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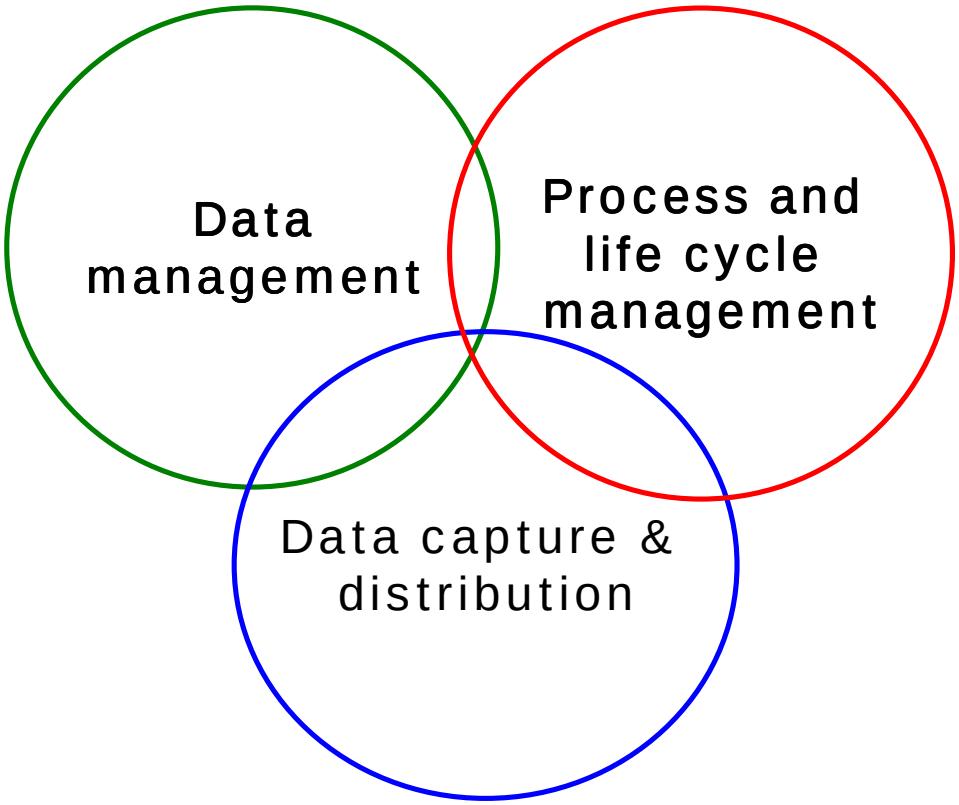
VTT TIEDOTTEITA

**Jukka Kääriäinen, Pekka Savolainen,
Jorma Taramaa & Kari Leppälä**

Product Data Management (PDM)
Design, exchange and integration viewpoints



TECHNICAL RESEARCH CENTRE OF FINLAND

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Abstract

The electronics and electrical industries have become an important branch of industry in Finland. They produce products which are used in health care, industry, and every-day living such as mobile phones, industrial instruments and automotive electronics.

In the global markets there are many competitors and companies seeking new ways to decrease costs. This hard competition forces companies to specialise and focus on a certain market-segment. Products are containing more functionality, and product development is a continuous process to fulfil customer needs. Developers have to master a range of technology and the total amount of product data is increasing.

This report describes the requirements of the embedded product's design data management. Analysis covers different product technologies as well as development processes. The challenge of the design data management is to manage the total set of data related to the structure of the product during the product's life-cycle.

The result of the analysis is the framework which represents the requirements of the design data management of the embedded product. This classification contains three subsets: data management, process and life-cycle management, and data capture and distribution.

This framework is used to evaluate three commercial PDM systems. This consideration brings out the fact that the current solutions do not meet all the requirements of the embedded product's design data management.

Preface

This report is a part of VTT Electronics' strategic PRIMA (PRoduct Information MAnagement for the electronics industry) project, which deals with product data management in the electronics industry. This report presents the concept of product data management in the electronics industry.

I would like to thank VTT Electronics and all the people who have helped me during this research and have thereby made this research possible. I would also like to thank PDM systems resellers who have kindly introduced their solutions:

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Hannu Lehtimäki from Ideal Product Data Oy, and

Tuomo Kähkönen and Kari Kakkonen from Software Engineering Center SEC Oy.

Furthermore, I want to thank my supervisors: Embedded Product Data Management – research group Section Manager Pekka Savolainen, and Professor Martti Penttonen of the University of Kuopio. I would also like to thank Dr. Jorma Taramaa and Dr. Kari Leppälä who have helped me during this work.

I would like to give my special thanks to my fiancée, Kati, and my parents, who have supported me during my studies.

Jukka Kääriäinen

Contents

List of abbreviations

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AP	Application Protocol
ASCII	American Standard Code for Information Interchange
ASIC	Application Specific Integrated Circuit
BOM	Bill Of Material
CAD	Computer Aided Design
CAPP	Computer Aided Process Plan
CASE	Computer Aided Software Engineering
CDIF	Case Data Interchange Format
CE	Concurrent Engineering
COE	Customer Order Entry
CORBA	Common Object Request Broker Architecture
DAD	Design Automation Division
DBMS	DataBase Management System
DOCSTEP	Product Documentation Creation and Management using STEP
DSP	Digital Signal Processing
DTD	Document Type Definition
DVDM	Data Vault and Document Management
DXF	Drawing Interchange Format
EAI	Enterprise Application Integration
EBCDIC	Extended Binary Coded Decimal Interchange Code
ECAD	Electronics Computer Aided Design
ECP	Engineering Change Proposal
EDA	Electronics Design Automation
EDIF	Electronic Design Interchange Format
EDM	Engineering Document Management
EIA	Electronics Industry Association
EIDX	Electronics Industry Data Exchange
EIG	Electronic Information Group
EPDM	Enterprise Product Data Management
EPM	Windchill Enterprise Product Modeler
ERP	Enterprise Resource Planning
FPGA	Field Programmable Gate Array
HTML	HyperText Markup Language
HW	HardWare
IAD	Industrial Automation Division
IDF	Intermediate Data Format
IPDMUG	International PDM Users Group
ISO	International Organisation for Standardisation
MCAD	Mechanical Computer Aided Manufacturing
METADM	Metaphase Document Management
METASM	Metaphase Storage Management
METAVPDM	Metaphase Virtual Product Development Manager
NC	Numeric Control
OMG	Object Management Group

PDES	Product Data Exchange Specifications
PDF	Portable Document Format
PDM	Product Data Management
PIM	Product Information Management
PM	Program Management
PSM	Product Structure Management
QFD	Quality Function Deployment
RDBMS	Relational DataBase Management System
SCCS	Source Code Control System
SCM	Software Configuration Management
SDAI	Standard Data Access Interface
SDRC	Structural Dynamics Research Corporation
SGML	Standard Generalised Markup Language
SQL	Structured Query Language
STEP	Standard for the Exchange of Product model data
SW	SoftWare
TDM	Technical Document Management
TIM	Technical Information Management
UML	Unified Modeling Language
URL	Uniform Resource Locator
VHDL	VHSIC Hardware Description Language
VTT	Technical Research Centre of Finland (Valtion Teknillinen Tutkimuskeskus)
WBS	Work Breakdown Structure
WPM	Workflow and Process Management
WWW	World Wide Web
XML	Extensible Markup Language

1. Introduction

1.1 Background

The development of embedded products requires a range of technologies such as software, electronics, and mechanics. Software is typically in close relation with electronics and mechanics in these products [OiS98]. These intelligent products, which often operate in uncontrolled and difficult environments, are called embedded products. The role of the software is important in the electronics industries [Sep97]. Software is increasingly used e.g. for the control and data transfer functions of the product as well as the implementation of customised features [Sep97].

The globalisation of design activities requires data exchange with other sites, customers, sub-contractors, and suppliers. The development and use of the product adds concept "life-cycle" to this report. One of the definitions of the *life-cycle* emphasising software is [BeE89]:

The life-cycle is a period of time that starts when a software product is specified and ends when the product is no longer available for use.

Product development contains a set of activities, tools, methods, and procedures by which customer needs are translated into a product [MaM97]. Figure 1 illustrates interaction between electronic products and their development processes [Sep97].

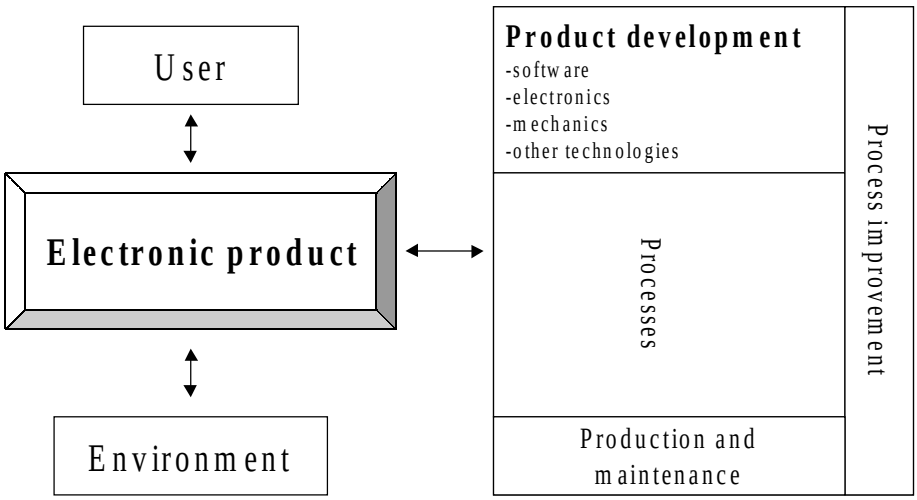

Figure 1. Interaction between the product and the product development process [Sep97, p. 69].

Product development is very important in the business activity, and success during that process is important for a company. CimData [MaM97] defines "process" as an ordered sequence of steps performed for a given purpose, such as the software development process. Development also contains functions like document version control, which maintains a document's version history. Process improvement aims to improve processes to meet business goals [OiS98].

The developers of embedded products have to master a range of technologies, e.g. electronics and software. The increasing use of these technologies increases the total amount of product data [HaH95]. Product data is a set of data which uniquely defines a product for the enterprise [MaM97]. This product data contains e.g. drawings, decisions, specifications and calculations which are used in production and maintenance. All this product data should be documented and managed, and documents should be available even after decades (maintenance). The operational environment of a company nowadays also requires fast time-to-market, co-operation and cost efficiency [HaH95]. These requirements create challenges for a company's data management system.

1.2 Related research and research problems

CimData [MaM97] defines the parts of PDM and introduces many commercial PDM systems. CimData defines PDM as follows [MaM97]:

A Product Data Management system is used within an enterprise to organise, access and control all data related to its products, and manage the life-cycle of those products.

This report focuses on the design data management. How do PDM systems manage a product's design, data exchange and tool integration? However, at the same time it is worth noticing that PDM's scope is even broader.

Halttunen & Hokkanen [HaH95] have examined the background and solutions related to PDM, as well as PDM in product planning and production. Halttunen & Hokkanen also introduce the ways in which PDM can support Concurrent Engineering (CE). When considering the design data management of an embedded product, the management of embedded software and software documents is one part of a product's whole management [Tar98]. Many design tools and management systems are used during a product's design, and interaction between these systems is needed [Har98]. One possibility for interaction of these systems is the use of data representation and exchange standards [PeT98] [Sää98].

There are literature and research results available that deal with design data management and product data management [HaL96, PeT98, PiM97]. However, it is difficult to find a good examination which clearly defines design data management requirements in the electronics industry. Thus the definition of these requirements is essential. This report also presents how commercial systems meet these requirements.

In conclusion, the aim of this research is to find the answers to the following questions:

- What kinds of demands does the development of multi-technological product (design combines hardware (HW), software (SW) and mechanics) bring into product data management?

- What kind of solutions can be found to meet these demands (emphasis on the PDM systems)?

1.3 Structure of the report

The scope of this report was defined to cover the electronics industry. Within this industry sector the focus is on embedded product design.

This report has been divided into six chapters according to Figure 2.

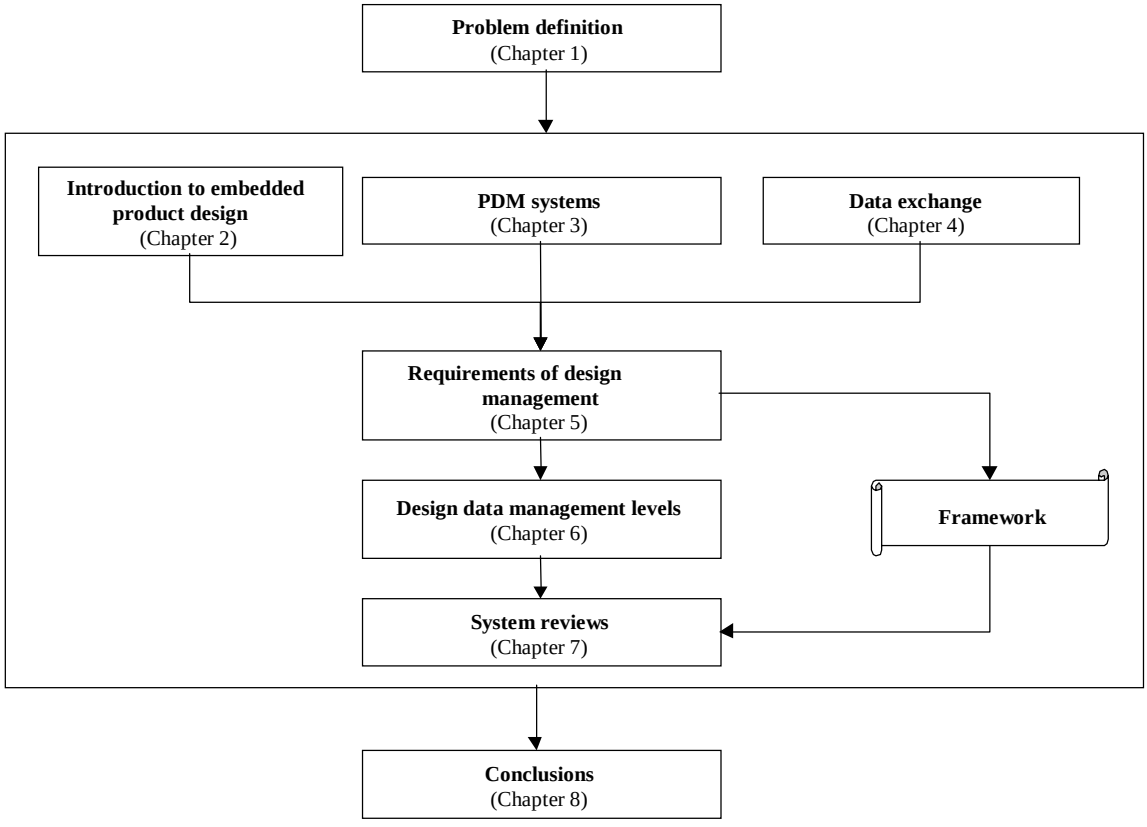

Figure 2. Structure of the report.

The first chapter contains an introduction to the problem. This chapter also introduces the related research. The second chapter concentrates on the general considerations and requirements of the problem, and introduces the product development process of the

embedded product. The chapter also presents Concurrent Engineering design principles and the general dimensions of engineering data management. The third chapter presents PDM definition and some state-of-the-art solutions for PDM. This chapter presents the general requirements for product data management. The fourth chapter introduces several standards which are used in data exchange. These standards are: STEP, CDIF, and SGML. The fifth chapter defines special requirements for design data management of embedded product and presents a framework of these requirements. This framework is used in Chapter 7 when commercial PDM systems are analysed. The sixth chapter presents the levels of design data management (levels of solutions). These levels represent the basic solution categories.

The seventh chapter contains the examination of selected commercial PDM systems and one project management system. The eighth chapter contains conclusions.

The report begins with a literature and article review (Chapter 2), which collects requirements for the design data management. Chapter 3 presents the state-of-the-art - section based on literature, articles, and enquiries from PDM vendors. Chapter 4 contains the analysis of data exchange problems and solutions according to the literature. Chapter 5 contains a specific analysis of the problem. Chapter 6 considers design data management levels according to the literature. The system review (Chapter 7) contains a consideration of product data management systems, how well do the existing systems meet defined requirements of today. This information has been collected by interviews and experiments. The PDM resellers who have been interviewed are:

- Parametric Technology Finland, selling Windchill[1];
- Software Engineering Center, selling PVCS Dimensions[2];
- Ideal Product Data, selling Metaphase[3].

These tools represent different backgrounds. Windchill and Metaphase provide support mainly for mechanical and electrical design tools. PVCS Dimensions provides support mainly for the software tools.

[1] Windchill is a trademark of Windchill Technology Inc.
[2] PVCS Dimensions is a trademark of MERANT Solutions Inc.
[3] Metaphase is a registered trademark of Metaphase Technology Inc.

2. Overview of embedded product design

The success of manufacturing companies depends on their ability to meet customers' needs and to respond quickly to these needs by introducing new products [UlE95]. The following sections introduce the role of product design in a manufacturing system. They also introduce product design processes and consider product data management requirements.

Section 2.1 introduces product design as one of the activities in the manufacturing system. This design process creates information for production, but this information is also necessary for other functions, e.g. purchasing and sales. Section 2.2 introduces the systematic design process of an embedded product, starting from requirements analysis, up to the product's maintenance. Three discipline-specific design domains are discussed further in Section 2.3 (software, electronics, and mechanics).

The shortening of product life-cycle, and the requirements for variety stress the importance of the product design phase. Design is always a trade-off between cost, product performance and time to market [Kau99]. The majority of the product's costs are accumulated during the product's design process. This has lead to the evolution of new design principles (e.g. concurrent engineering), as well as new requirements for product data management [HaH95]. Concurrent engineering is discussed in Section 2.4. Section 2.5 defines general data management requirements for a product's design. These requirements do not depend on product implementation technology.

2.1 Design for manufacture

Product design can be seen as a sub-process of the manufacturing function (Figure 3). It creates manufacturing support information, such as drawings, assembly instructions and BOM (Bill Of Material). BOM is an ordered list of raw materials, parts, sub-assemblies, and assemblies. This design information contains a description of the product (e.g. design data from Computer Aided Design-tool (CAD)).

Design activities support manufacturing through the application of design principles, often defined as guidelines: modular design, design for simplification, and design for easy of automation. Modular design uses common components and assemblies in product design. Design for simplification tries to include as many standard components as possible in a product's structure. Design for ease of automation aims to reduce the complexity of the assembling processes [BaB91]. Nowadays, production process planning is an important part of the whole product's development [Kiv98]. For example, designers have to understand different materials' behaviour and special handling or processing requirements for components [PrS92].

An embedded product contains both electronics and software, and embedded software has become an integral part of products. Production costs can be decreased by implementing products with different features through software [Mil98].

