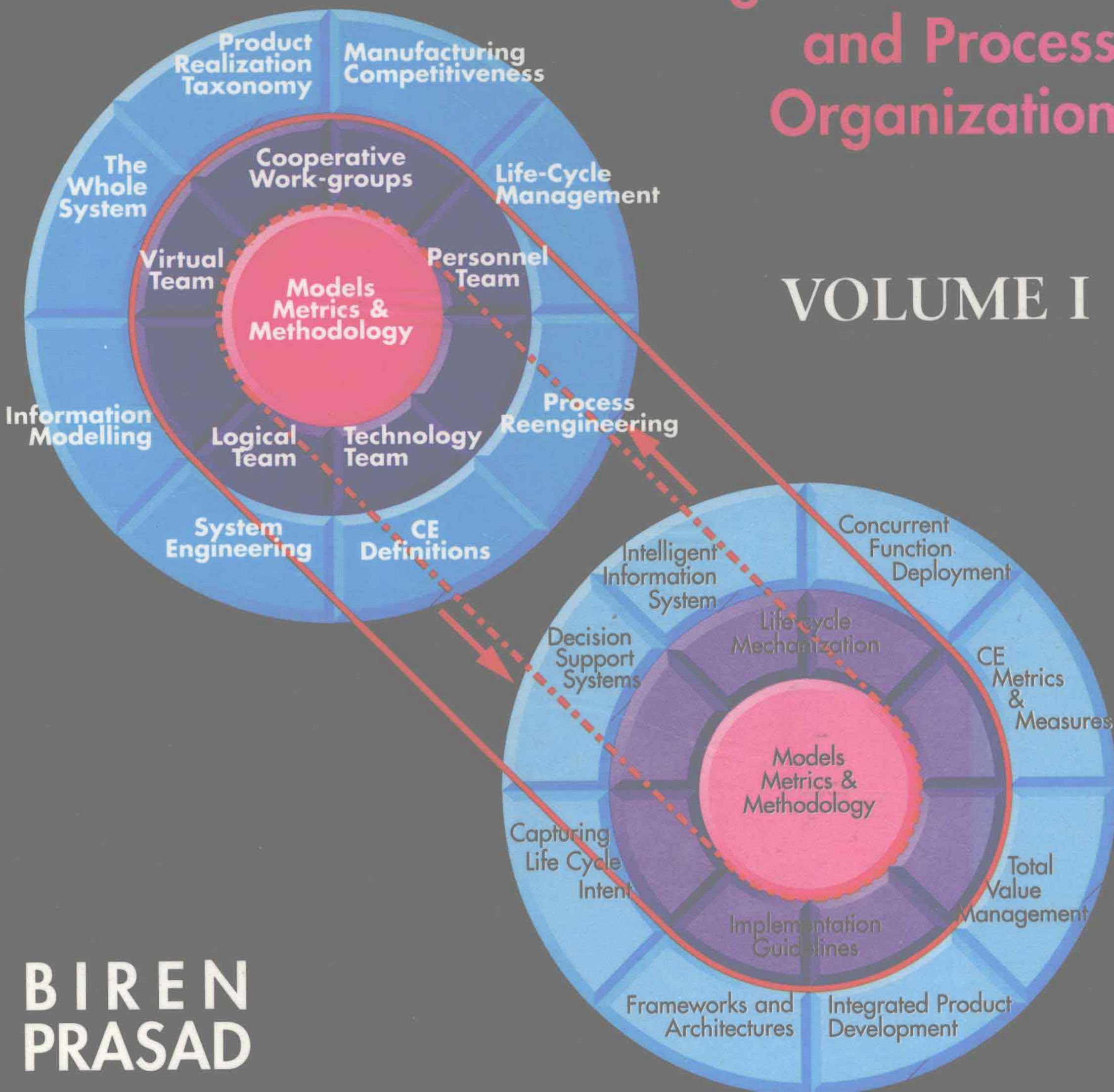
CONCURRENT ENGINEERING FUNDAMENTALS

Integrated Product and Process Organization



VOLUME I

BIREN PRASAD

CONCURRENT ENGINEERING FUNDAMENTALS

Integrated Product and Process Organization

Biren Prasad

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CONCURRENT ENGINEERING FUNDAMENTALS

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for your patience and support.

