratch by the use of manufacturing rules that come from manufacturing companies [73]. There are several advantages for case-based systems over rule-based systems, some of which are 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 with the easy maintainability. When manufacturing resources change in a company, or the CAPP systems are applied in another company, it is really 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.

Despite the progress, most of the currently developed systems focus on modeling and manipulation of geometric information such as solid modeling, CNC machining path generation, rapid prototyping, reverse engineering, and so on [60]. Modeling of non-geometric design information such as design requirements, conceptual design candidates and other product development life-cycle considerations, is not well understood and studied for developing these computer based systems. Therefore, the
computer-based systems that support the entire product development life cycle, especially the processes at the early conceptual design stage, have to be introduced.

2.6. Gaps Observed from Literature Review

All the reported approaches tackle the problem from a certain perspective, but so far, an integrated perspective with a holistic notion of context is still missing [102]. Moreover, these researches almost focus on explicit knowledge management. Both tacit and explicit knowledge supports for product design are rather rare, and little work has been done on the research of knowledge in product design such as what knowledge is used in the product design process. To address these issues, previous researchers have done lots of valuable work in many different fields. The following are some of the future research directions for CAPP systems [30]:

1. Architecture and constraints for machining operations should be considered while developing a CAPP system. In this connection, tolerance and surface finish specifications related to feed rate and other parameters for different machine tools, cutting tools, and workpiece material combinations require more attention.

2. A major limitation with existing systems is that most of them require mainframe computers, which are too expensive and complicated for shop floor use. As a result, they require high initial capital outlay and a long learning curve, which are often beyond the reach of small and medium sized companies. There is also a notable absence of the cost estimating capability in most of the existing CAPP systems. Therefore, a CAPP system has to be developed to offer an integrated facility for process planning and cost estimation to cater for small and medium-sized companies, which account for a large part of the machining activities in the manufacturing industry.

3. Common work piece materials and tools needs to be determined to make optimal use of the available resources. Options, such as the ability to use different machine tools for roughing and finishing
passes, need to be included in an integrated package for effective use of manufacturing capabilities.

2.7 Research Issue

In today’s advanced manufacturing environment, an investment in automated production machinery and systems have increased steadily. These machines and systems place high demands on manufacturing planning that serves as the bridge between product design and manufacturing in order to convert design specifications to manufacturing instructions. The main tasks of manufacturing planning include identifying design information, determining a sequence of manufacturing operations, preparing corresponding manufacturing resources such as machine tools, cutters and fixtures, and generating manufacturing documents. Currently, Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) systems are the standard engineering tools used in industry.

The scope of manufacturing planning is constantly changing in the machine tool industry due to the new demands in product development practice. In recent years, a new production mode, mass customization, has been introduced and widely applied in industries. It allows customized products to be made to suit special customer needs while maintaining near mass production efficiency. Compared to conventional mass production, mass customization allows for more product variety in which products are grouped into families. In the design stage, product structures are decomposed into modules by the use of modularity principles. The reuse of certain modules may simplify new product design. In the production stage, low cost is achieved primarily through full utilization of manufacturing process capability. Hence, difficulty of manufacturing planning in mass customization is greatly increased due to the complexity of manufacturing process capability analysis and utilization.

Primary reason for the limited application of Computer Aided
Manufacturing and Planning (CAMP) decision support tool is the lack of correct information models of parts, planning methodologies, manufacturing processes, and resources. There are two aspects to these information models, i.e., the conceptual models and the implemented models or the computer models. It should be pointed out that finding conceptual models for manufacturing planning is very difficult not only because of the complex interaction between manufacturing planning and other activities in a manufacturing enterprise, but also because of the distinctive challenges of planning within different types of industries.

In order to pursue smaller turn-around time and increase the response speed to customer’s needs, modularity analysis in the design stage can be applied to manufacturing planning stage to finish by using interrelated modules. Some of these modules, including the planning methodologies and information modeling, are to be realized by research in the area of CAMP. The others are designed for specific companies that have accumulated a variety of best of practice (BOP). As a result, the study on CAMP of mass customization requires a clear structure of planning tasks, a redefinition of planning methodologies, and the establishment of correct information models, as well as the description and utilization of BOP.