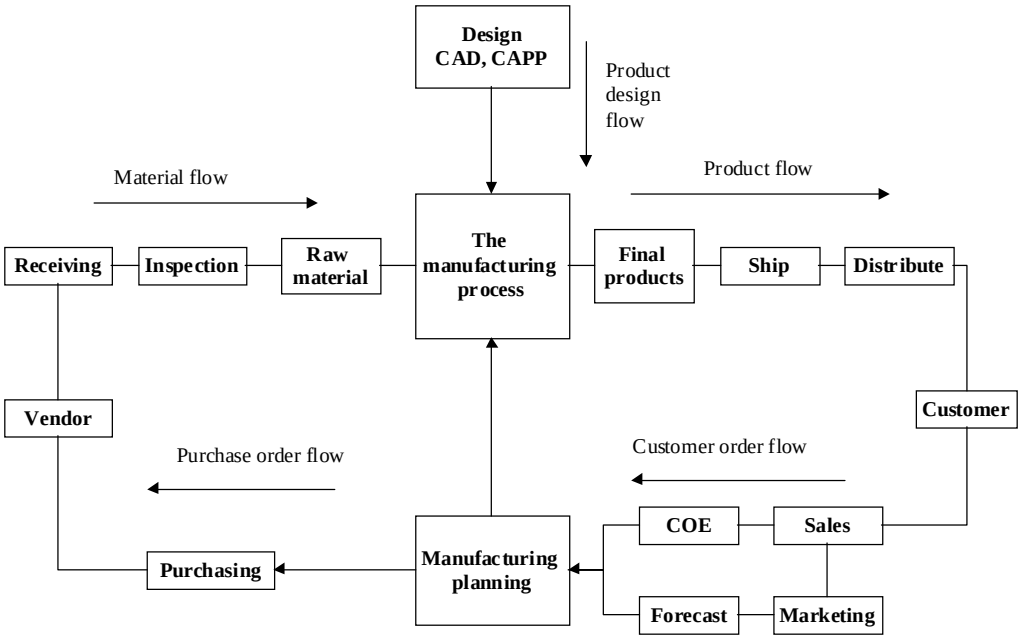

Figure 3. The design process as part of the manufacturing system [BaB91, p. 237].

The customer order flow (Figure 3) identifies the production requirements, and manufacturing planning defines schedules for the product's manufacture. These schedules are also used to organise the purchasing of raw materials. The material flow receives and inspects raw materials and components. Finally, the manufacturing process uses raw materials according to the schedule by using a defined processes to manufacture the product. [BaB91]

2.2 Design of embedded products

The product development process can be described as a sequence of specific tasks such as concept design, design, and testing. A traditional state-gate model identifies the main tasks for the development process, and gates which define decisions between the tasks. The stage-gate model provides the basic principle for application of managerial control on design processes. [Kau99]

Embedded products are complicated multi-technology artefacts, so there is a need for a discipline which brings different skills, disciplines, development stages and stakeholders together. The systems engineering model was originally created to master the creation of very large and complicated defence and computer systems. Systems engineering provides a comprehensive reference model for the development of new embedded products. Systems engineering can be defined as follows [Joh99]:

An interdisciplinary collaboration approach to derive, evolve, and verify a life-cycle balanced system solution that satisfies customer's exceptions and meets public acceptability.

Keller & Shumate defines systems engineering as follows [KeS92]:

Systems engineering is the process used to transform an operational need into a working system that satisfies the requirements.

Figure 4 illustrates the development process of an embedded product which emphasises the systems engineering involvement during the whole design process (modified according to Keller & Shumate [KeS92]).

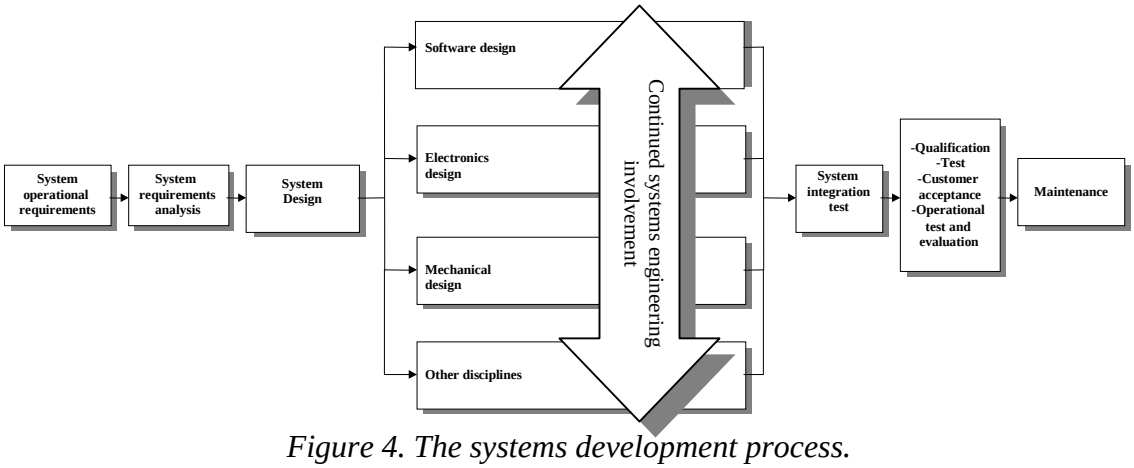

Figure 4. The systems development process.

Requirements analysis transfers product requirements into a set of capabilities and performance requirements, suitable for a refinement of the design process, and for allocation of requirements to components of the design. Also the system qualification requirements are developed and documented. The system design defines the overall system architecture, which will satisfy the requirements. The discipline-specific design processes are running in parallel, but are co-ordinated. The system will then be integrated and tested. The remaining tasks involve the testing and maintenance functions.

Kauppinen [Kau99] divides organisational models of product development into four types: serial, parallel, coupled and concurrent. In a serial process one task must be completed before the next one can begin. This approach has been criticised, as quicker product development cycles are needed. The parallel model can shorten the development cycle but it demands a clear and detailed description of the tasks. The coupled model improves on the parallel model by adding interaction and iteration during the design process. The concurrent model accelerates sequential tasks by overlapping, providing interaction and co-ordinating parallel activities.

Changes in customers and production requirements, and refinement of the design tasks can raise a need for product modifications during or after the product development process. The Engineering Change Management process manages this modification process. Figure 5 describes the Engineering Change process. [BeE89]

An engineering change proposal or request (ECP, ECR) describes the suggested changes. It also identifies the related items and documents. These suggestions are then evaluated. If the change is approved, it should be incorporated, documents updated, and change tested. Finally all parties should be notified. [BeE89, PeT98, Ber92]

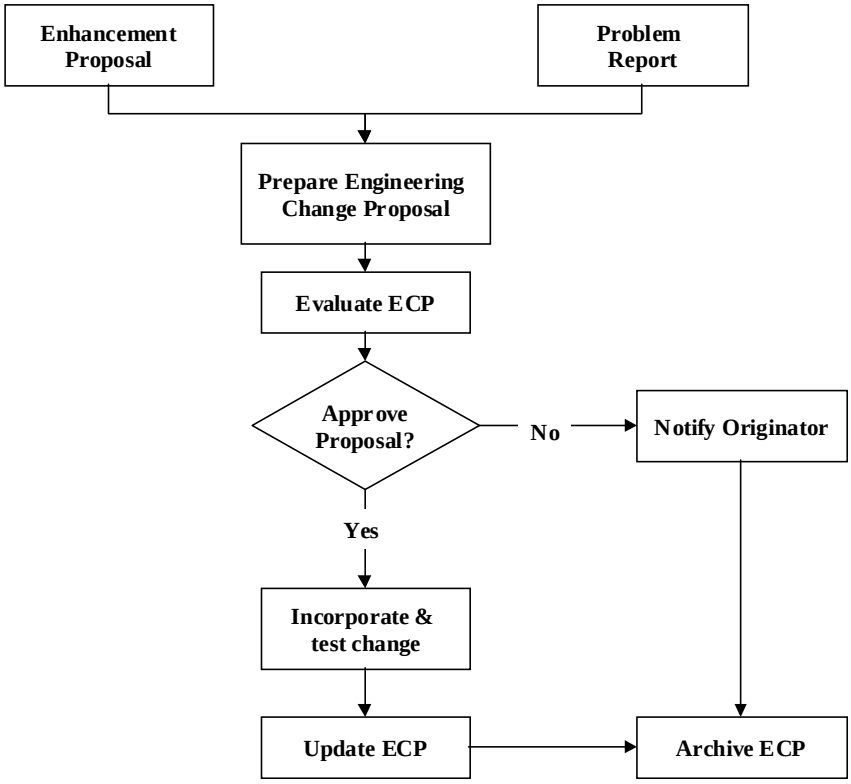

Figure 5. Change control flow [BeE89, p. 129].

Engineering change management can be divided into change information, and actions needed to make the change. During the change process people act according to their roles, e.g. programmer, designer, build manager. For example, after a programmer completes his/her change task the file is checked back in the system. Then the system notifies the test manager, who promotes the file to the test stage. [Wil97]

The engineering change process is a complex iterative process, and the example above is simplified. The amount of engineering data is increasing, and concurrent module updates are possible [PeT98]. Engineering and product data management needs to be able to cope with this complex environment [Tar98].

2.3 Technical design disciplines and document management

The design process refines design specifications into discipline-specific design documents, which are reviewed in the product design process. In this chapter we discuss technical design disciplines: software design, electronics design and mechanical design. we also include software/hardware co-design. Naturally, product design may also contain parts like motors, sensors, actuators, hydraulics and pneumatics.

2.3.1 Software design

There are several design models, developed specially for software design. They include the waterfall model [Roy70, Boe76], which divides development into smaller sequential steps, and the spiral model [Boe88].

The ISO standard 12207 [Inf95] defines a software life-cycle process within the context of three main process categories. The processes are divided into five primary processes, eight supporting processes, and four organisational processes. One of the primary processes is software development, which contains the activities and tasks of the developer. The documentation is created according to the documentation process, one of the supporting processes. It defines the activities for recording the information produced by a life-cycle process.

Figure 6 [Pes93] describes a simplified software development process which has the same main phases as the ISO 12207 -standard. This figure also illustrates the parallel activities of different technologies. All documents during the phases are reviewed.

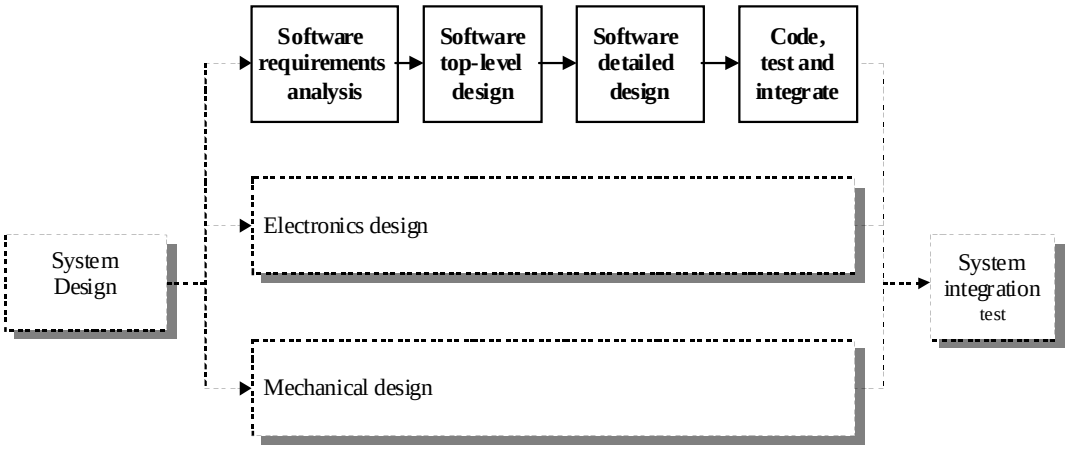

Figure 6. Software design process as part of systems design.

The system design produces the specifications for software design. Software requirements analysis describes detailed specification of the necessary functionality of each software component. Top-level design process explains the top-level structure of the software and describes interfaces between the major modules within that architecture. The developer defines preliminary test requirements and the schedule for software integration. Detailed design specifies the detailed structure for each software component (e.g. pseudo code) and interfaces between software components and units. The developer also defines preliminary requirements and the schedule for software units as well as updating the test requirements and the schedule for software integration. After design the modules are coded (program code) and tested (results are documented). The developer updates the test requirements of integration. In the software integration phase the modules are integrated as the software system and tested so that the software is developed according to the integration plan. The information is documented and reviewed. [Pes93, Inf95]

Saukkonen and Oivo have considered and represented features related to the development process of embedded software [OiS98]:

- parallel design of hardware and software,
- parallel development of different kinds of software,
- strong product and product data management viewpoint, and
- difference between design and user environments.

The parallel development of electronics hardware and different kinds of software (e.g. man-machine interface software, application software, device drivers, digital signal processing (DSP) software) requires good change management, because changes in electronics can effect the software and vice versa [OiS98]. Working interfaces between hardware and software development processes are essential in efficient product development. As several people usually work in parallel, management of parallel modifications is also necessary [Leb94]

The embedded software is a part of the product, and even after decades it may become necessary to track product configuration information, including software components [OiS98] [Leb94].

Hardware-software co-design is a special type of embedded product design, and it will be discussed in Section 2.3.3.

2.3.2 Electronics design

The electronics design process creates the description of the electronics parts of the product. Part of this information is used to control the production process and its sub-processes, for example assembly drawings (for assembly or assembly machine programming) and layout files (to control printed circuit board manufacturing

machinery) and parts lists (to control purchasing and material logistics). Design outputs may be characterised as manufacturing templates and information platforms.

It is typical for electronics that component technology evolves rapidly. Product updates need to be made frequently, due the changing situation of component supply and markets. Maintenance, for example, needs to track the documents for a proper product configuration even after many years. [PeR96]

The next list is based on VTT Electronics' quality system and represents the main phases of electronics design [VTT97a]:

- General design of modules: this phase specifies system-level specification and creates module-level specifications. This phase also produces e.g. the functional descriptions of the modules.

- Detailed design of modules: this phase uses system-level and module level specifications and produces design documents and test plans.

- Module prototype manufacturing: this phase produces module prototypes, which are used to verify the design.

- Module prototype testing: this phase tests module prototypes.

These phases are common for all types of electronics design from printed circuit board designs up to the design of programmable or application specific microcircuits ASIC). [VTT97a]. Electronics design can include the designing of circuit boards, application-specific integrated circuits (ASIC), or programmable gate arrays. An illustrative electronics design flow is shown in Figure 7 (supplemented from [PeR96]).

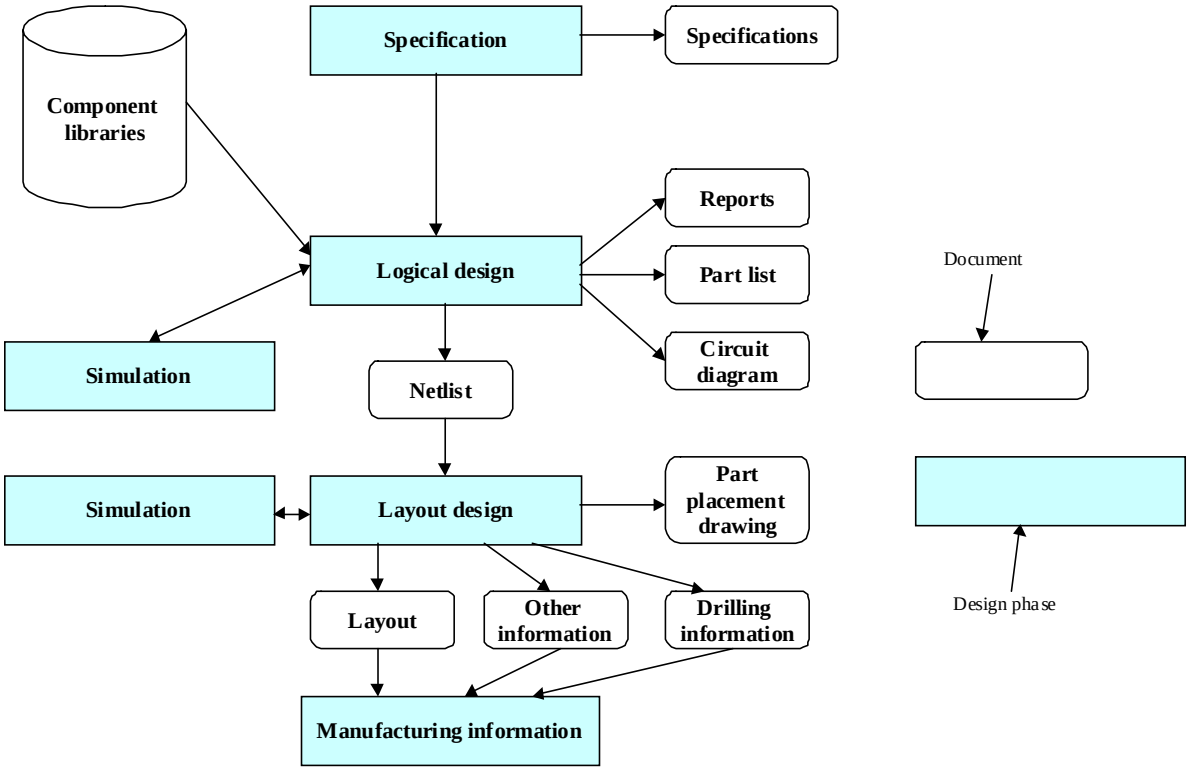

Figure 7. Circuit board design process [PeR96, p. 140].

The details of the electronics are specified using, for example, graphical notation of high level hardware description languages, and nowadays the design is usually performed by means of computer based tools (called e.g. EDA or CAE tools). The logical[4] design process refers to components located in tool specific component libraries. The output of the tool is the netlist, which specifies the components and their connections. Simulation is used to check the accuracy of design and the results are documented. Logical design also produces a part list and it is possible to export it to an inventory management program.

The layout or physical design uses the netlist to define physical placement for the components and wiring geometry between them. Again, simulation is used to check the design. In addition to functional simulation, simulation may involve thermal behaviour and electromagnetic properties. The physical design phase produces placement diagrams, mechanical drawing of the circuit board, and wiring geometry, which are all referred to as "layout". All appropriate information will be converted into machine readable format for circuit board manufacture and for the planning and programming of assembly operations. [PeR96]

The logical design process for microcircuits is in principle very similar. However, the physical design phase is different. With application-specific circuits (ASICS), the physical layout process creates the design (geometry of components and wirings)

[4] logical is used to denote "abstract". It may involve analogue or digital (logical) components. For clarity, design with logical circuits is referred as "digital design".

directly on silicon, utilising special design tools. The result of the process is a set of design files, which are delivered to some microcircuit factory.

With programmable logic circuits, the logical design is compiled into programming information, which is then used to program the pre-manufactured circuit templates.

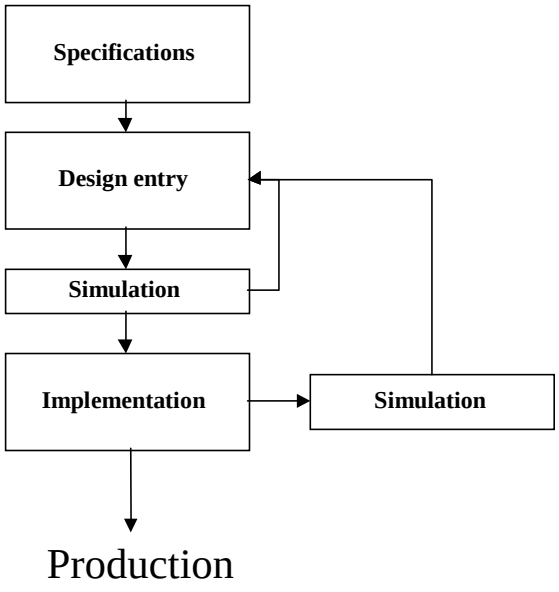

Figure 8. Programmable logic circuit design flow [Wik98, p. 51].