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COMPUTER ACRONYMS

ANSI	American National Standards Institute
API	Application Programming Interface
ATIS	A Tools Integration Standards
CA	Computational Architecture
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CALS	Computer-Aided Acquisition and Logistics Support
CAM	Computer-Aided Manufacturing
CAPP	Computer-Aided Process Planning
CASA	Computer-Aided Society of Manufacturing Engineers
CASE	Computer-Aided Process Engineering
CFD	Computational Fluid Dynamics
CFI	CAD Framework Initiative
CIM	Computer-Integrated Manufacturing
CPU	Central Processing Unit
DBMS	Database Management Systems
DDL	Dynamic Data Linking
DNS	Distributed Name Service
FEA	Finite Element Analysis
FEM	Finite Element Modeling
FMEA	Failure Mode and Effects Analysis
ICAM	Integrated Computer-Aided Manufacturing program
IGES	Initial Graphics Exchange Specification
IOS	Input/output Subsystems

ISO	International Standards Organization (ISO)
LAN	Local Area Network
MCAE	Mechanical Computer-Aided Engineering
MFLOPS	Million Instructions per Second
MIS	Mainframe Information System
MRP	Material Requirements Planning
NAS	Network Application Services
NC	Numerical Control
NCS	Network Computing System
NFS	Network File System
NURBS	Non-Uniform Rational B-Splines
PC	Personal Computer
PDES	Product Data Exchange using STEP
PHIGS	Programmers' Hierarchical Interactive Graphic Standard
PIM	Product Information Management
PPO	Product, Process, and Organization model
QFD	Quality Function Deployment
RISC	Reduced Instruction Set Computing
RPC	Remote Procedure Call
SLA	Stereolithography Apparatus
SME	Society of Manufacturing Engineers
SPEC	System Performance Evaluation Cooperative
SQL	Structured Query Language
SSD	Secondary Storage Device
STEP	Standard for the Exchange of Product Data
TCP/IP	Transmission Control Protocol/Internet Protocol
TQM	Total Quality Management
WAN	Wide Area Network

PREFACE

As the name implies, the book describes the fundamentals of Concurrent Engineering and explains the basic principles on which this very subject is founded. The most of the materials in the book are either original ideas or their extension to CE. Most is never reported elsewhere and is based on the author's successes while practicing CE on the job, and decades of his research and learning working with electronic, automotive, aerospace and railroad industries including Ford, General Motors, Electronic Data Systems, Association of American Railroads, NASA and numerous other places abroad. Concurrent Engineering approach to product design and development has two major themes. The first theme is establishing a ***concurrent product and process organization.*** This is referred to herein as ***"process taxonomy."*** The second theme is applying this process taxonomy (or methodology) to design and develop the total product system. This is referred to as ***integrated product development*** (IPD). Each theme is divided into several essential parts forming major chapters of this book.

The first volume called ***integrated product and process organization*** has nine chapters. The second volume named ***integrated product development*** has ten chapters. The materials in these two volumes are brought together to balance the interests of both the customers and the companies. The contents of Volume One are: Manufacturing Competitiveness: *Life-cycle Management, Process Reengineering, Concurrent Engineering Definitions, Cooperative Work Teams, System Engineering, Information Modeling, The Whole System,* and *Product Realization Taxonomy.* The contents of Volume Two are: *Total Value Management, CE Metrics and Measures, Concurrent Function Deployment, Integrated Product Development, Frameworks and Architectures, Decision Support System, Intelligent Information System, Capturing Life-Cycle Values, Life-Cycle Mechanization,* and *CE Implementation Guidelines.*

In Concurrent Engineering (CE) system, each modification of the product represents a transformation relationship between specifications (inputs, requirements and constraints), outputs, and the concept the modification represents. At the beginning of the transformation, the specifications are generally in abstract forms. As more and more of the specifications are satisfied, the product begins to take shape (begins to evolve into a physical form). To illustrate how a full CE system will work, and to show the inner-working of its elements, author defines this CE system as a set of two synchronized wheels. The representation is analogous to a set of ***synchronized wheels of a bicycle.*** Figure 1 shows this CE wheel set.