2.8 Research Objectives

The scope of manufacturing planning is constantly changing, in machine tool industry, due to the new demands in product development practice. In recent years, mass customization, has been introduced and widely applied in industries. It allows customized products to be made to suit special customer needs while maintaining near mass production efficiency. The difficulty of manufacturing planning in mass customization is due to the complexity of manufacturing process capability analysis and utilisation.

Primary reason for limited application of Computer Aided Manufacturing
and Planning (CAMP) decision support tool is the lack of appropriate information models of parts, planning methodologies, manufacturing processes, and resources. Traditionally, each of these 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. Because of this, many revisions have to be made, numerous iterations are needed and a long period of time passes until a satisfactory part is produced. In order to pursue smaller turn-around time and increase the response speed to customer’s needs, modularity analysis in the design stage can be applied to the manufacturing planning stage to finish by interrelated modules. The reuse of planning methodologies and variety of Best Of Practice (BOP) will greatly reduce engineers’ workload and increase their planning efficiency.

The objectives of the research were to develop an Integrated Product and Process Planning Information System (IPPPIS) for a machine tool manufacturing firm, with following tasks.

- Integrate part, tool and process design
- Deploy the concept of reuse and to design part-coding mechanism suitable for a machine tool company, to keep the part in part database.
- To design classifying and coding system for tools to be kept in a tool database
- To collect and encode available machine data and process that can be carried out on them (capability).
- To develop a mechanism to link part-tool-process and machine.
- To design systems for checking part similarity and by interacting with database to pull out part-tool-process-machine data for selected similar parts- modify them to make new parts- process and store them.
- The above to be demonstrated on ORACLE Relational Database management system (RDBM) platform in multiuser mode.
2.9 Research Methodology

The first part of research work presented in this thesis is the selection of a CE implementation model and process for a machine tool manufacturing company. For this following steps are performed.

- Identification of the constituents and process of a machine tool manufacturing company by interacting with the different departments and functional experts.
- Study of similar solved problems by information gathering from literature and interaction with subject experts to generate alternatives.
- Review and evaluation of each alternative.
- Synthesis of a possible alternative and design of the model.
- Selection of a CE implementation model and process, after analysing the fundamental elements necessary for modeling manufacturing and process planning framework used in collaborative design and manufacturing in machine tool manufacturing.

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. A systematic information modeling technology is proposed to describe the information relationships and associations, in which Object-oriented Systems Analysis (OSA) approach is employed to develop the information models.

- Development of a tool to test the Model and process: - IPPPIS is developed using Oracle 9i RDBMS, PLSQL, Forms 6i, and Reports 6i.
- Trials with the model and process.
- Analysis of the trial results is carried out for synthesis or innovation.
- Review of results is carried out for corrective action
- Reporting of the findings
2.10 Conclusion

Manufacturing information modeling efforts have been focused on manufacturing resource capability modeling, process plan modeling, and manufacturing cost modeling. Several manufacturing information models have been developed, but they have not yet been standardized. The above-mentioned models have not been fully integrated with each other or with another information models. Some specific issues to be addressed are as follows:

1. A tool that supports knowledge-intensive processes should provide the designer with contextually selected, task- and user-specific background knowledge.

2. Since tacit knowledge is difficult to manage, knowledge sharing and learning is a good measure to convert tacit knowledge to explicit knowledge, which is easier to manage. This means that we should be able to provide a mechanism to identify the missing designer competencies for product design task execution and to provide the designer with a connection to the person who has the knowledge.

3. Knowledge in product design should be identified.

4. Most published process plan models for detailed process planning, not the preliminary process planning in the early product development stage and needs to be extended to the following manufacturing information hierarchical structure of manufacturing entities, workpiece information, processing and manufacturing cost.

5. Most manufacturing resource models incorporate many functional and geometric characteristics of resources, but not the needed behavioral characteristics and capability related characteristics.

6. The type of methods used for manufacturing cost and time estimation to be integrated into the manufacturing process model.

The work in this thesis attempts to bridge this gap by developing a model for integrated product and process design environment. The model is driven by a database of material and process dependent cost factors, minimizing
user inputs. Through analysis of the information relationships among the part design, the processes, and the manufacturing resource capabilities, it enables that new features, processes, and manufacturing resources can be added and utilized in the IPPPIS.