2.3.3 Software-hardware co-design

Software and hardware (electronics) can be alternative implementation technologies for some of the product's functions. Careful software-hardware partitioning is an essential part of the design phase. Errors and omissions may lead to difficult and non-optimal designs and errors, which will show up in a later phase.

Co-design is defined to be an engineering methodology, which aims at designing the system as a whole and achieving shared functionality and performance goals [SoH98, AyJ96], Figure 9.

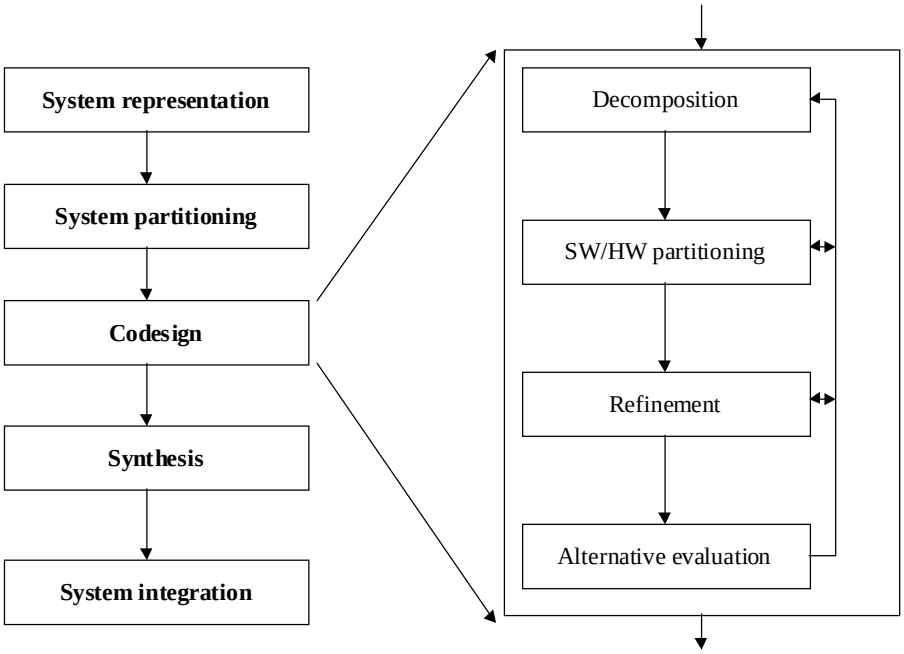

Figure 9. System design methodology supporting co-design [AyJ96, p. 100].

The co-design may be seen as an iterative process, which consists of [Hei97]:

- decomposition: the partition of system function into the collection of sub-functions.
- hardware-software partitioning, which allocates sub-functions onto hardware or software modules.
- refinement: to produce alternative implementations.
- Alternative evaluation: compares individual alternatives and their impact on the overall system.

Co-design, defined in this way, can be seen as an alternative name for the architectural design phase of the systems engineering process (Chapter 2.2). A narrower definition for co-design implies a design cycle, which allows *co- simulation*. The main requirement is that both electronics and software functions are expressed in some high-level programming language, which allows computer simulation of the entire system functionality – either using a uniform or compatible description language for hardware and software, or using heterogeneous descriptions (in the latter case we deal with mixed-mode simulation) [AyJ96, SoH98].

2.3.4 Mechanical design

The mechanical design process resembles that of electronics design – actually it is historically the oldest, and is a paragon for all systematic engineering processes. The following list is based on VTT Electronics' quality system and represents main phases of mechanical design [VTT97b]:

- General design: this phase specifies system-level specification and creates module-level specifications. This phase also produces e.g. module partition and strength calculations.

- Industrial design: this phase uses specifications which relate to the industrial design and create aesthetics and ergonomics solutions, which are in harmony with the functional requirements of the product.

- Detailed design: this phase uses system level and module level specifications and produces e.g. design documents, part lists and test plans.

- Module prototype manufacturing: this phase produces module prototypes which are used to verify the design.

- Module prototype testing: this phase tests module prototypes.

Mechanical design naturally requires co-operation with designers of other disciplines.

Mechanical design – like electronics – operates with physical products, and therefore it interacts with assembly and parts/materials purchasing tasks. Design also creates templates for production. Usually, some output files of mechanical design are used to create NC (Numeric Control) machine tool control programs.

2.4 Concurrent engineering

Concurrent engineering (CE) can be defined as follows [WiP88]:

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support.

Like co-design, concurrent engineering can be seen as one viewpoint to the system engineering process. It may stress concurrency aspects, for the shortening of the design cycle, or communication aspects, to ensure that all product stakeholders can participate in the early phases of the design process (Figure 10).

Concurrency decreases the design lead-time but also increases the amount of communication. Efficient communication is essential for avoiding unnecessary design changes and redesigns.

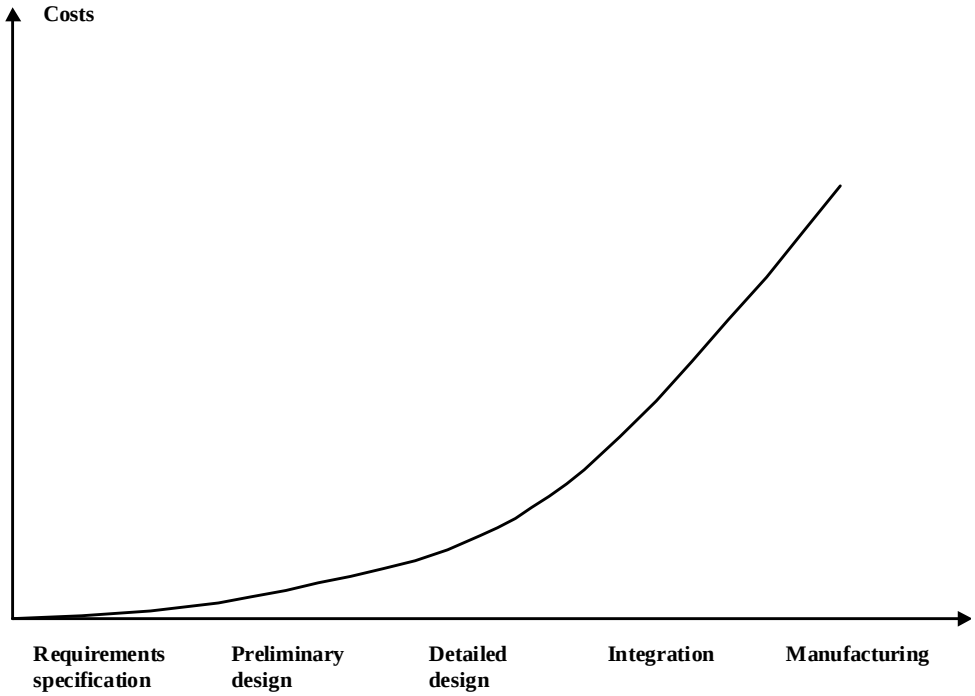

Figure 10. Cost of failure in the product engineering process.

2.5 Design data management

Systematic design has two main realms: design processes, and management of design data. According to Peter Van Hamer and Kees Lepoeter [HaL96], design data management can be divided into five orthogonal dimensions, which are also related to the processes. These dimensions are common to all technologies:

1. Version

Version dimension divides the results of a design into an order of versions. Usually a designer has to execute his/her design process iteratively which produces new versions. Engineering changes also produce new versions of the product. Because any earlier version could be the basis for new modifications, version management leads to a tree structure (Figure 11).

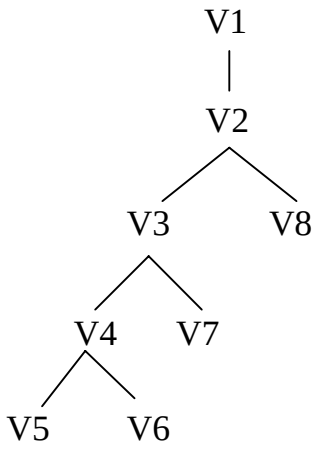

Figure 11. Example of the version tree. Version 6 has been created from version 4 and version 8 from version 2.

2. Views:

Products can be too complex to be represented by using just one description. There are usually many descriptions of the product and this dimension also has a close relationship with the design process. The design processes refine the product descriptions from an abstract level to a more specific representation.

3. Hierarchy:

Products decompose into sub-systems, assemblies, sub-assemblies and parts. The product hiearchy is called the product structure. For example, a printed circuit module can be divided into blocks, which represent the sub-systems (Figure 12).

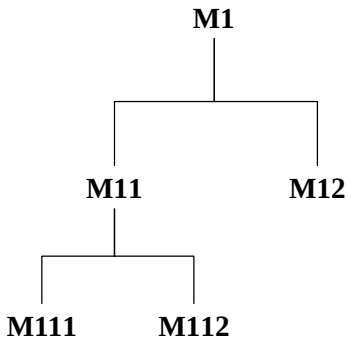

Figure 12. Hierarchical module structure.

4. Status:

Status reflects the evolution and control of design documents through the product's life-cycle (Figure 13). The change of the status does not require changes to the information itself. The engineering organisation has to decide when information meets certain requirements. Status also has an effect on the information visibility. For example, information with low status can be visible to the team and the same information promoted to the higher status can be visible to the department.

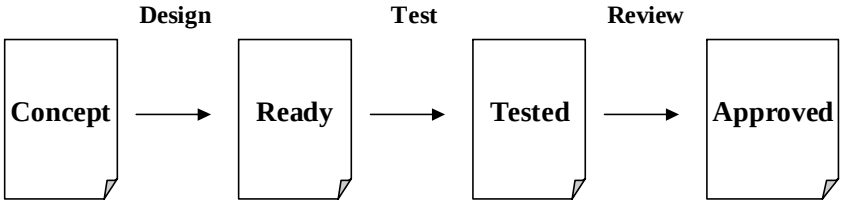

Figure 13. The picture illustrates the changes in the design status.

5. Variants:

Variants may be products, which are for example designed for different markets or computer programs, which have been designed for different platforms. The terms "version" and "variant" are often confused with each other. The term "version" refers to design evolution and "variant" to the development of families of related products.

In product engineering, several dimensions to documents and their relations have to be considered simultaneously (Figure 14):

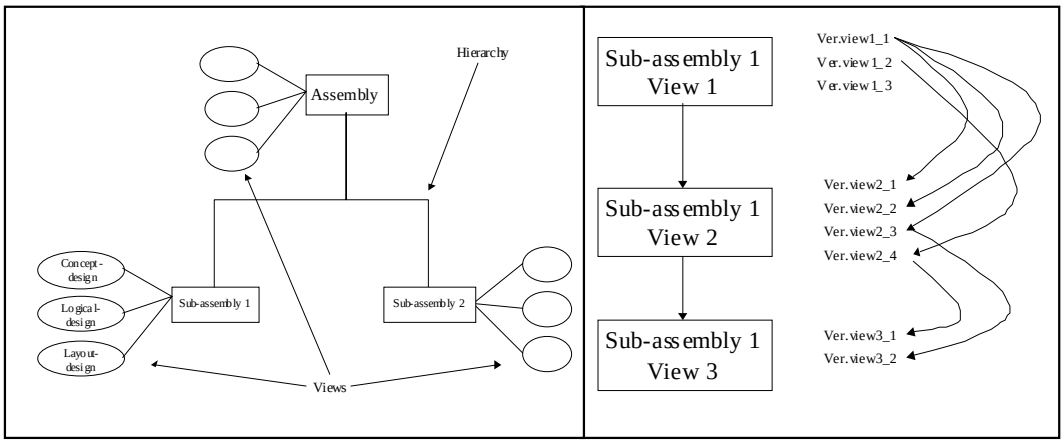

Figure 14. Hierarchical structure where several views exist and each view has several versions [HaL96, p. 48].

Document management aims to manage documents with respect to different dimensions. For example, the total amount of product configurations can be enormous. However, not all product configurations are allowed or useful so it is essential to save all useful baselines. The baseline is a formally reviewed and agreed configuration, which contains all appropriate documents at a certain moment [MaM97]. After the baseline has been reached, all changes will be made according to the appropriate change process [Ber92]. When the product consists of several technologies, it is essential that there is a unifying system which controls the configurations of the product.

3. PDM systems

The enterprise-wide design data management requires management of all product-related design documents which have something to do with product design, production and maintenance (maintenance needs e.g. assembly documents). The Product Data Management manages product-related data during a product's whole life-cycle (Figure 15) [MaM97]. Section 3.1 introduces the major groups of PDM functions. This section provides the basic classification of PDM functions, which can be used when considering requirements for enterprise-level design data management in the electronics industry. In addition, Section 3.2 introduces some PDM state-of-the-art trends according to articles, literature, and several PDM vendors.

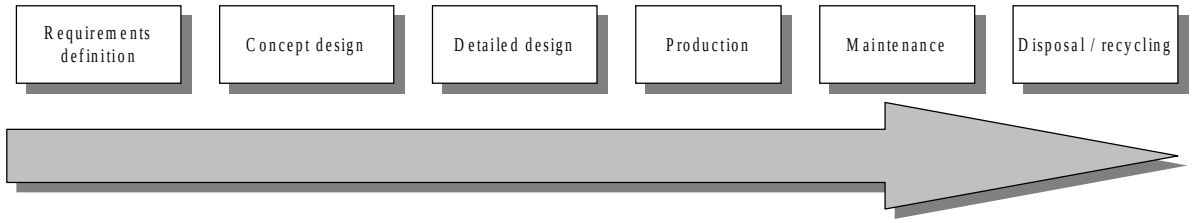

Figure 15. An example of a product's life-cycle.

The concept PDM is not very well-known. Therefore there are related terms such as [MaM97]:

- Engineering Document Management (EDM),
- Product Information Management (PIM),
- Technical Data Management,
- Technical Document Management (TDM),
- Technical Information Management (TIM).

3.1 Product Data Management (PDM)

The functionality of commercial Product Data Management systems depends on the purpose of the system. Traditional PDM systems focused on the data vault -function and managed mainly mechanical engineering data. This means managing CAD drawings, other picture formats and text documents. The data management capabilities are also common in workgroup systems used by workgroups and teams. In this report a PDM system’s functionality contains more than the data vault function and therefore it is reasonable to define parts of the PDM (according CimData) [MaM97]:

- Data Vault and Document Management,
- Workflow and Process Management,
- Product Structure Management,
- Classification and Retrieval,
- Program Management,
- Communication and Notification,
- Data Transport,
- Data translation,
- Image Services, and
- Administrator services.

The Data Vault and Document Management (DVDM) function is the core functionality of the system. It offers a secure, controlled storage for all the data (files, forms, etc) and the metadata, and also a tool for the system administrator. Metadata means data about data. For example, a text document's metadata could be the name of the person who wrote the document, a description about the content, the status of the document (e.g. concept, ready, approved), and the document's location (also a reference to non-digital data is possible). Search functions could use this metadata for information searching. It is possible to create this metadata by using a PDM system or it could be created by using a native application (e.g. CAD application). The Data Vault also controls data access with the check-in and check-out function and with the user-management function. The authorised users could check-out documents from the PDM system to modify them, for example. During modification the other users cannot access the document. After modifications the designer checks-in the document back to the system. The Check-in function makes the document "visible" in the system. The system should also allow multiple elements to be associated with the same part or assembly and maintain version compatibility when elements are changed. A system administrator can tailor the PDM system to meet a company's needs.

The Workflow and Process Management function (WPM) is used with the DVDM-function to create processes (e.g. software development process). Workflow Management Coalition [Wor99] defines a term "workflow" as follows:

The automation of a business process, in a whole or part, during which documents, information or tasks are passed from one participant to another for action, according to a set of procedural rules.

So, workflow is a specific representation of a certain process (e.g. sequential tasks). However, the use of concepts (process or workflow) depends on the PDM vendor. Processes can be site-defined (an enterprise or a department defines their own

processes) and process management makes sure that different processes will be made according to the site-defined rules (e.g. who is authorised to approve documents). WPM includes methods for incorporating changes into the released and baselined product data. The system administrator defines processes and user authorisation.

With the Product Structure Management (PSM) function it is possible to create, manage and maintain part list, assembly, product configuration and bill of material (BOM) structures and link the PDM managed items to these structures (e.g. drawings and supporting documents). It should also extend these basic structures into a more complete product structure, with relationships such as options, versions, substitutes, and effectivities added. Functionality also enables easy search, access and user-defined view-functions to the structures and items. The system provides graphical viewing (easy browsing) of the structures and the possibility to link other data items (like specifications) to the structure. PSM should also allow the user to define alternative, substitute and optional parts within the product structure, likewise a definition of the relationships of the versioned parts. The system administrator creates and maintains authorisations to the users to access, create and modify the product structure.

With the Classification and Retrieval function it is possible to define attributes to the product data (metadata). The attributes could be related to a part, assembly or relationship (Figure 16). The authorised users can search parts with these attributes. It is also possible for a PDM system to organise and present product data according to these attributes (Figure 17). Modern classification systems also allow the organisation and presentation of standard parts in a hierarchical manner. These systems allow component retrieval and reuse.

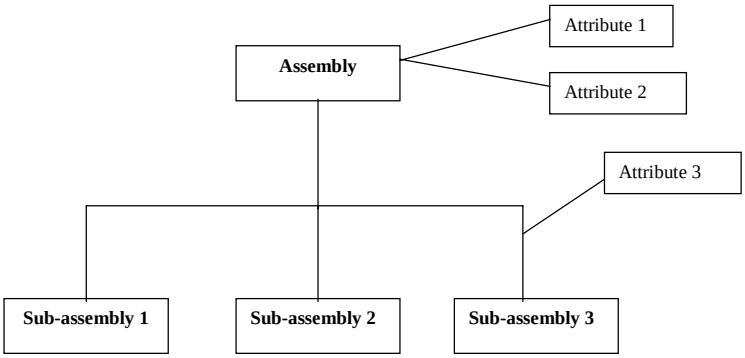

Figure 16. Attributes in a product structure.

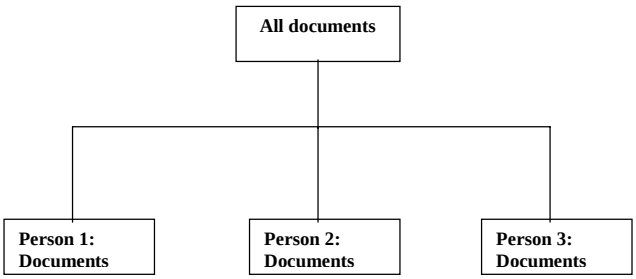

Figure 17. Product (document) structure according to authors.

Program Management (PM) offers integrated, computer-based project management. Its main function is to create and modify a Work Breakdown Structure (WBS). The WBS includes major tasks, sub-tasks and detailed tasks. The PM assigns resources and expenditures to these tasks. The PM allows users to relate detailed WBS tasks with the PDM controlled elements.