CONCURRENT ENGINEERING WHEELS

The first CE wheel represents the ***integrated product and process organization.*** The second CE wheel accomplishes the ***integrated product development.*** The two wheels together harmonize the interests of the customers and the fostering CE organization (frequently referred to as an enterprise). The contents of the first wheel are described in Volume One and the contents of second wheel are described in Volume Two of the ***CE fundamental*** books. Three concentric rings represent the three essential elements of a wheel. The middle ring represents the CE work-groups, which drive the customer and the enterprise like how a human drives a bike. The work-groups are divided into four quadrants representing the four so called CE teams. These teams are: *the personnel team, the technology team, the logical team, and the virtual team.* They are discussed in Chapter 5. The outer ring for each wheel is divided into eight parts. Each part represents a chapter of this book. The parts for the first wheel are discussed in Volume One. This volume explains how the CE design process (called herein CE process taxonomy) provides a stable, repeatable process through which increased accuracy is achieved. The book starts with an introductory chapter on manufacturing competitiveness reviewing the history and emerging trends. The remaining chapters of the book (Volume One) describe CE design process, explain how concurrent design process can create a competitive advantage, define CE process taxonomy, and address a number of major issues related to *product and process organization.* The parts of the second wheel are discussed in Volume Two. A separate chapter in the book is dedicated to discussing each part of the two CE wheels.

First CE Wheel: Integrated Product and Process Organization

The innermost ring of the first CE wheel is a hub. The layout of the hub is same for both wheels. The hub represents four supporting "M" elements: *models, methods, metrics and measures.* Models refer to information modeling. Methods refer to *product realization taxonomy.* They are discussed in Chapters 7 and 9 of Volume One, respectively. *CE Metrics and Measures* are discussed in Chapter 2 of Volume Two. The complexity of the product design and development (PDD) process differs depending upon the