Communication and notification is essential for the concurrent design environment. Users should be notified about tasks and changes (perhaps automatically). Also, day-to-day operations need communication. Communication should be possible with the system's e-mail application or with external e-mail application (this requires an interface).

The Data Transport isolates users from the network and operating system commands. The system automatically transports files and other data, even in heterogeneous hardware and software environment, to the user workspace.

The Data translation is essential for achieving an integrated working environment (it prevents isolated islands). The Data transport may also need the data translation function when exchanging data between two applications or systems (data exchange). This is made possible by using data translation from one application's format to another format. The use of a neutral standard format is possible (e.g. STEP) and data translation can be performed automatically before executing the next task during workflow execution.

The Image Services makes it possible to work with the appropriate picture formats. The basic functionality is the view function, which can be used in change review processes. In addition, the user can perhaps redline or edit images.

The System Administrator has a huge role in the implementation of the PDM system. The administrator makes required customisations of the system, defines meta-data and creates user authorisations. Enabling the distribution of the PDM data is essential in heterogeneous hardware, software and operating systems environments.

When PDM is considered as an information system it is possible to define some requirements for it based on the development process [PiM96]:

- the information system has to support a work methodology with baselines (document development until a baseline is reached, then the document is frozen),

- the system has to support stage overlapping between product development phases,
- the system must support all documents produced during the project, and
- the system must offer access to this data.

3.2 State-of-the-art trends of PDM

Traditional PDM systems had centralised data vault functions and change management. This centralised model no longer meets companies' requirements in the new business environment. Nowadays the companies globalise functions, differentiate products and try to focus on certain market segments. This development has created a close collaboration with sub-contractors, suppliers, and vendors.

All this meant was that when using old PDM systems, massive centralised PDM-data and administrative data control was necessary. Independent sub-contractors are also reluctant to allow other companies to control their data. PDM vendors have to adapt to this situation and provide federated solutions where local administration is possible (Figure 18).

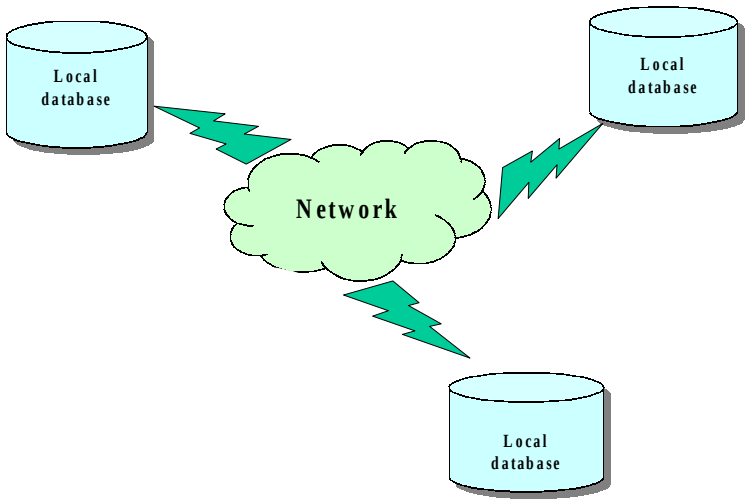

Figure 18. Independent organisation and centralised data management.

Many early PDM systems were developed by mechanical CAD (MCAD) vendors to help manage files [MaM97]. Thus, PDM systems have well-established techniques in the field of mechanical engineering design, but other technologies have been left with minor attention [Sto99]. For example, the need for electrical CAD (ECAD) applications data management has led to the creation of modules that offer some limited PDM functions for the certain design tool (e.g. tools frameworks can contain this kind of functionality) [MaM97]. Nowadays the products are complex and the design combines many different technologies. Embedded software has particularly become an alternative implementation technology for electronics [Tar98, AyJ96]. One reason for this is versatility. PDM deliverers already provide some integration with the software, ECAD

(electronic computer aided design) and publication tools [MaM97]. In the future, PDM systems may also replace the lower-level frameworks and provide data management services directly for design tools [MaM97].

Concurrent engineering (CE) strategy allows different design-participants to work concurrently which gives the company the possibility to decrease costs and reduce a product's time-to-market [Hei97]. PDM systems support CE by providing easy communication, early access to the design data and data exchange functions.

The rapid development of Web-technology and the Internet has an effect on the PDM systems user interfaces. Java-based user interface will replace traditional client-based interfaces because Java offers platform and operating systems independence (Figure 19).

An ERP (Enterprise Resource Planning) system controls a company's whole production chains operations that includes such things as contract management, production, and procurement. Figure 3 in Chapter 2 represents manufacturing flows. The flows of material, product, customer and purchasing are under the control of ERP, and a product's design is under the control of PDM. However, there is some overlap between PDM and ERP (e.g. BOM). This overlapping causes difficulties when systems have to maintain integrity of data. The integration of these systems creates better life-cycle management of the product data.

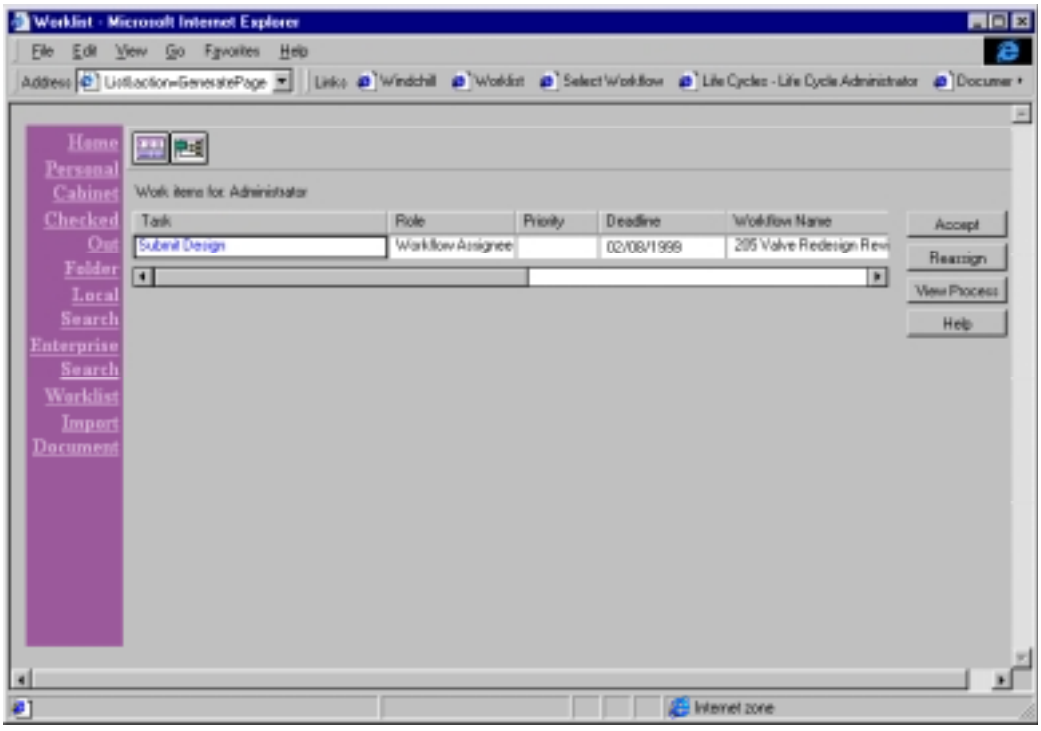

Figure 19. Windchill-system Java-based user interface.

Other trends are the increasing use of object technology, project management integration and focused solutions. The project management integration will integrate resources (persons and costs) into the product data management. By using this feature it is possible to consider the state of the project and project documents as well as to consider resource allocation. Focused solutions solve specific problems in particular industries or processes [Mil99]. This specialisation allows e.g. quicker implementation and contains specialised terminology as well as discipline-specific reporting formats [Mil99].

4. Data exchange

Data exchange exists between tools, organisations and people (globalisation, sub-contracting). For example, an engineer creates a design and sends it to the next engineer for modifications. The data translation may be essential, for example, because the first engineer's design tool does not include all required features. The next engineer may have difficulties working with the information created by the first engineer. This situation arises because the data that the first engineer created can be structured and represented using data format which the receiver does not recognise.

Data exchange is possible, for example, via shared databases, but still the basic problem remains: how can different systems understand each other? This chapter represents some standards which can support the data exchange between systems. Section 4.1 contains a general introduction to the problem. Section 4.2 presents the architecture of the STEP standard which is used in CAD data exchange. The section also represents PDM Schema which provides a neutral format for the product data exchange. Section 4.3 presents the CDIF standard which is used for CASE data exchange. Section 4.4 introduces the SGML standard which is used in document exchange.

4.1 Data formats and translators in data exchange

The different data formats are a problem when exchanging data between two systems. This problem can be solved by using translators, which translate data from one format to another (the receiver needs to understand the sender's data format) (see data translation in Section 3.1). This solution is efficient if there are only a few tools which need data exchange. Figure 20 illustrates a situation where data exchange is needed between four design tools.

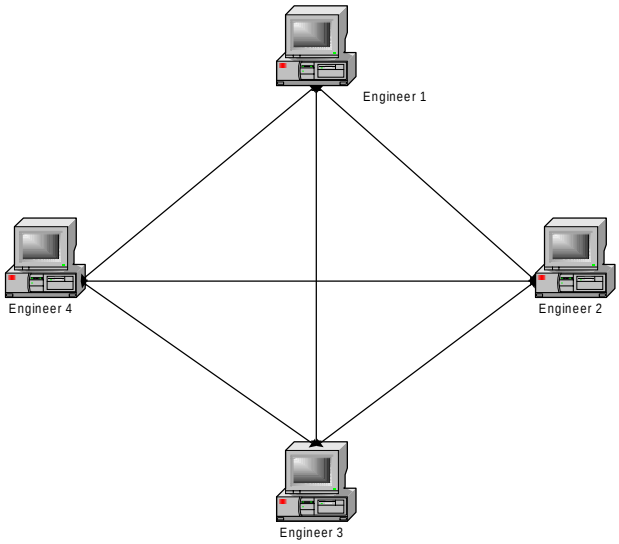

Figure 20. Data exchange between different design tools using translators.

Each design tool communicates with three other systems. In the worst case, "engineer 1" requires six data translators, three for data export and three for data import. So the need for a common exchange format is obvious in heterogeneous environments.

There are three other approaches when considering solutions for information exchange [Sää98]:

- "total software" that includes all the necessary software components to do the engineering task,
- a common communication language (tool or discipline specific), and
- a standard that aims to handle all kinds of data (e.g. STEP).

"Total software" is a good solution but is hard to implement (all users should have the same applications). The second approach is tool or discipline specific and therefore it is not very versatile. In an ideal situation there is no need for the native formats because every application produces and reads the same standard format (regardless or the type of the data: text, picture, voice, etc.). The last approach aims to provide a standard for data exchange that can handle all kinds of information relating to a product. [Sää98]

There are several standards and de facto standards for data exchange. For example, data exchange between these tools is possible with the use of the DXF (Drawing Interchange Format) or IDF (Intermediate Data Format) format. DXF is AutoDesk's de facto standard. IDF provides a neutral representation for exchanging printed circuit assembly data. This kind of data exchange is essential because of printed circuit board geometrics (keep-in, keep-out-areas, vias, board geometry), among other things. However, this report focuses on three standards: STEP, CDIF and SGML.

4.2 STEP (STandard for the Exchange of Product model data)

Nowadays, companies globalise their functions, and applications must run in different hardware and operating system environments. Easy data transfer from one application to another is important. The design and data modelling techniques are also in continuous evolution and therefore it is important that tools can be extended to take advantage of new and innovative techniques without data exchange problems.

The STEP standard's initial release was approved by the ISO-Standard (ISO 10303) in 1994 [PeT98]. The basic idea of STEP is to enable organisations to share and transfer product data between different computer systems and environments [MaM97]. The following list contains the basic components of STEP (the classification is based on the ISO 10303 standard) (Figure 21) [Ind94].

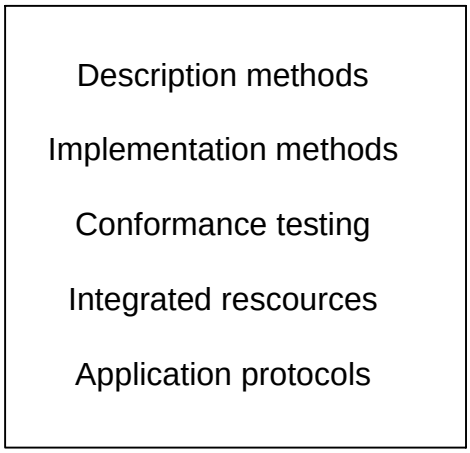

Figure 21. The basic components of STEP.

1. *Description methods* describe a common mechanism for the specification of data. Integrated resources and application protocols are expressed using EXPRESS, which is an object-orientated data modelling language. EXPRESS-G is a subset of EXPRESS, supporting the graphical notations of schema. The basic aspects of EXPRESS are:

- schema: a collection of related information,
- entity: a real world concept (object),
- attribute: the property for the object, and
- type: a representation of value domains (also an ordered set of values is possible).

The next example illustrates these aspects by using EXPRESS (Figure 22).

```
TYPE week_day = ENUMERATION OF
(Monday,
 Tuesday,
 Wednesday,
 Thursday,
 Friday,
 Saturday,
 Sunday);
END_TYPE;

ENTITY Information;
name : STRING;
age : INTEGER;
day_off : week_day;
END_ENTITY;
```

Figure 22. Employees' day-off information defined by EXPRESS.

2. *Implementation methods* include implementation techniques for the information structures defined in the application protocols. An ISO 10303-21 defines text encoding for the exchanged data (Figure 23). This physical STEP file can be used to exchange data. SDAI (Standard Data Access Interface) (ISO 10303-22) is a programming language independent application programming interface for STEP data. By using SDAI designers can access the data defined in EXPRESS.

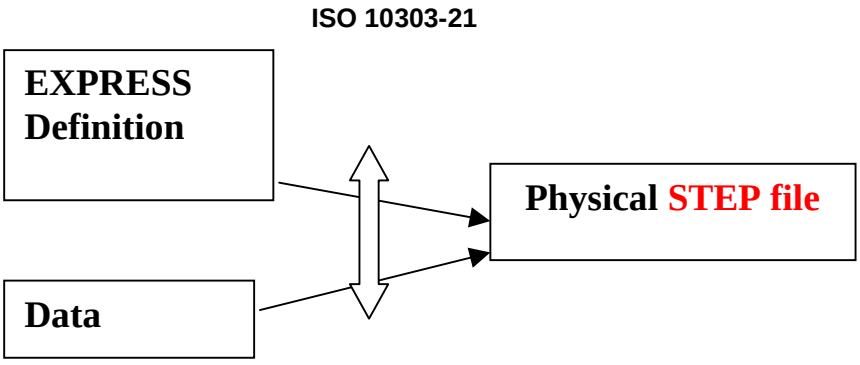

Figure 23. ISO 10303-21 defines encoding of data when exchanging information.

3. *Conformance testing* provides data which is used to test the conformance of a given implementation.

4. *Integrated resources* contain generic and application resources. The generic resources are application-context-independent data constructs which constitute the minimal set of entities (generic data structures) that are used by all application protocols (AP). The application resources can reference the generic resources and add other resource constructs for use by a group of similar applications [Ind94].

5. *Application Protocols* (AP) interpret integrated resources to meet the product information requirements of specific applications [Ind94]. So, integrated resources are not intended to be implemented directly. The interpretation is achieved by selecting appropriate resource constructs and refining their meaning by specifying any appropriate constraints, relationships, and attributes [Ind94]. So AP represents the data for the specific product or industrial needs. We can consider AP as a selective filter. It specifies those generic concepts from the Integrated Resources that are needed for a particular purpose and defines the meaning of these generic concepts in the specific context of the application. The STEP data file used for data exchange, defined in Part 21, is then defined by the AP and can be implemented in the computer software so that the use of Standard becomes transparent to the user. There are APs for example for electronic design and installation (ISO 10303-212).

STEP supports four levels of data sharing and transfer [MaM97]:

1. File exchange: data is exchanged between systems or applications using STEP exchange files (physical STEP file).

2. Working form exchange: data is shared with the use of a working form, which is normally a common file shared by the systems.

3. Shared database: data in STEP format is available in a shared data environment (controlled by DBMS (Database Management System)). The database provides concurrent access to a STEP database from multiple applications.

4. Knowledge base: data is shared within a Knowledgebase Management System promising to provide advanced tools for virtual and distributed enterprises (e.g. expert systems).

PDM Schema is a reference information model for a central, common subset of the data being managed within a PDM system. It represents a set of common requirements and data structures from a range of STEP Application Protocols, all generally within the domains of design and development of discrete electro/mechanical parts and assemblies (Figure 24). [Usa99]

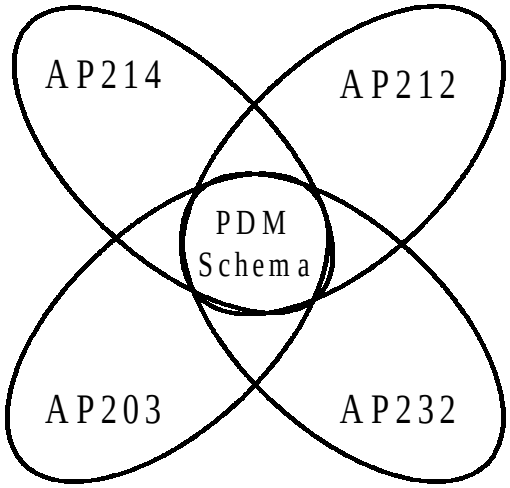

Figure 24. PDM Schema as a subset of four application protocols [Usa99].

The PDM Schema is a subset of the PDM related application protocols [Usa99]:

- AP203: Configuration Controlled Design,
- AP212: Electrotechnical Design and Installation,
- AP214: Automotive Design,
- AP232: Technical Data Packaging.

It contains the following modular semantic units of functionality [Usa99]:

- Part Identification,
- Part Classification,
- Part Properties,
- Part Structures and Relationships,
- Document Identification,
- Document Classification,
- Document and File Properties,
- Document Structure and Relationships,
- External Files,

- Document and file association to product data,
- Alias identification,
- Authorisation,
- Configuration and Effectivity information,
- Work Management data.

The next example (Figure 25) represents how a product structure is defined with the use of PDM Schema (STEP file example). A-1 is an assembly and P-1 and P-2 are the product's components.

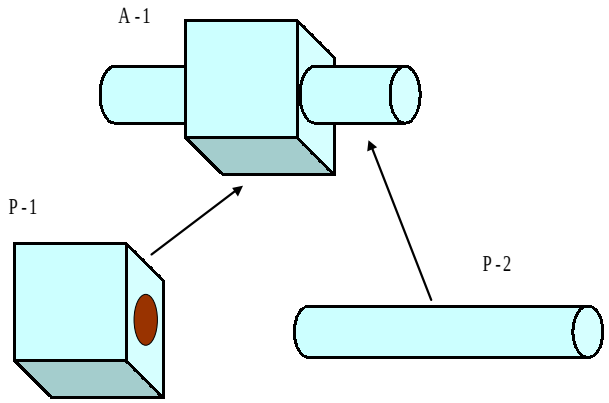

Figure 25. A simple product structure.