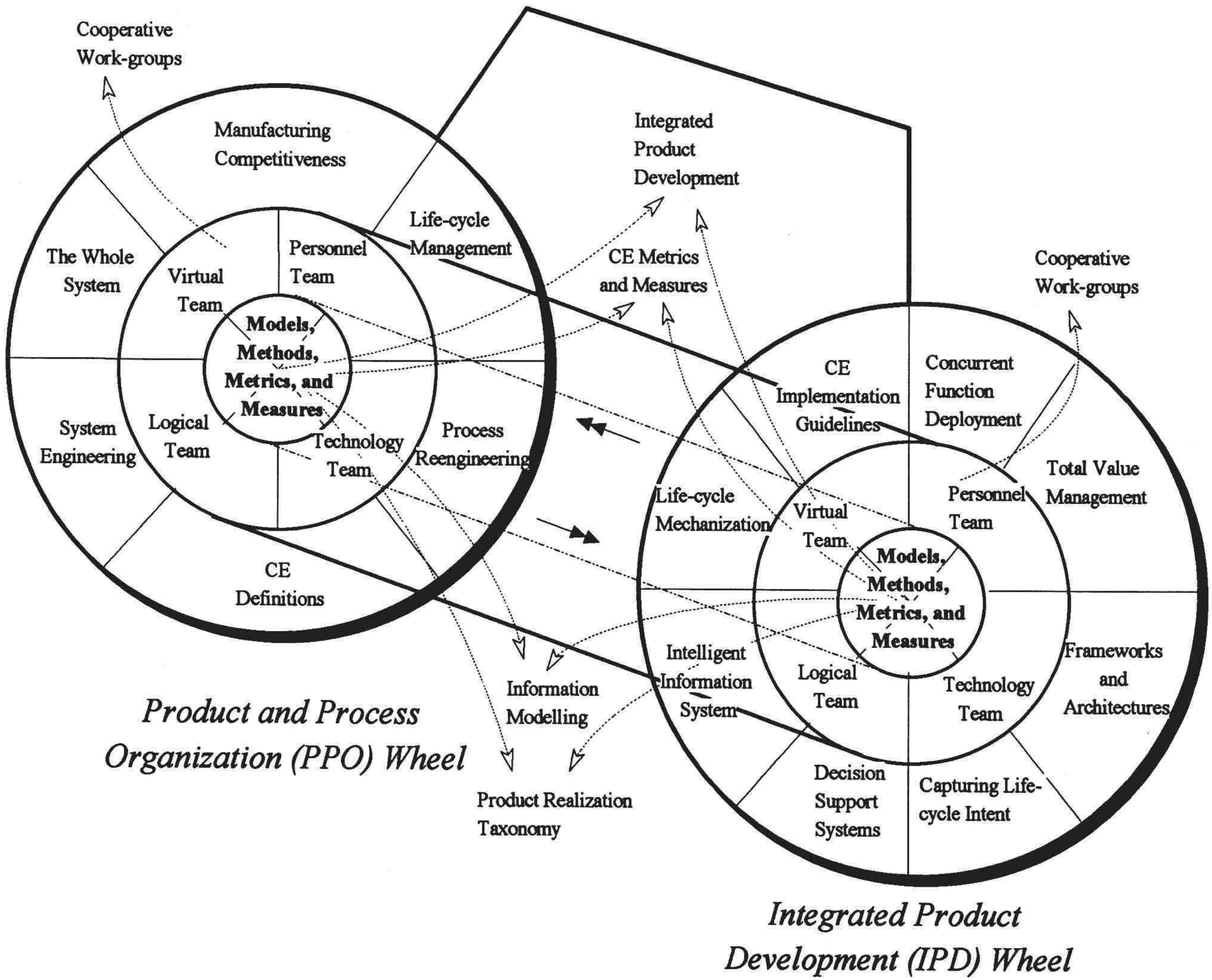

FIGURE 1 A Synchronized set of CE Wheels

(i) Types of information and sources
(ii) Complexity of tasks
(iii) Degree of their incompleteness or ambiguity

Other dimensions encountered during this PDD process that cannot be easily accommodated using traditional process (such as serial engineering) are:

(iv) Timing of decision making
(v) Order of decision making
(vi) Communication mechanism

The elements of the first CE wheel define a set of systems and processes that have the ability to handle all of the above six dimensions. In the following some salient points of the chapters are briefly highlighted:

- *Manufacturing Competitiveness:* The price of the product is dictated by world economy and not by one's own economy or a company's market edge alone. Those companies that can quickly change to world changing market place can position themselves to complete globally. This chapter outlines what is required to become a market leader and compete globally. Successful companies have been the ones who have gained a better focus on eliminating waste, normally sneaked into their products, by understanding what drives product and process costs and, how value can be added. They have focused on a product and process delivery-system—how to transform process innovations into technical success and how to leverage the implementation know-how into big commercial success. Many have chosen to emphasize high-quality flexible or agile production in product delivery rather than high-volume (mass) production.
- *Life-cycle Management:* Today, most companies are under extreme pressure to develop products within time periods that are rapidly shrinking. As the market changes so do the requirements. This has chilling effect in managing the complexity of such continuously varying product specifications and handling the changes within this shrinking time period. The ongoing success of an organization lies in its ability to: continue to evolve; quickly react to changing requirements; reinvent itself on a regular basis; and keep up with ever changing technology and innovation. Many companies are stepping up the pace of new product introduction, and are constantly learning new ways of engineering products more correctly the first time, and more often thereafter. This chapter outlines life-cycle management techniques, such as management change, and process improvement to remain globally competitive.
- *Process Reengineering:* The global marketplace of the 1990s has shown no sympathy to tradition. The reality is that if the products manufactured do not meet the market needs, demand declines and profits dwindle. Many companies are finding that true increase in productivity and efficiency begins with such factors as clean and efficient process, good communication infrastructure, teamwork, a constancy of shared vision and purpose. The challenge is simply not to crank up the speed of the

machines so that its outputs (per unit of time) are increased or doubled, but to change the basic machinery or process that produces the outputs. To accomplish the latter goals, this chapter describes several techniques to achieve competitive superiority such as benchmarking, CPI, organizational restructuring, renovation, process re-engineering, etc.