The example contains one assembly and each component has only one version and life-cycle view. This means that there is only one configuration. If there were several versions from the components, the total amount of configurations would increase.

ISO 10303-21 describes physical text encoding for the STEP exchange file. The next STEP file example represents previous assembly (only configuration information) (Figure 26).

```
...
/* STEP excahange file format that contains assembly information.

#10 = APPLICATION_CONTEXT('');
#20 = PRODUCT_CONTEXT('', #10, '');
#30 = APPLICATION_PROTOCOL_DEFINITION('version 1.1', 'pdm_schema', 1998, #10);

/* assembly and part instances
#40 = PRODUCT('A-1','A cube with a dowel', '',  (#20));
#50 = PRODUCT('P-1','Cube', '',  (#20));
#60 = PRODUCT('P-2','Dowel', '',  (#20));

/* life-cycle instance (available lifecycles)
#70 = PRODUCT_DEFINITION_CONTEXT('part definition', #10, 'design');

/* version instances (no multiple versions)
#80 = PRODUCT_DEFINITION_FORMATION('1A-1', '', #40);
#90 = PRODUCT_DEFINITION_FORMATION('1P-1', '', #50);
#100 = PRODUCT_DEFINITION_FORMATION('1P-2', '', #60);

/* view instances (one view for each component)
#110 = PRODUCT_DEFINITION('Assembly view', '', #80, #70);
#120 = PRODUCT_DEFINITION('Cube view', '', #90, #70);
#130 = PRODUCT_DEFINITION('Dowel view', '', #100, #70);

/* instances that define the product structure
#140 = NEXT_ASSEMBLY_USAGE _OCCURRENCE('CP-1', 'Assembly instance of cube', 'Cube', #110, #120, $);
#150 = NEXT_ASSEMBLY_USAGE _OCCURRENCE('CP-2', 'Assembly instance of dowel', 'Dovel', #110, #130, $);
...
```

Figure 26. Part of the STEP exchange file, which represents assembly information presented in Figure 25.

However, the PDM Schema is not a specification for the complete PDM system functionality.

To conclude, STEP contains product and industrial specific Application Protocols (it specifies the representation of product information) which is based on a common foundation (generic resources). The standard is not easy to adopt because not all PDM systems support STEP. The solution for these problems can be the PDM Schema, which is a subset of PDM-related application protocols.

4.3 CDIF (Case Data Interchange Format)

The Electronic Information Group (EIG), established in 1993, consists of five divisions: CDIF, DAD (Design Automation Division), EDIF (Electronic Design Interchange Format), EIDX (Electronics Industry Data Exchange) and IAD (Industrial Automation Division). Each of these divisions cover a different domain of information exchange solutions for the electronics industry.

CDIF is a family of standards, which can be used to exchange data between two CASE tools (Computer Aided Software Engineering) (Figure 27) [CDI99a]. The goal of the standards is to allow modelling tools to understand each other. The CDIF focuses on the description of the information to be transferred, not on data management. It defines the information content, the transfer mechanism and interfaces, but not implementations.

Figure 27. CDIF transfer [CDI99a].

Information exchange between design tools is important because companies use several design tools with different capabilities, and information consistency between all these tools is essential. The CDIF defines layers of information (meta-layers) (Figure 28) [CDI99a].

User Data contains physical information. This data is not relevant for the CDIF standard (CASE tools produce model-data). The Layer Model describes this User Data. For example, the model can explain that a system includes Order data and Customer data (Order Processing System), and according to this model one customer can have one or multiple orders (Figure 29). Layer User Data then allows the description of information according to these rules. In data exchange the model-data is exchanged between CASE tools.

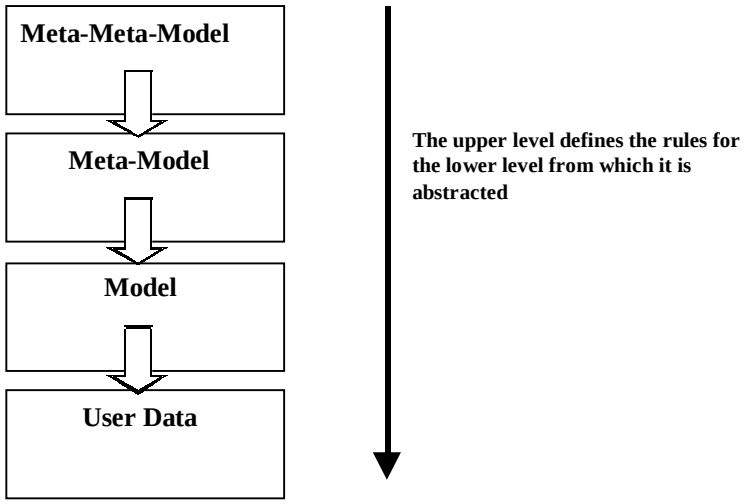

Figure 28. Layers of information [CDI99a].

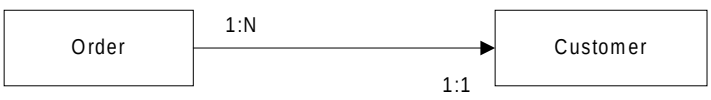

Figure 29. Data model [CDI99a].

The Meta-Model defines the standard structures and data which are allowed when data models are described. A Meta-Meta-Model defines meta-data structures for the Meta-Model. The Meta-Meta-Model is defined as a standard EIA/IS-107. So, the Meta-Meta-Model defines rules for the Meta-Model which in turn defines rules for the Model.

CDIF separates the definition of what information is transferred from the definition of transfer format (Figure 30) [CDI99a].

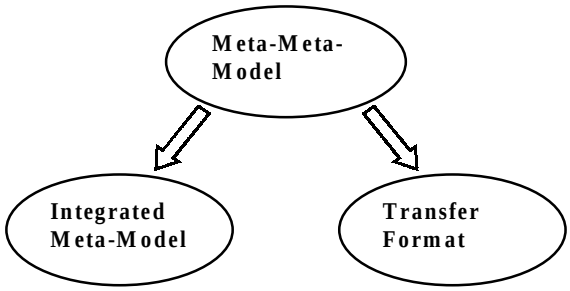

Figure 30. Architecture of CDIF [CDI99a].

The Integrated Meta-Model is a standardised meta-model and it attempts to provide definitions for all the information of the CASE tool. This is not easy to define because Software Engineering is continually developing. Therefore, the Integrated Meta-Model provides definitions for small areas called "subject areas". Each subject area is a separate standard (e.g. Data Flow Model Subject Area / EIA/IS-115). If these common areas don't support a certain information definition need, it is possible to extend these definitions. These extensions must be well defined. [CDI99a]

When a model is transferred from one system to another, both the systems must have a complete Meta-Meta-model and Meta-model. In addition, a complete definition of the transfer format is required. A CDIF transfer contains a Transfer Envelope and Transfer Contents (Figure 31). The Transfer Envelope defines a CDIF signature, syntax, and an encoding. The signature identifies the transfer as a CDIF transfer. Syntax and encoding that will be used in the transfer is identified by Syntax Identifier and Encoding Identifier. [CDI99b]

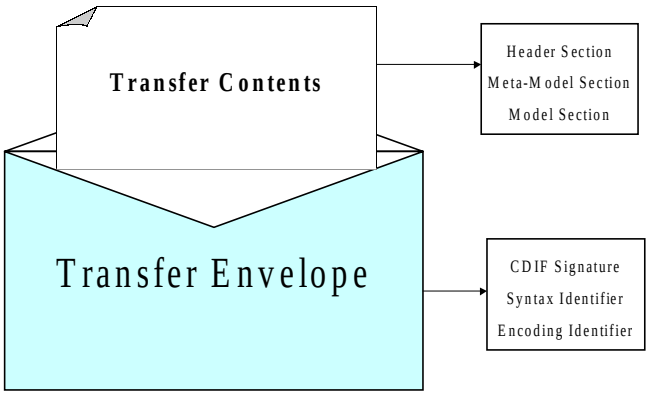

Figure 31. CDIF Transfer [CDI99b].

Transfer Contents contains a Header, a Meta-Model and a Model. The Header Section is not mandatory. It can contain information about the transfer (e.g. name and version of exporting tool, publisher, date and time). The Meta-Model section defines the subject areas and the Meta-model extensions that are used in transfer. This section contains a reference to the subject area (defines which subject area is used), and the extensions that extend the information model (non-standardised definitions). The Model Section contains instances of meta-entities and meta-relationships (model data). [CDI99b]

When we consider the CDIF and the STEP, some similarities can be found. Both of them have a layered modelling framework. The STEP has process and data models and the CDIF model levels. They both organise transfer standards into the domains. The STEP has the Application Protocols and the CDIF the subject areas. However, the STEP covers almost all product definition aspects when the CDIF focuses on information technology systems. [Joh99]

4.4 SGML (Standard Generalized Markup Language)

Documents are produced by using different applications (different data formats) and platforms. Different data formats are a problem when exchanging data in this heterogeneous environment. So, a standard for representation of document structure is essential. The SGML standard was released in 1986 (ISO 8879). The basic idea of this standard is to achieve software and platform autonomy when storing text documents. It also distinguishes document content from its styling. By using SGML it is possible to create descriptions for logical structures of different kinds of documents (meta-language). The SGML does not interfere with the way in which the applications represent documents.

An SGML document consists of an SGML Declaration, Document Type Definition (DTD), and the instance of the document. The SGML Declaration gives the precise details of how SGML is applied to a certain document as well as describing a character set (ASCII, EBCDIC, etc) and special characters (e.g. < and >). The DTD defines the structure of a document. All documents must have DTD. It can be stored internally in

the document, or externally (the document contains it or has a reference to the file which contains DTD). The document instance is the document itself. Its contents have been marked by using DTD. [Her94]

A company's design process produces the product data and technical documentation. The Commission of the European Communities partly the funded DOCSTEP project which tries to integrate product data and product documentation. The product data can be represented by using the STEP standard and the technical documentation by using SGML. [ElK97]

The structured documents can provide better retrieval when the user searches for information. It is possible to search and parse information from documents according to the structures, and represent information found using an appropriate format (e.g. search from SGML documents and represent found information to the user by using an HTML (HyperText Markup Language)). HTML is an SGML-conformant markup language [Mau96]. It defines a document's layout but it does not define what kind of information it contains [Haro98]. XML (Extensible Markup Language), which is actually a subset of the SGML, allows the definition of the document's content [Haro98].

5. Requirements of design data management

This chapter defines the requirements for the embedded product's design data management. Section 5.1 contains a short introduction to the business and design environment. Section 5.2 considers requirements in an embedded product's design. Section 5.3 collects the requirements from the previous consideration and presents them in table format. This framework will be used when analysing different commercial solutions for the design data management in Chapter 7.

5.1 Introduction

New products have become complex and their design processes produce more and more data. Customers require more customised products and better quality. In addition, the design process needs specialists from many disciplines. Companies also focus on their core know-how and hive off other functions to subcontractors.

Companies have to globalise design and manufacturing, and operate without the restrictions of physical distance or time [TaA99]. This globalisation of design is called "global design", which includes spatial and time globalisation [TaA99]. Spatial globalisation contains design co-operation and the time globalisation reuses past designs and accumulates design expertise [TaA99]. This development increases external communication and requires efficient data exchange. Also the integrity of the information is essential when a company operates in the global design environment. In addition, in large organisations, terminology can differ between departments as well as between computer systems, which complicates communication [SvM99].

Mass customisation means the customisation of products and services for individual customers at a mass production price. This approach allows the company to meet demanding customers' needs [Soi97]. The basic idea is that the product is customised when it is sold. The customer can, for example, interactively define what kind of products s/he wants. This kind of approach needs modularity and product variation management [Soi97]. In this case, information about the exact configuration containing design data is essential for good maintenance (what kind of product the customer has bought and what kind of design documents relate to the certain delivery).

5.2 Requirements for the embedded product's design data management

According the previous analysis in this report it is possible to define a requirement for the enterprise-level design data management of a multi-technological product:

A design data management system of enterprise which operates in a global design environment should be able to collect, save, provide access and manage all the (useful) design-related information of a multi-technology product, distribute this information and also support a company's working methods during a product's life-cycle.

This definition includes the following main parts:

- data management,
- process and life-cycle management,
- data capture & distribution, and
- support for working methods.

The next sections consider each of these parts. This classification is not strict, for example during the change process version management and product structure management is required. So, these parts support each other.

5.2.1 Data Management

Data management should provide data vault, product structure management, classification, retrieval and document management. These functions are defined in sections 2.5 and 3.1.

The configuration of a multi-technological product contains components and sub-assemblies implemented by using different technologies. The information system should be able to construct a description of this multi-technological configuration including embedded software. Nowadays, manufacturers fail to manage software as an integral part of a whole product's design [Mil98].

Embedded products can have the same mechanical configuration but differences are constructed by using embedded software [Mil98]. So it is possible to carry out customer specific features by using embedded software [Sep97]. An embedded product's structure can also contain e.g. HW/SW interface documents and other non-hierarchical relations, which requires the management of items relationships [Tar98].

The design of a software system needs tools which build software products (software program build using the right modules and configurations). These SW configurations are based on certain baselines and tracking this information is needed. For example, maintenance needs to know which item versions have been used in a certain product release. Information about customers is also required (what kind of configuration has someone bought) [AuT96]. All parameters and flags used in the software build should also be saved [Leb94]. The version control needs to manage version history (all design documents) and to allow the tracking of previous versions [Leb94].

As mentioned in Section 2.3.1, parallel modifications are needed in software design, and therefore the system should allow multiple copies from one item and control how to merge these items when checking in (Figure 32). [Wil97]

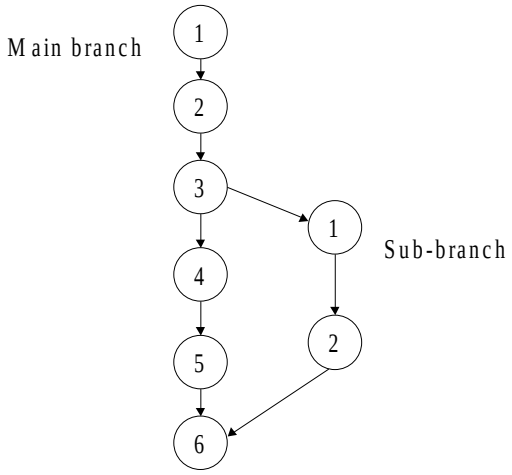

Figure 32. Multiple copies, parallel development and merging.

Engineering changes were considered in Section 2.2. Software changes differ from hardware changes [Ber92]. Hardware is a set of physical parts but software is intangible [Ber92]. If you want to examine the reason for the error you have to sometime examine both the software and the hardware [Ber92]. By using impact analysis it is possible to recognise the impact of changes when e.g. HW change is performed [Tar98]. This requires the definition of relationships between components.

5.2.2 Process and life-cycle management

Process (see Section 3.1) and life-cycle management has a strong connection with the production and use of data. Companies perform duties according to certain processes. When they are performing a certain task they may need to link some support information to the task, or the purpose of the task may be to produce information (e.g. drawing). So this function links design documents to the company's processes.

The importance of software has rapidly increased and this development needs process and life-cycle automation which keeps track of e.g. who is working on what, which module a designer is responsible for, what kind of tests each module has passed, etc [Wil97]. Life-cycle management saves information about these objects (designs, documents, configurations, etc) and controls how these objects mature during a product's design process.

In addition, production process planning has to be a part of a whole product's development when considering electronic products [Kiv98]. The designer needs to understand how different materials match from a physical and chemical point of view when manufacturing the product [Kiv98].

5.2.3 Data capture & distribution

The development of an embedded product contains several discipline-specific design processes (see Section 2.3) (Figure 33) [Rah99]. Communication and co-development technologies between these processes are important [Hei97]. The system should provide information for global distribution when necessary. It should also allow users to view and comment on design documents without using native design tools.

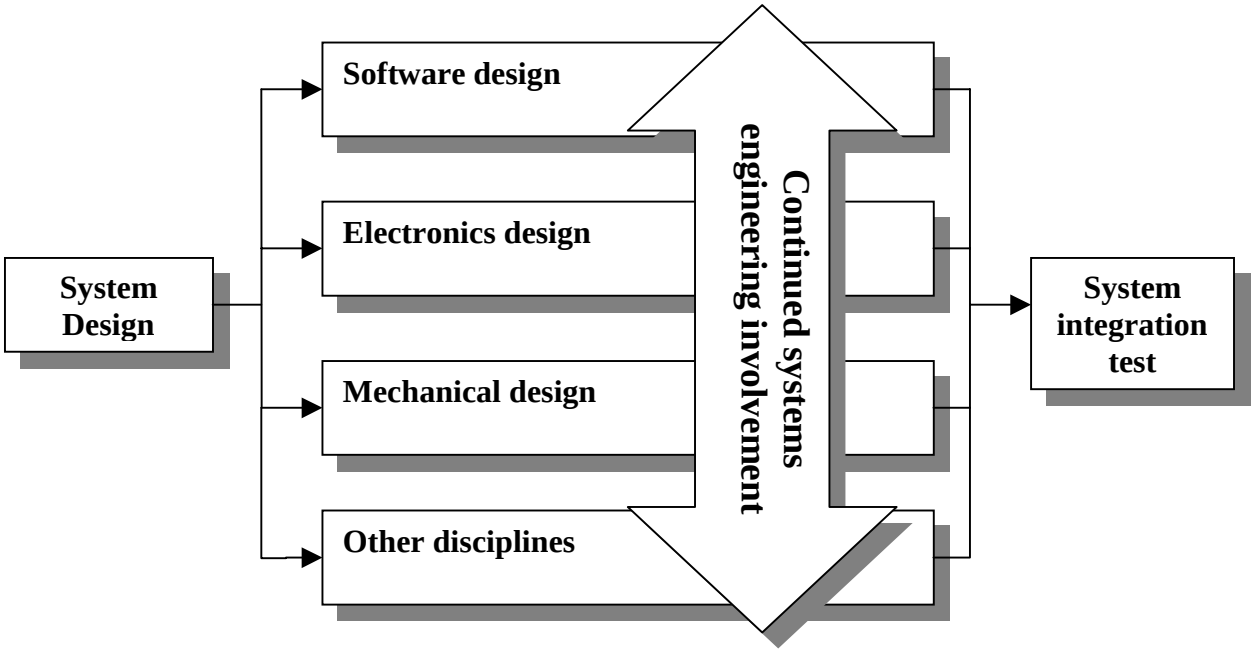

Figure 33. Co-operation and communication between technical design processes.

The integration of a design tool and a data management system is essential in enterprise level data management. Data management systems do not create new product information, they only help to control it. The design process of multi-technology products include multiple design tools and design systems (these tools and systems create product information). Within a design team the data is usually easier to manage (design team data management solutions) but these kinds of solutions do not solve the enterprise level data management problems. These solutions only create "automated islands" inside which the data management is well realised, but information exchange between the teams remains difficult. Anyway, all this information should be visible in the organisation, which requires tool integration and data exchange.

Fast and accurate data exchange during a product's life-cycle is essential to the company because transfer doesn't refine exchanged information. The data being moved between two systems must be translated from one application's format to the other’s, or they must use a standard format common for both parties [MaM97]. Different users also need different kinds of information and they also have requirements of how the information is represented.

The International PDM Users Group (IPDMUG) represents requirements for the integration of PDM and ECAD (data-objects and functions). Data-objects required are ECAD design database, engineering BOM file and viewable images. The functions contain e.g. Check-in/out, copy out, and data compaction functions. In addition, IPDMUG defines some objects and functions, which provide additional value to the user. IPDMUG includes additional features for the data-objects and a whole new object-type. First, design database should include a simulation database. Second, the BOM should also contain component substitution capability. Third, images should contain manufacturing and assembly notes. Finally, one object-type was added: derived files (like board fabrication files). [Ele99]

The functions which provide the additional value to the user are: [Ele99]

- integration with component management system,
- integration with the ERP system, and
- process (workflow) integration between PDM and ECAD design tools.

5.2.4 Support for working methods

Different working methods can provide a company with better time-to-market, among other things. These methods may also have requirements for the company's information system. This report focuses on two methods (or principles): concurrent engineering and knowledge management. Actually CE is a collection of several methods, tools and human factors [Hei97], but in this report it is referred to as a working method or principle. The rest of this section considers both principles. These principles are useful for all kinds of production (not only for the production of an embedded product).

The information system should provide tools and features which support a company's working methods. For example, nowadays, enterprise level PDM systems (EPDM) provide features that support concurrency during a product's design. However, these features don't automatically bring the Concurrent Engineering (CE) principles into the company. CE needs commitment and a strategy, and the information systems only provide some tools for it. Section 2.4 offered a quick glance at the CE.

PDM systems are useful for concurrent engineering because they offer product data throughout a company during the product's life-cycle. During a design project, data should be represented along with the product data (project and product documentation). Then it is easier to consider the design project's state and documents. Also the integration of development teams is important when one considers concurrent engineering. The integration mechanism can be described with five dimensions according to Figure 34. The sequential work methodology is on the left hand side and concurrent on the right. [PiM96]

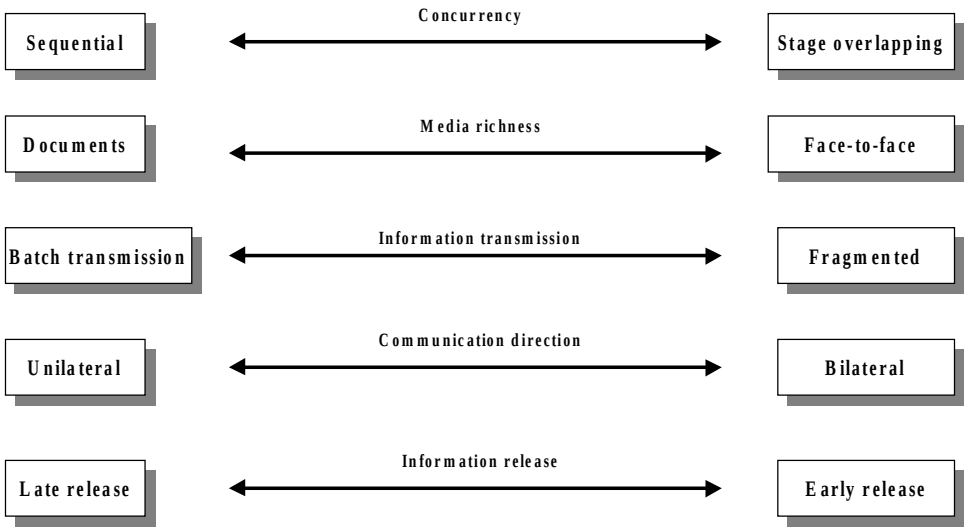

Figure 34. Dimensions of the integration mechanism [PiM96].

The concurrency considers how much overlapping there is between design phases. This overlapping between stages requires good communication and good data exchange. The media richness means the "quality" of the contact between designers. It could be, for example, just document exchange or more physical contact (video, audio) between designers. The information transmission considers how the documents are transmitted to the system. The fragmented approach transfers a document to the system directly when the document is ready for it. The communication direction should be bilateral, which supports feedback and comments. The information release has an effect on concurrent engineering. The early release supports concurrent work by providing the early visibility of information (preliminary information can have e.g. "draft" status). [PiM96]

The PDM should also automate certain non-value adding processes like document reviews. This means, for example, automatic notification and automatic workflow progress after specific tasks. [PiM96]

PDM systems also provide features that support the management of knowledge in a company. Knowledge includes information, experience and skills. Knowledge Management is complex, and it contains [Lah98]:

- a network containing people and machines,
- a recognition of what the organisation knows and what it should know, and
- the creation of means that distribute this information.

Design knowledge contains all the information which is needed to design a product [Kor96]. This information contains e.g. drawings, specifications and all decisions during the design process. This knowledge can be captured for example in a design review

(decisions and comments are documented) and these documented decisions should be attached to the appropriate product structure or component (design and project data integration). The design knowledge can be divided into two main parts: product-related knowledge and design related knowledge [Kor96]. Product related knowledge is a designer's description of the product. The design-related knowledge contains all the design decisions, the reasons for these decisions, and the design history (e.g. partitions, see Section 2.3.3). A data management system should be able to collect, store, and share this information.

5.3 Requirements for enterprise-level design data management

These requirements have been collected from the previous analysis. When using the word "product", we mean especially an embedded product. Table 1 contains requirements (or features) based on product development, PDM classification, data exchange, and embedded product design consideration.

Table 1. Classification for design data management of an embedded product.

Data Management:	***How to manage all the data?***
Data vault and document management	-support for all data types -user definitions, access and security functions (administrator) -meta-data and files or links to files (also external repositories but central management) -check-in / check-out-functions -document version management (also possibility to parallel development)
Product structure management	-product structure creation -multi-technology product (include SW, HW, and other modules) -structure from workgroup-tool or design-tool -also manual creation and modification -configuration creation and modifications -configurations & customers management (what kind of design documents relate to a certain delivery) -also non-hierarchical relations -supports document incorporation to the structure -user-defined views to structure (as-manufactured, as-planned) -graphical view, search, navigation -automatic bill of material (BOM) creation -possibility to define substitute components and reconstruct past configurations -software build
Classification and retrieval	-part (component) management, retrieval, reuse, and classification (including suppliers and other information) -attribute (meta-data) definition to parts, assemblies, documents, and relations -possibility to search documents according to different attributes and content -information representation according to classification rules (e.g. part families)
Process and life-cycle management:	***How to connect data management to a company's processes and how to manage these processes?***
Process management	-possibility to define and modify processes (like engineering change and approval processes) -project management, including resources and expenditures (or integration with external management application) -support for nested processes, branching, merging, notification -process state monitoring -incorporation of documents as well as other supporting information (work packets) into processes and tasks and their review -production process plan and incorporation of information to phases
Life-cycle management	-possibility to define life-cycle for objects (product, design, documents, components) and rules for transitions -possibility to track design and document history during design (documents, who modified and when, status, etc) -access control according to life-cycle state
Data capture & distribution:	***How to collect and distribute all information?***
Data exchange	-data translation (automatic / manual) -support for neutral exchange formats -tool (application) integration (all appropriate tools e.g. MCAD, ECAD, ERP, Component Management system)
Image services	-possibility to view design documents (all appropriate formats and use of neutral formats such as PDF) -document redline and comment capability
Global access, notification, and communication	-possibility of global access (e.g. Web, traditional client) -possibility to communicate (e.g. use of internal or external e-mail system) -automatic notification (e.g. when there is a new document in system, or during processes)
Methods:	***How can a system support the working methods of a company?***
Design knowledge management	-system should allow an organisation to collect, save and share all design-related knowledge
Concurrent engineering	-possibility to represent project data with the product data -support for the stage overlapping (e.g. parallel modifications) -fast and early data release -integration of the development teams -possibility to automate processes (e.g. automatic notification and progress, data translation between phases)

The data management, process and life-cycle management, and capture & distribution should support a company's working methods (Figure 35).

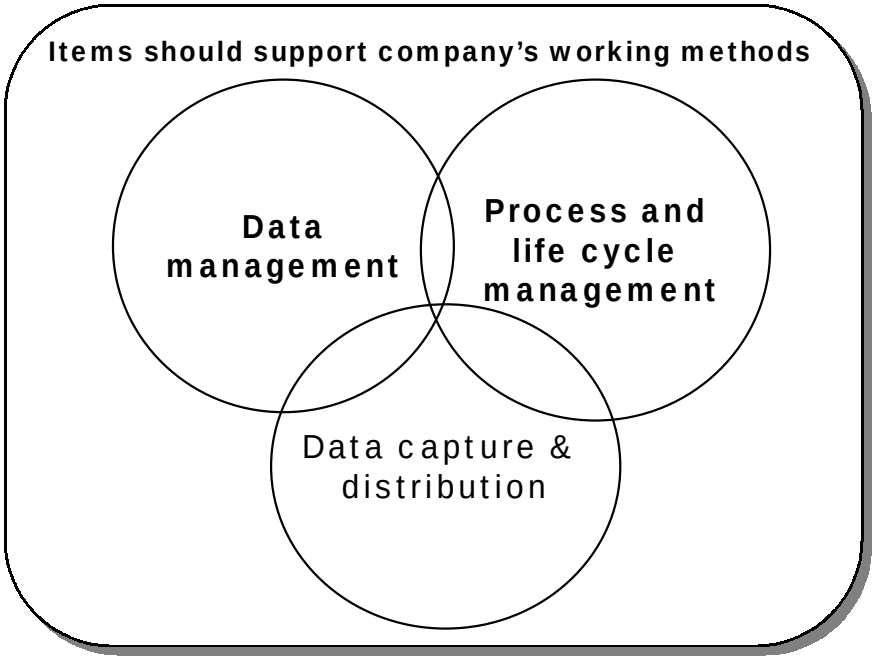

Figure 35. Features and company's working methods.

The working methods of the company aim to support business requirements (e.g. decrease time-to-market). So, the data management, process and life-cycle management and data capture and distribution don't solve the company's problems but they do introduce features which can support working methods or principles.

Data management introduces basic features which are used by the other parts. Processes and life-cycle management connects data management with a company's processes. Data capture and distribution makes it possible to collect data, communicate with design systems, and distribute data in the correct form to all parties.

When a company considers PDM implementation, it is essential that the system meets the company's needs and resources. Companies' requirements vary and therefore one company can choose a simple solution (e.g. central data vault with check-in and check-out functions) and another a complex solution like the PDM system which offers many design tools features like the creation of BOM and the possibility to view design documents. So, we have to consider what kind of functions we want under the management system when considering PDM implementation.

6. Design data management levels

It is a fact that design data management occurs at different levels (Figure 36). Two kinds of PDM implementations can be found: the first focuses on the enterprise level (EPDM, Enterprise Product Data Management) and the second on the department or workgroup level (Team-PDM) [MaM97]. However, design tools also have document management capabilities, mainly concerning an individual designer. So there are three design data management levels and the company can have systems for every level.

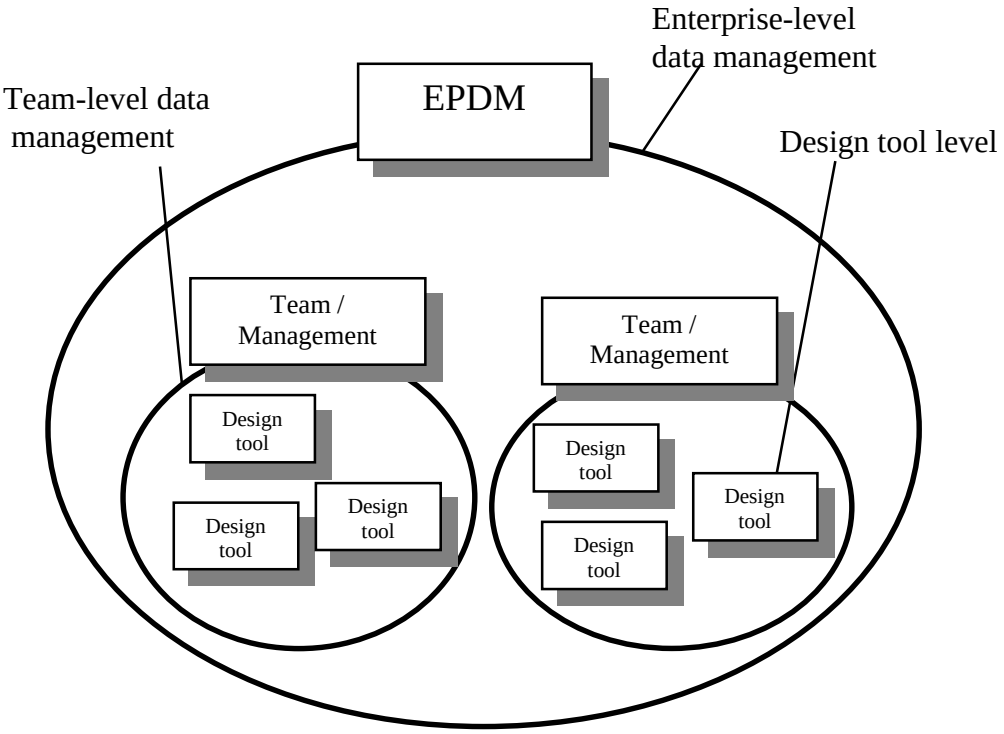

Figure 36. Levels of the design data management.

This classification is not always clear because the differences between systems are difficult to define. The PDM vendors sometimes use the same terminology to describe different capabilities, and PDM products reflect the vendor's different interests, backgrounds, and technologies [MaM97]. This report considers levels of design data management. Section 6.1 introduces tool-level design data management. Section 6.2 contains a consideration of team-level design data management which can be utilised when a company is planning to introduce an enterprise-level design data management system. Section 6.3 contains a consideration of enterprise-level design data management.

6.1 The design data management features of design tools

The design tools offer some data management features and PDM modules for controlling design data [MaM97]. In the electronics industry these design tools can be office applications, mechanical CAD, electrical CAD, and software tools, or other

technology-specific tools. This section focuses on the design tools data management features, usually used by a single designer. The following examples represent document management possibilities referring to certain applications:

1. AutoCAD

Autodesk is a software company providing design solutions. Their design solution named AutoCAD is a mechanical design tool (MCAD). This solution also offers some design data management features to designers (AutoCAD LT contains a subset of the same features).

AutoCAD allows designers to create reusable design components using blocks and reference drawings. A block contains e.g. one part (drawing) or logo. These blocks can be collected in a block library. It is possible to manage block-libraries with the use of utility programs. The block can also contain attributes which allow designers to define alternative alphanumeric information to blocks. The AutoCAD reference drawing system can be used to produce the reference drawings (Figure 37). When using a reference drawing system, the assembly drawing only contains pictures from the external drawings. Reference drawing is always updated when an user opens it. This feature assures that the assembly is always updated after part modification. [Sal97]

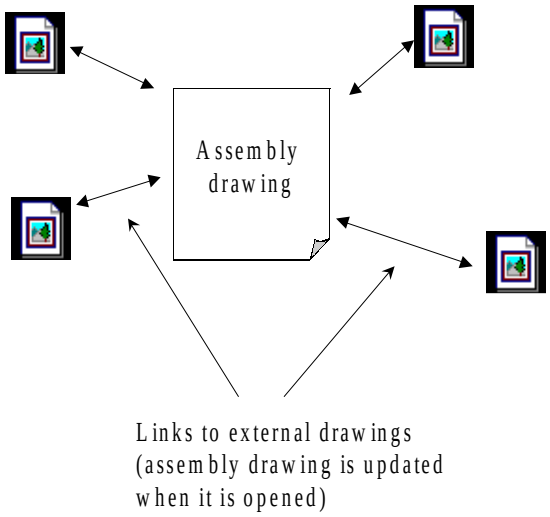

Figure 37. Assembly drawing contains references to several external drawings.

It is also recommended that all related drawings should be saved in the same project folder. Network technology also allows the use of shared network folders, and data exchange with other design system is possible with the use of e.g. DXF de facto standard format. [Sal97]

2. Cadence EDA (Electronic Design Automation) design tools:

Cadence Design Systems offer an electronics design environment containing applications for electronics design. Cadence's schematic design tool Concept HDL supports top-down design, which allows the user to define system functions and levels of hierarchy. Cadence Hierarchy Manager (part of Concept HDL) allows the designer to choose a symbol to depict modules and their relationships. By using Cadence's layout design tool it is possible to read and save the information in DXF format and IDF format. This information translation is important when exchanging information with MCAD (Figure 38). It is also possible to convert the design to a producer's machine tool format (e.g. Gerber). So the design file is directly readable for the machine tool (e.g. a drilling machine)**.**

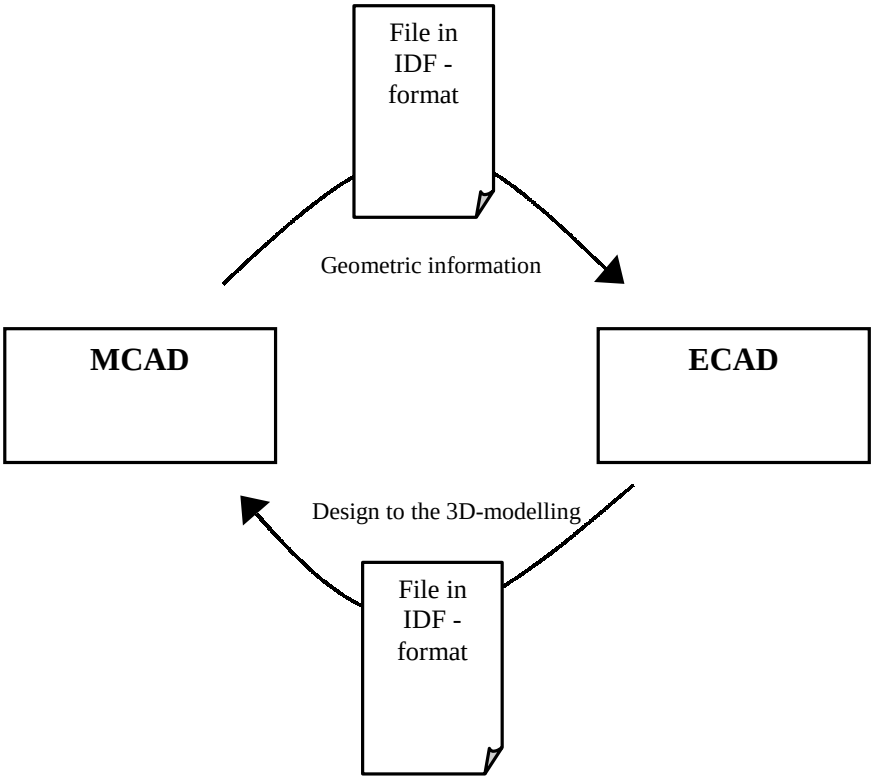

Figure 38. An example of the design data exchange between MCAD and ECAD.