- *CE Definitions:* The changing market conditions and international competitiveness are making the time-to-market a fast shrinking target. Over the same period, diversity and complexity of the products have increased multi-folds. Concurrency is the major force of Concurrent Engineering. Paralleling describes a "time overlap" of one or more work-groups, activities, tasks, etc. This chapter describes seven CE principles to aim at: *Parallel Work-group, Parallel Product Decomposition; Concurrent Resource Scheduling; Concurrent Processing; Minimize Interfaces; Transparent Communication; and Quick Processing.* This chapter also describes the seven forces that influence the domain of CE (called here as agents or 7Ts) namely: *talents, tasks, teams, techniques, technology, time and tools.*
- *Cooperative Work-groups:* It has been the challenge for the design and manufacturing engineers to work together as teams to improve quality while reducing costs, weight, and lead-time. A single person, or a team of persons, is not enough to provide all the links between: human knowledge and skills; logical organization; technology; and a set of 7Cs coordination features. A number of supporting teams is required, some either virtual or at least virtually collocated. For the waltz of CE synthesis to succeed, CE teams need clear choreography. This chapter describes for the first time the four collaborative teams that are essential for managing a CE organization. Examples of collaborative features include capabilities of electronic meeting such as message-posting and interactions through voice, text, graphics and pictures.
- *System Engineering:* Most groups diligently work to optimize their sub-systems, but due to lack of incentives they tend to work independently of each other. This results in a product, which is often sub-optimized at each decomposed level. System engineering requires that product realization problem is viewed as a "system-centered" problem as opposed to "component-centered." *Systems Engineering* does not disagree with the idea of compartments or divisions of works, but it emphasizes that the interface requirements between the divisions (inter-divisional) and across the level should be adequately covered. That way, when the time comes to modernize other components of the system, an enterprise has the assurance that previously introduced technologies and processes will work logically in a fully integrated fashion, thereby increasing the net efficiency and profitability.
- *Information Modeling:* A successful integrated product development (IPD) requires a sufficient understanding of the product and process behaviors. One way to achieve this understanding is to use a series of reliable information models for planning, designing, optimizing and controlling each unit of the IPD process. The demands go beyond the 3-D CAD geometric modeling. The demands require schemes that can model all phases of a product's life-cycle from cradle to grave. The different aspects of product design (planning, feasibility, design, process-planning), process design (process-execution, production, manufacturing, product support), the human be-

havior in teamwork, and the organization or environment in which it will operate, all have to be taken into account. Five major classes of modeling schemata are discussed in this chapter. The are: (a) Product representation schemes and tools for capturing and describing the product development process and design of various interfaces, such as design-manufacturing interface; (b) Schemes for modeling physical processes, including simulation, as well as models useful for product assessments, such as DFA/DFX, manufacturability evaluation of in-progress designs; (c) Schemes for capturing (product, process, and organization structure) requirements or characteristics for setting strategic and business goals; (d) Schemes to model enterprise activities (data and work flow) in order to determine what types of functions best fit the desired profitability, responsiveness, quality and productivity goals; and (e) Schemes to model team behavior, because most effective manufacturing environments involve a carefully orchestrated interplay between teams and machines.

- *The Whole System:* Often while designing an artifact, work-groups forget that the product is a system. It consists of a number of subassemblies, each fulfilling a different but distinct function. A product is far more than the collection of components. Without a structure or "constancy-of-purpose" there is no system. The central difference between a CE transformation system and any other manufacturing system, such as serial engineering, is the manner in which the tasks' distribution is stated and requirements are accomplished. In a CE transformation system, the purpose of every process step of a manufacturing system is not just to achieve a transformation but to accomplish this in an optimal and concurrent way. This chapter proposes a system-based taxonomy, which is founded on parallel scheduling of tasks and a breakdown structures for product, process and work to realize a drastic reduction in time and cost in product and process realizations.
- *Product Realization Taxonomy:* This constitutes a "state of series of evolution or transformation" leading to a complete design maturity. Product Realization Taxonomy involves items related to design incompleteness, product development practices, readiness feasibility, and assessing goodness. In addition, CE requires these taxonomies to have a unified "product realization base." The enterprise integration metrics of the CE model should be well characterized and the modeling methodologies and/or associated ontology for developing them should be adequate for describing and integrating enterprise functions. The methodologies should have built-in product and service accelerators. Taxonomy comprises of the product, process descriptions, classification techniques, information concepts, representation, and transformation model for product realization. They are included as part of the taxonomy descriptions.

Second CE Wheel: Integrated Product Development

The second CE wheel defines the integrated product development (IPD). This is discussed in the second Volume. IPD in this context does not imply a step-by-step serial process. Indeed, the beauty of this wheel (integrated product development) is that it offers a framework for a concurrent product design and development. A framework within which, the CE teams have flexibility to move about, fitting together bits of the jigsaw as they come together. CE teams have opportunity to apply a variety of techniques contained in this volume (such as: *Concurrent Function Development, Total Value Management, Metrics and Measures,* etc.) and through their use have opportunity to achieve steady overall progress towards a finished product.