6.2 Team-level design data management

MCAD, ECAD and software application vendors have created modules which provide a limited team-level PDM functionality [MaM97]. These tools focus on their own applications' document and design process management. The CAD frameworks are the common user interfaces for the co-operative use of tools [MaM97]. The framework guides users through the proper order of steps, applications and data conversations [MaM97]. In this report these frameworks are one type of team-level management systems.

The surveys show that electronics engineers can spend 25% or more time searching drawings, archiving new data and checking to see which file is current. This is the reason why electronics engineers also need PDM functionality. It is estimated that less than 20% of electronic engineers are using any kind of PDM tools. [Sto99]

This paragraph provides one viewpoint to integration. The team or workgroup-level design management systems are of great importance to enterprise-level data management when using EDA tools. The user-level EDA design tools and enterprise-level data management systems are very dissimilar, which makes it difficult to integrate design tools with the PDM systems. One solution to this is the use of a team-level design management tool (Figure 39). This team-level tool provides access (for the PDM system) to team level data and it also manages the design process. [Cut98]

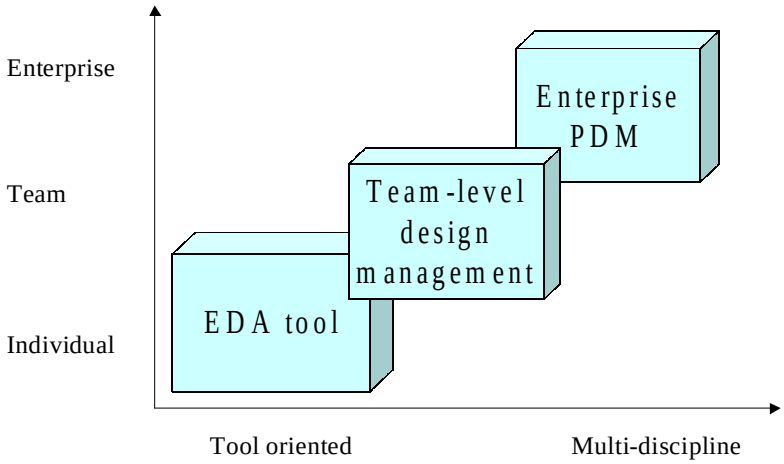

Figure 39. Team-level design management [Cut98].

This approach can also be suitable for other disciplines' design tools integration with the EPDM systems [MaM97]. The EPDM systems use discipline-specific frameworks to control a whole product's data [MaM97]. For example, it is possible to connect a mechanical design group to the Winchill EPDM system by using Windchill's gateway to the Pro/INTRALINK application (a team-level data management system).

Software has become an important part of embedded products. The management of embedded software is an integral part of product development. One of the simplest ways to carry out software assembly is the use of a make-tool [AuT96]. All relations are described in a makefile, which is a source file for the make program. The execution of the make program compiles and links a code using appropriate modules.

Software development tool vendors also offer some limited PDM functionality [MaM97]. These team-level management tools for software configuration management (SCM) include for example version and change control as well as program assembly tools [Tar98]. Bell and Evans define configuration management as follows [BeE89]:

The process of identifying and defining the deliverable system items, and controlling the release and change of these items throughout the system life-cycle.

The EPDM system integration with software tools can be done using local data managers (like EPDM and MCAD integration) [Mil98]. This means the use of a software configuration management tool as a team level design management tool, which connects the system to the enterprise level.

The implementation of a PDM system can be focused on a single department or a team instead of at enterprise level [MaM97]. Within a team the data is usually easier to manage (team-level solutions) but these kinds of solutions do not solve the enterprise level data management problems. These solutions only create "automated islands" inside which the data management is well realised, but the information exchange between the teams remains difficult [PiM97].

6.3 Enterprise level design data management

The next consideration includes issues with regards to the enterprise level management of design data. These systems are usually solutions which manage all the data of the enterprise. The EPDM systems cover all product-related data and these solutions are one possibility for enterprise-wide data management. The utilisation of existing systems is nowadays essential in order to achieve enterprise-level data management (e.g. team-level design management systems handle many data management tasks and all changes are reported to the enterprise-level system). In the future it is possible that PDM systems will replace all these existing lower level systems (e.g. frameworks) [MaM97].

International standards (e.g. ISO 9000) require the documentation of a company's processes and evidence that the processes have been executed according to this documentation. PDM systems can support the standards by forcing the company to operate within these parameters. [HaH95]

When one considers design system integration and the enterprise-wide design data management of an embedded product's design it is important to collect the whole product's documentation under a single management system. The products contain sub-assemblies and modules. Therefore, design data management should link all design documents to the correct structure of the product. The EPDM systems interface with discipline-specific tools and frameworks to incorporate them to the enterprise level data management [MaM97]. This creates a "virtual" product structure, which means that the product structure contains sub-structures from several design systems (e.g. mechanical and electronics modules). Nowadays, EPDM vendors offer limited interfaces to ECAD frameworks but there are only a few interfaces to the CASE tools [Mil98]. So, companies can have a certain SCM system for the embedded software management and the PDM system for mechanical and electronics information management. However, the embedded software should also be managed under the enterprise's PDM system (the whole product's configuration management). The next figure illustrates a solution where an archive contains a product structure and the electronics and software engineering data are managed by using technology-specific systems (Figure 40) [PiM97]. The mechanics engineering data is managed by using the enterprise level PDM system.

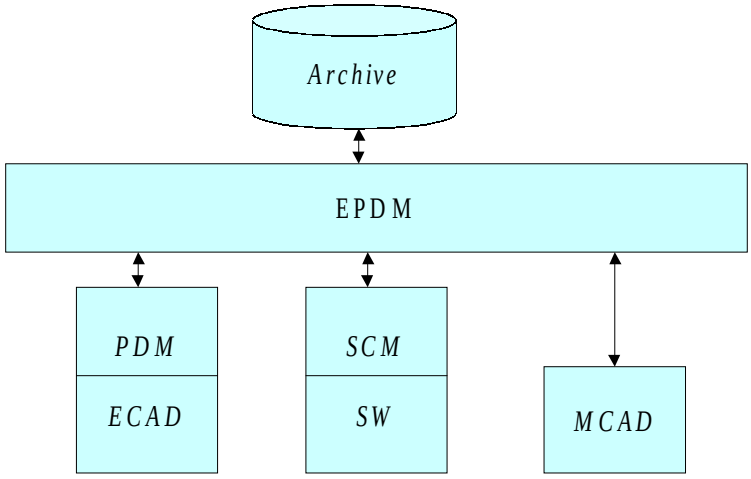

Figure 40. The connection between EPDM and different design teams [PiM97].

Design teams need to exchange information and to be integrated with the PDM system. The application integration with PDM provides access to the functional capabilities and the database of the PDM system. CimData divides application integration into three levels; encapsulation, interface, and integration. Encapsulation is the simplest way to carry out integration. It provides the possibility to the PDM system to launch application, but data does not dynamically flow between the PDM system and an application. The interface means middle level integration where an application's menu may contain direct calls to the PDM functions (e.g. check-in and check-out). The integration makes the application and PDM system look like they are the same programs. Menus contain direct calls to the PDM functions and all types of data that needs to be shared are common for both the systems. [MaM97]

When considering ECAD and PDM integration, the International PDM Users Group (IPDMUG) represents three kinds of integration (like CimData): simple integration, off the self integration, and full custom integration. Simple integration may need manual steps when exporting data to the PDM system. The second integration type provides some direct calls to the PDM functions (e.g. check-in and check-out functions). The third integration type means tight integration and it is usually tailored to specific processes. [Ele99]

IPDMUG represents four techniques to integrate two systems. These techniques mainly deal with PDM and ERP systems integration but can also be used in other kinds of integration (e.g. CAD and PDM). The techniques are: [ERP99]

1. People and paper:

Integration is accomplished at most manufacturing companies by using this technique. In this case the people use paper, meetings, manual data entry, and manual data re-entry. This is slow and error prone but reasonable if integration with other techniques is too expensive.

2. File transfer:

This technique automates the extraction, storage, and loading of data via files. One advantage is that this approach isolates systems, which is important when systems are updated. This technique also usually involves minimal changes to the business processes. One possibility to implement this is to use standard formats like STEP. If a company builds its own proprietary set of formats and therefore moves away from standard data export, it is possible that the number of data formats increases. This kind of system can be difficult to maintain.

3. API (Application Programming Interface):

This technique uses custom code to link both systems' application programming interfaces together. These programs allow real-time access to the other systems and provide tighter functional integration. However, this technique is complex and requires support and maintenance. One possibility which provides simplified connection is access to another system's underlying database by using database vendor commands. In any case, this method is quite similar to the file transfer technique.

4. Interfaces based on distributed objects:

Object technology makes it possible to divide large systems into smaller ones. These distributed objects provide the means for dynamically changing the servers that clients use without them realising it. For example, CORBA (Common Object Request Broker Architecture) supports distributed objects. It is a protocol to extend object technology across multiple systems.

Data exchange and integration with other applications is possible e.g. by using STEP (Figure 41) [Har98].

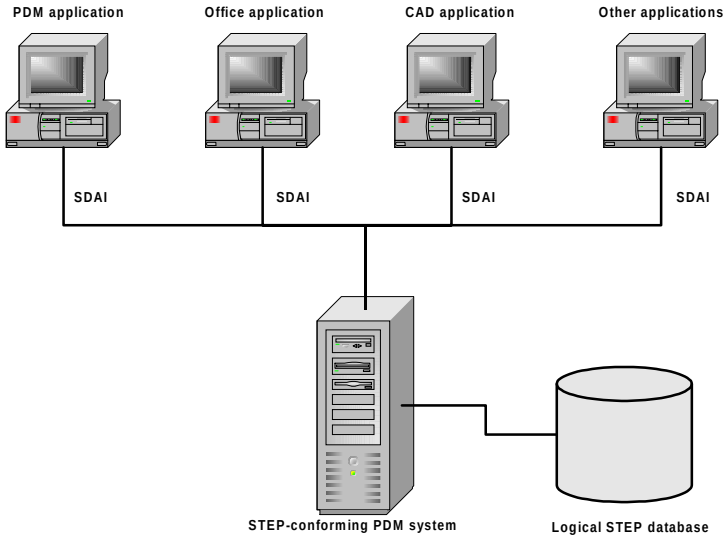

Figure 41. Application integration with STEP [Har98, p. 17].

The interaction between the PDM system and the applications that create and change product data using STEP provides application independence for data. The STEP standard allows an organisation to use a central, neutral STEP database, and applications can use this data via interfaces. So all applications that use SDAI (application programming interface to STEP data) are able to communicate with all other compatible applications. [Har98]

7. System review

This section introduces three PDM systems. It also presents how these systems meet the design data management requirements defined in Chapter 4. The PDM systems which are presented are:

- Windchill (Section 7.1),
- Metaphase (Section 7.2), and
- PVCS Dimensions (Section 7.3).

All these systems are enterprise-level management systems which support multiple sites. This report does not contain system comparison because different systems reflect vendors' different interests and backgrounds. However, Section 7.5 contains observations about this review.

7.1 Windchill EPDM system

Windchill EPDM system, provided by the Parametric Technology Corporation, is an enterprise-level data management system for the management of product life-cycle. The Windchill's first version was announced in July 1998. An interesting feature of this product is the use of Web technology instead of traditional client-server technology. Windchill provides a completely CAD-neutral environment and an integrated suite of applications for the management of all phases in the product's life-cycle. This report represents the features of Version 3. Version 4 was announced in autumn 1999 and provides more functionality. This information is based on interviews and experiments provided by Parametric Technology Finland, the reseller of Windchill in Finland.

7.1.1 Windchill 3.0 EPDM system

The Windchill system is modular. The Windchill Foundation contains core functionality, and a solution called Info Engine provides data acquisition and linking functions. ProductView allows data review and Application Suite brings additional functionality to the whole system. Finally, Information Modeler is the development environment of the system. The following picture represents Windchill's modularity (Figure 42).

Figure 42. Windchill product and process life-cycle management solution.

The main elements of the Windchill system are:

- Windchill Federation Platform
- Windchill Life-cycle Applications Suite
- Windchill Information Modeler.

1. The Windchill Federation Platform:

The Parametric Technology Corporation defines a "Federated System" as follows:

Multiple information repositories are involved in the solution. In addition, the systems were implemented independently and hence include various versions, technologies and implementations.

Therefore, the working environment of the system is not homogeneous. There can be multiple data repositories and different implementation technologies. Windchill provides a federated "central" information system and manages links with information that is located in multiple repositories. This Federated Platform is built upon three Web-based information-handling capabilities:

Federated Data Management:

This capability contains Windchill Foundation, which is the core application of the Windchill-system. First, the Foundation offers Data Vault and Document Management

functions. It manages publications at multiple revision levels and in different formats. Outsourced files linked to the publications are also possible (URL-links). Second, the Foundation offers an integrated Search Engine which enables a fast and simple cross-system search (multiple, dissimilar repositories and different data types). Third, Life-cycle Management offers the possibility to manage the way in which products and related information mature. The user can define "states" through which an object (data) passes and criteria that the object must meet in order to pass through into the next state. Fourth, Workflow Management allows the company to create unique processes (process description). It also allows the company to automate and monitor these processes. Finally, the Security and System Administration function offers e.g. access, role and project definition capabilities.

Federated Data Acquisition:

The Info Engine is an Enterprise Application Integration (EAI) framework. It will connect and relate information together across various repositories and allow the user to make queries, find information, and select desired information. Windchill uses "proxy objects" (links to the external data) which include attributes that describe the remote data and address (URL) of the data. These proxy objects can be used in various applications and processes.

Federated Data Visualisation:

ProductView is a Web-based application for file viewing. It allows users to review many types of information without requiring a design tool and therefore allows also non-engineering users to participate in the engineering process.

2. The Windchill Life-cycle Applications Suite:

The Life-cycle Application Suite contains applications to support life-cycle management of the product and processes. The Application Suite contains:

- Windchill Enterprise Product Modeler (EPM)
- Windchill Component & Supplier Management (CSM)
- Windchill Content Libraries
- Windchill Product Data Management (PDM)
- Windchill Product Configurator
- Windchill Process Planning
- Windchill Release to Manufacturing.

Only the EPM and PDM modules have been announced (Version 3.0). The other modules are under construction.

The Windchill Enterprise Product Modeler:

EPM is a family of applications providing integration between Windchill and workgroup data management or engineering authoring tools. The applications enable linking objects (data) directly to the Windchill-managed enterprise objects and also provide security control and the possibility for the reuse of the objects. Designers and reviewers can access the same data by using the design tool or viewer.

Windchill Component & Supplier Management:

CSM allows information-sharing between engineering and component procurement (suppliers). The application also facilitates the identification and reuse of components. Content Libraries contain detailed information about commercially available components and suppliers.

Windchill Product Data Management:

With PDM it is possible to manage the product's life-cycle by managing product structures and engineering changes. Users have easy access to the product structures by using Web pages, applets, browsers, hyperlinks, and search engines.

The Windchill Product Configurator:

The Product Configurator offers a solution for those companies who want to individualise their products. It makes it possible to define a generic product family to allow quick customisation of the product structure (mass customisation). Generic product structure includes "white spots". These items or structures will be designed later (Engineer-To-Order). This feature is important when designing client-customised products.

Windchill Process Planning:

Process Planning is a family of applications which enables production process planning. Users can define the steps required to manufacture a product and add descriptive information to the processes.

Windchill Release to Manufacturing:

Release to Manufacturing allows bi-directional data exchange between Windchill and the ERP environment. This solution blocks data duplication on two systems.

3. The Windchill Information Modeler:

The Information Modeler is an object-orientated development environment for the building of customised applications. It contains the following tools and technologies:

Windchill Object Model: provides functional building blocks that are supplied with Windchill Foundation.

Graphical Development of Object Model: object-oriented analysis and design by using Rational Rose.

Windchill System Generator: generates Java code and data definition language.

Application development: this is used for the development of graphical user interfaces.

The development process starts with an object-orientated analysis and design using Unified Modelling Language (UML). The System Generator generates Java code and data definition language. Finally, by using Windchill's embedded version of Symantec Visual Café it is possible to create user interfaces e.g. for applets.

7.1.2 Solutions for design data management

Data Management

Data Vault and document management:

Data Vault supports all data formats (files, forms, and links). The system supports a federated environment (multiple repositories (independent implementation also possible), central management). Windchill Foundation uses the Oracle 8 database (relational database system) and its object model is created by using UML-language (Unified Modelling Language). The Data Vault function controls access to information and prevents unauthorised use. Check-in and Check-out functions provide the mechanism which allows the acquisition of documents from the vault for modification and the storage of them back there. The system allows the addition of meta-data to the structures and files. Oracle takes care of information backup.

Version control allows the following of changes and the reviewing of historical data. Check-in/Check-out creates a new iteration (A.1, A.2, etc) or version (A.3, B.1, etc). The system saves historical information. It is also possible to compare different versions and see the altered information. The Check-out function locks the document, so parallel modifications are not allowed.

Product structure management:

Windchill allows the creation of multiple representations of product structure and components. It defines product structures where components can have references to documentation (any type). The user can navigate inside the structure and see sub-assemblies and parts. It is possible to create baselines (useful configurations) from the structure and add effectivities to the product structure (for example after a change process the changed part is defined as effective (can be used)). Windchill's product structure can be "virtual". This means that the whole product's structure can contain sub-structures from different design systems (teams). All items are called objects and the structure is based on Uses–Used by relation (hierarchical). BOM is produced automatically by using Product Explorer.

Classification and retrieval:

Windchill uses the Verity search engine to retrieve information from external and internal repositories. Windchill's InfoEngine solution allows the system to link to external repositories (e.g. Metaphase). It uses "proxy objects" as placeholders to refer to external information. These objects contain attributes that describe external data and a URL, which refers to the external source. Objects also have status (e.g. concept, reviewed). These objects can be associated with the product structure. The user can view the product structure from several views (as manufactured, as designed). Information retrieval is Web-based and it is possible to attach search results to the Web document (e.g. distribution to the project members).

Process and life-cycle management

Process management:

During the engineering change process it is possible to attach documents to the tasks or insert links to documents (URL). The change process contains change request, change order, and change activity functions. Windchill also allows the company to create unique graphical workflows. It provides predefined activity components (e.g. review component), an integrated Java compiler, and also support for nested processes, branching, merging, iterative loops, and response-based (e.g. during the approval process) and attribute-based routing. During execution the user can monitor the process and get information e.g. on duration, state and participants. Document injection into the workflow is possible but injection into tasks is difficult (the user has to create an HTML link). The system does not contain project management (it does contain some features like process description). The next example illustrates process definition and use.

Figure 43 illustrates a process template which contains activities (tasks), notification robots, one iteration link, and one sub-process. The activity can, for example, be an approval-task. The activity can contain events (Figure 44) which control the progress.