- *Concurrent Function Deployment:* The role of the organization and engineers is changing today, as is the method of doing business. Competition has driven organization to consider concepts such as time compression (fast-to-market), Concurrent Engineering, Design for X-ability, and Tools and Technology (such as Taguchi, Value Engineering) while designing and developing an artifact. Quality Function Deployment (QFD) addresses major aspects of "quality" with reference to the functions it performs, but this is one of the many functions that need to be deployed. With conventional deployment, it is difficult, however, to address all aspects of Total Values Management (TVM) such as *X-ability, Cost, Tools and Technology, Responsiveness and Organization* issues. It is not enough to deploy just the *"Quality"* into the product and expect the outcome to be the *World Class.* TVM efforts are vital in maintaining a competitive edge in today's world marketplace.
- *CE Merits and Measures:* Metrics are the basis of monitoring and measuring process improvement methodology and managing their effectiveness. Metric information assists in monitoring team progress, measuring quality of products produced, managing the effectiveness of the improved process, and providing related feedback. Individual assurances of DFX specifications (one at a time) do not capture the most important aspect of Concurrent Engineering—the system perspectives, or the tradeoff across the different DFX principles. While satisfying these DFX principles in this isolated manner, only those which are not in conflict are usually met. Concurrent engineering views the design and evaluates the artifact as a system, which has a wider impact than just sub-optimizing the sub-systems within each domain.
- *Total Value Management:* The most acclaimed slogan for introducing a quality program in early corporate days simply was to provide the most value for the lowest cost. This changed as the competitiveness became more fierce. For example, during the introduction of traditional TQM program in 1990 *"getting a quality product to market for a fair price"* was the name of the game. The new paradigm for CE now is total values management (TVM): *"to provide the total value for the lowest cost in the least amount of time, which satisfies the customers the most and lets the company make a fair profit."* Here use of "value" is not just limited to *"quality."* To provide long lasting added value, companies must change their philosophy towards things like *x-ability, responsiveness, functionality, tools and technology, cost, architecture,* etc.
- *Integrated Product Development:* A systematic methodology is essential in order to be able to integrate: (a) teamwork; (b) information modeling; (c) product realization taxonomy; and (d) measures of merits (called CE metrics), and quantitatively assess the effectiveness of the transformation. This may involve identification of perfor-

mance metrics for measuring the product and process behaviors. Integrated product development methodology is geared to take advantage of the product realization taxonomy.

- *Frameworks & Architectures:* In order to adequately support the CE—4Ms (namely: modeling, methods, metrics and measurements), it is necessary to have an architecture that is openly accessible across different CE teams, information systems, platforms, and networks, Architecture consists of information contents, integrated data structures, knowledge-bases, behavior and rules. An architecture not only provides an information base for easy storage, retrieval, and tracking version control, but can also be accessed by different users simultaneously, under ramp-up scheduling of parallel tasks, and in synchronization. We also need a product management system containing work management capabilities integrated with the database. This is essential because in CE there exists a large degree of flexibility for parallelism that must be managed in conjunction with other routine file and data management tasks.
- *Capturing Life-cycle Intent:* Most CAD/CAM tools are not really "capture" tools. In static representation of CAD geometry, configuration changes cannot be handled easily, particularly when parts and dimensions are linked. This has resulted in loss of configuration control, proliferation of changes to fix the errors caused by other changes, and sometimes ambiguous designs. By capturing "design intent": as opposed to "static geometry," configuration changes could be made and controlled more effectively using the power of the computer than through traditional CAD attributes (such as lines and surfaces). The power of a "capture" tool comes from the methods used in capturing the "design intent" initially so that the required changes can be made easily and quickly, if needed. "Life-cycle capture" refers to the definition of the physical object and its environment in some generic form. "Life-cycle intent" means representing the "life-cycle capture" in a form, which can be modified and iterated until all the life-cycle specifications for the product are fully satisfied.
- *Decision Support System:* In CE, cooperation is required between CE teams, management, suppliers, and customers. A knowledge based support system will help the participating teams in decision making and to reflect balanced views. Tradeoffs between conflicting requirements can be made on the basis of information obtained from sensitivity, multi-criterion objectives, simulation, or feedback. The taxonomy can be made a part of decision support system (DSS) in supporting decisions about product decomposition by keeping track of what specifications are satisfied, in ensuring common visibility in the state of product realization, including dispatching and monitoring of tasks, structure, corporate design histories, etc.
- *Intelligent Information System* (IIS): Another major goal of CE is to handle information intelligently in multimedia—audio, video, text, graphics. Since IIS equals CIM plus CE, with IIS, many relevant CE demands can be addressed and quickly processed. Examples include: (a) over local or wide area networks, such as SQL, which connects remote, multiple databases and multimedia repositories; (b) any needed information, such as recorded product designers' design notes, figures, decisions, etc., can be made available on demand at the right place at the right time; (c)