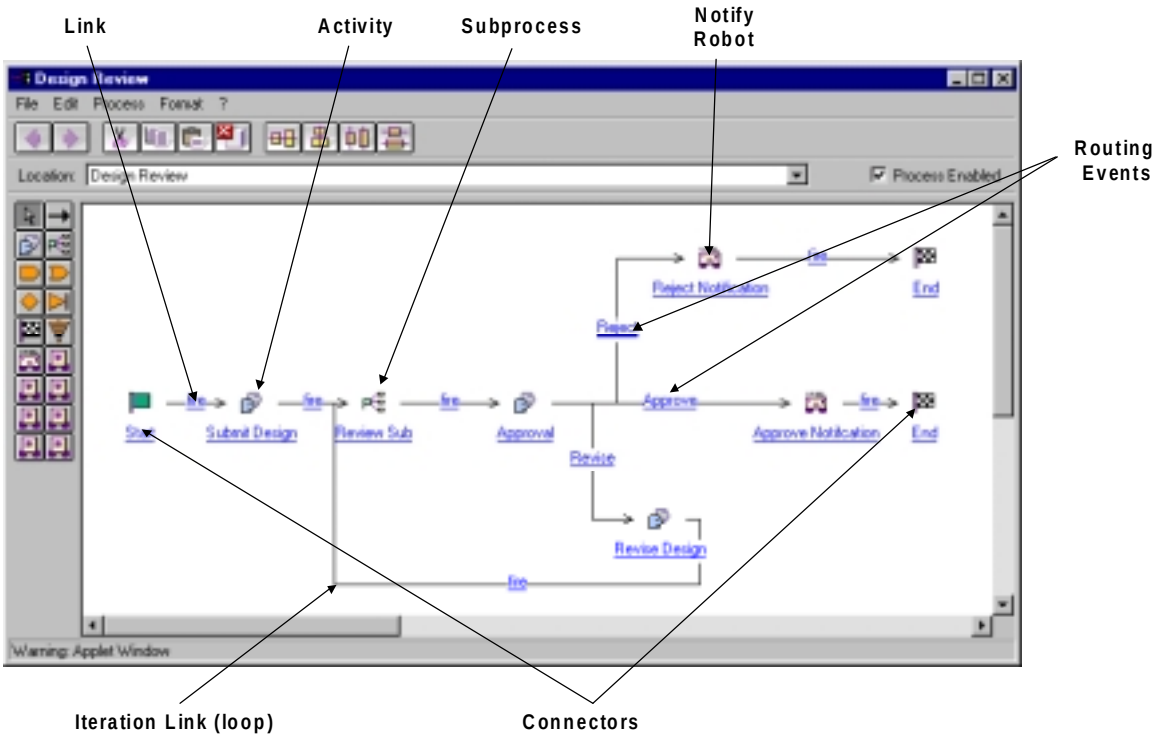

Figure 43. Process template definition.

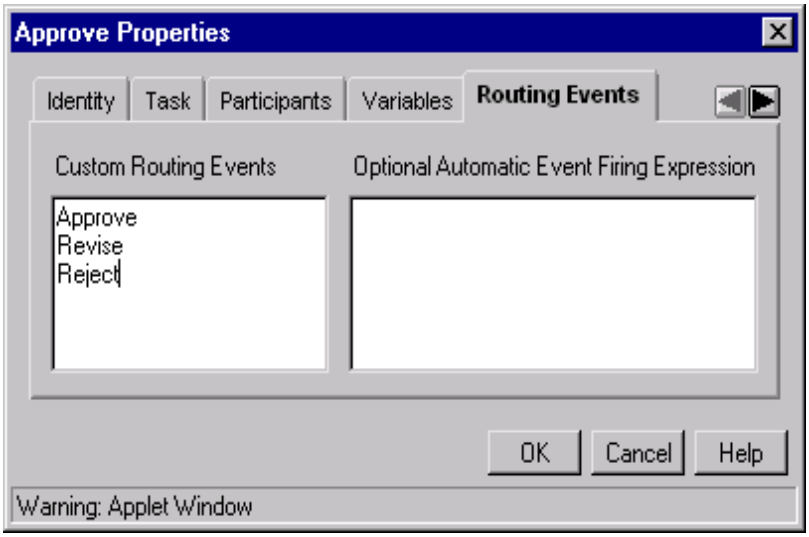

Figure 44. Approval activity's events.

This process definition produces a template which can be used in business. Figure 45 illustrates process instance definition, which creates the instance of process and adds objects and roles to the process. The worklist shows all work items (tasks) which a person has to complete.

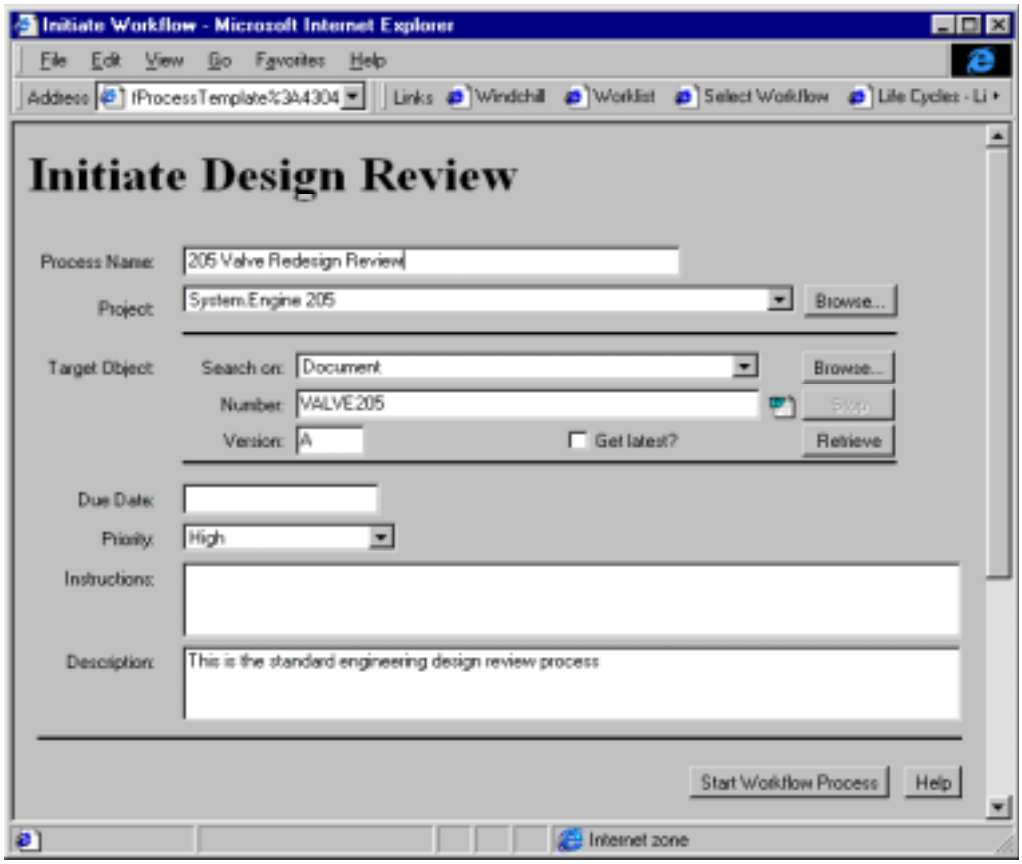

Figure 45. Process instance definition.

Figure 46 illustrates workitem notification which is useful when notifying people of tasks.

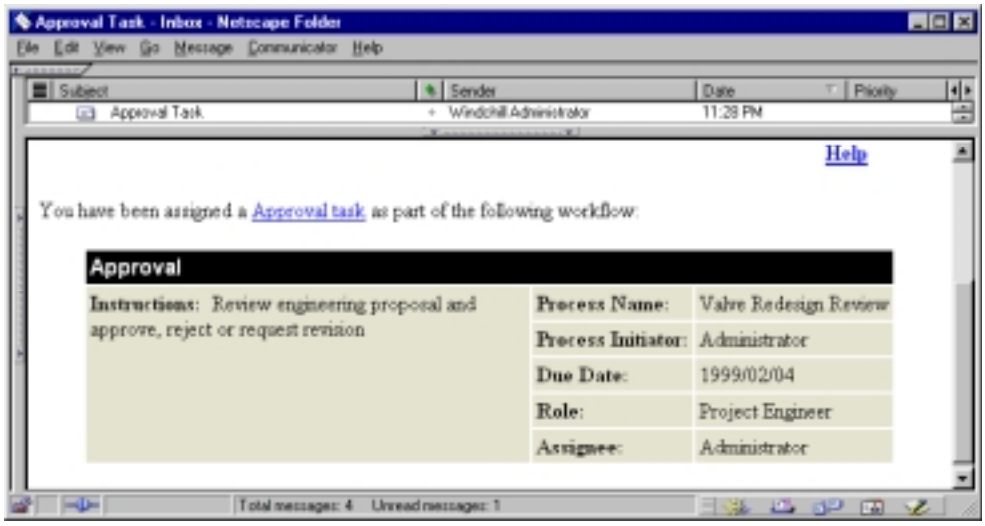

Figure 46. Workitem notification (e-mail).

Task-view can be used to complete a certain task (Figure 47). Task contains an object (in this case a valve) attached in the process instance definition. Comments can be attached to the tasks.

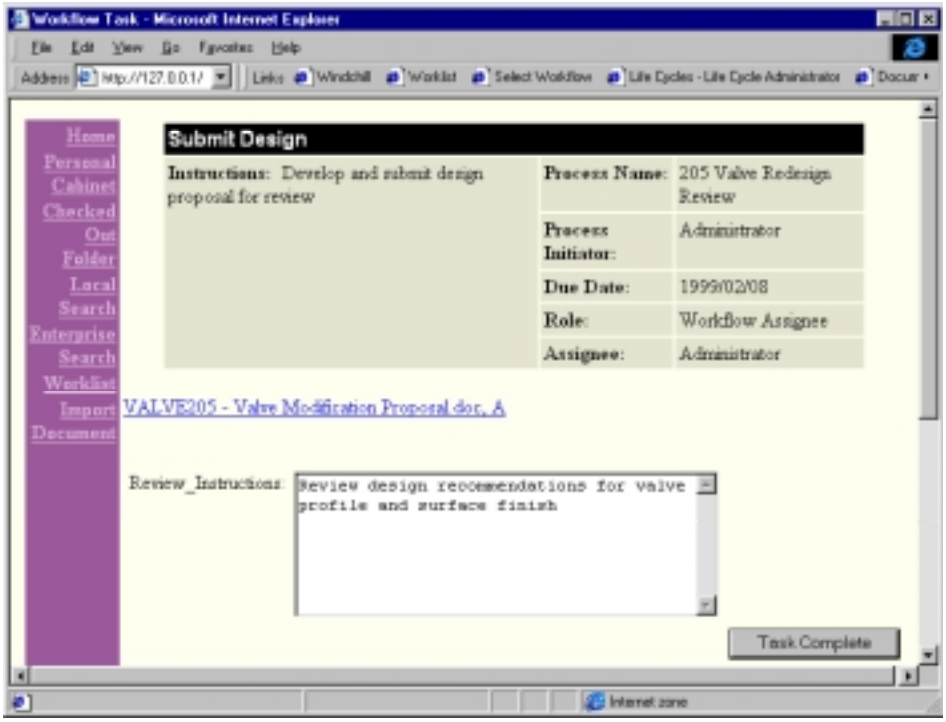

Figure 47. Work item (task) view and execution.

Figure 48 illustrates a task which contains comments about Design and Manufacturing review tasks. Task also contains three events defined in the process template definition (see Figure 43). The progress of the process (see Figure 43) depends on the person who completes the approval task (branching according decision).

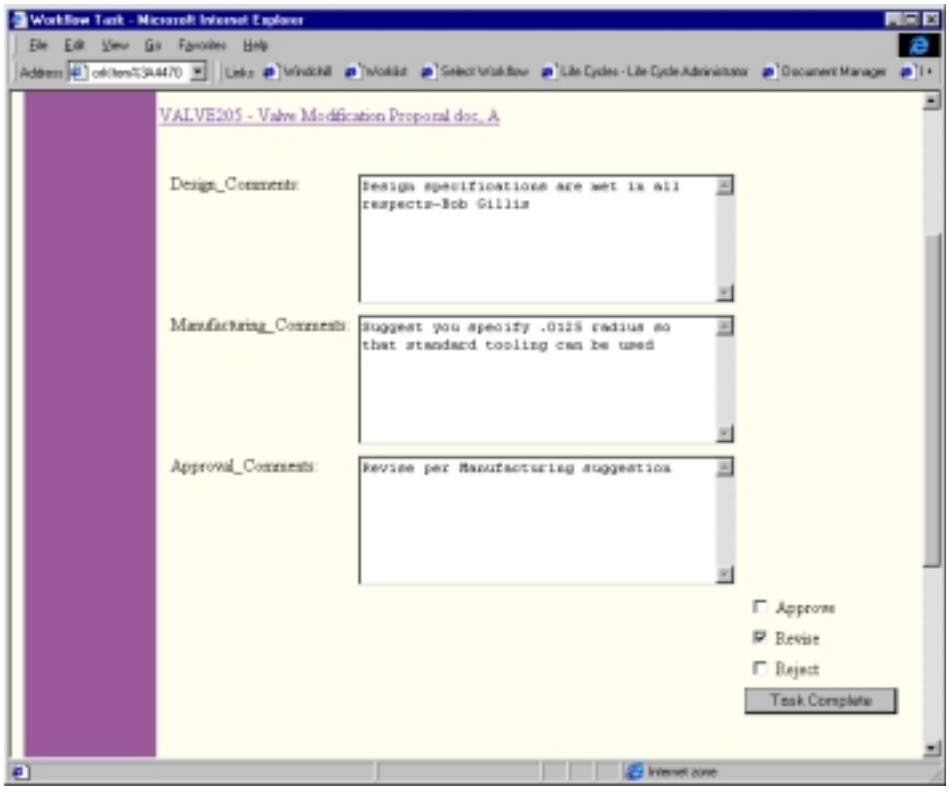

Figure 48. Completing the approval task.

Figure 49 illustrates the process progress view, which shows the state of the process and allows the user to see details about a selected activity.

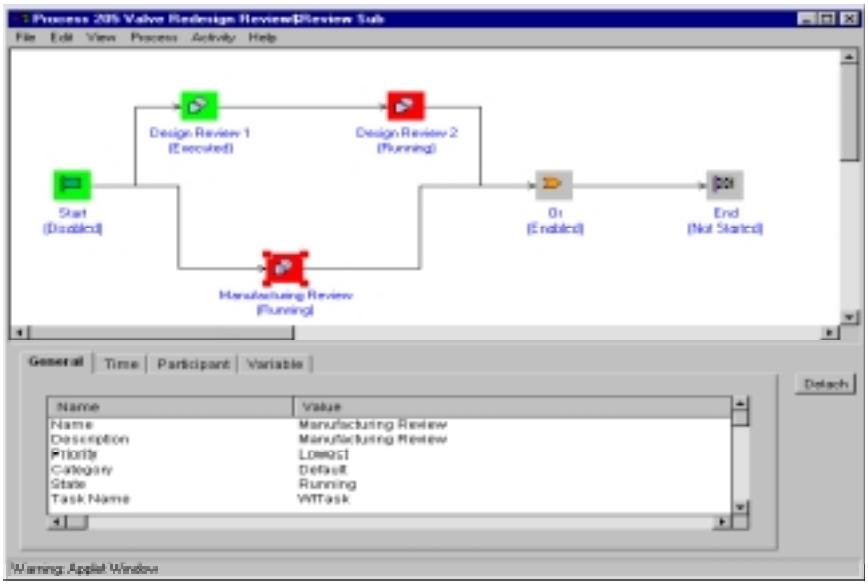

Figure 49. Workflow progress view.

Life-cycle management:

By using Windchill it is possible to define life-cycles which contain phases and gates (every object has a life-cycle) (Figure 50). It also enables management of the way information (object) matures during its life-cycle (the state of the design during the life-cycle). Phases and gates identify the current state of an object (e.g. design). The gate conditions must be satisfied before the object may continue on to the next phase. State-based access control allows organisations to control access to the objects according to the design phase. Project-based role definition allows the customer to define the roles included in a particular project and to assign actual participants to each role. Reuse of the template is also possible. Automatic notification notifies participants when the object's life-cycle phase changes. It is possible to track an object's life-cycle and even change it.

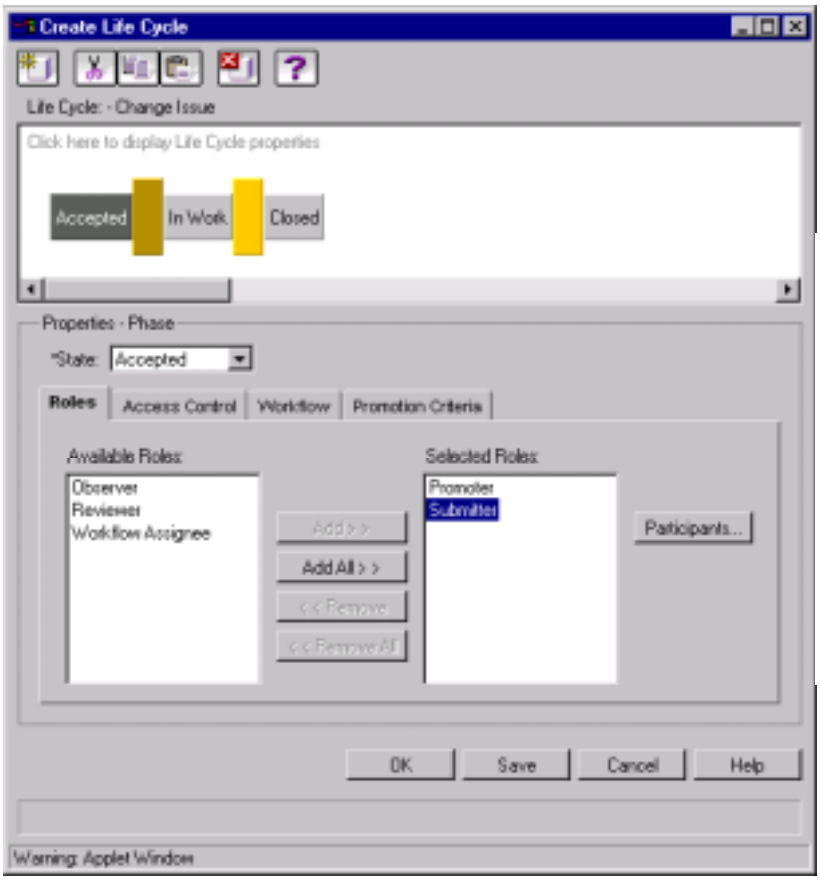

Figure 50. A life-cycle creation function.

Data capture & distribution

Data exchange:

Windchill offers data exchange e.g. with ERP systems (SAP) and PDM systems (Metaphase) by using Info Engine. Data exchange is also possible with the use of Gateways (nowadays only Gateway to Pro/Intralink) (version 3.0). Parametric

Technology partakes in the evolution of the STEP standard (ProSTEP, MariSTEP, PDES, OMG). It is also possible to save files manually into the system.

Data ownership is essential when using the enterprise-wide data management. The information must have an owner. In Figure 40 the owner of the mechanical data is the EPDM system, and other disciplines' data management systems control their own data. The EPDM system makes the electronics and software team's data visible in the enterprise (Figure 40). The next consideration represents Windchill's Gateway solution for the whole product's data management.

The example represents information integration between the Pro/Intralink-team-level data management (see Figure 40) system and Windchill EPDM system (Figure 51).

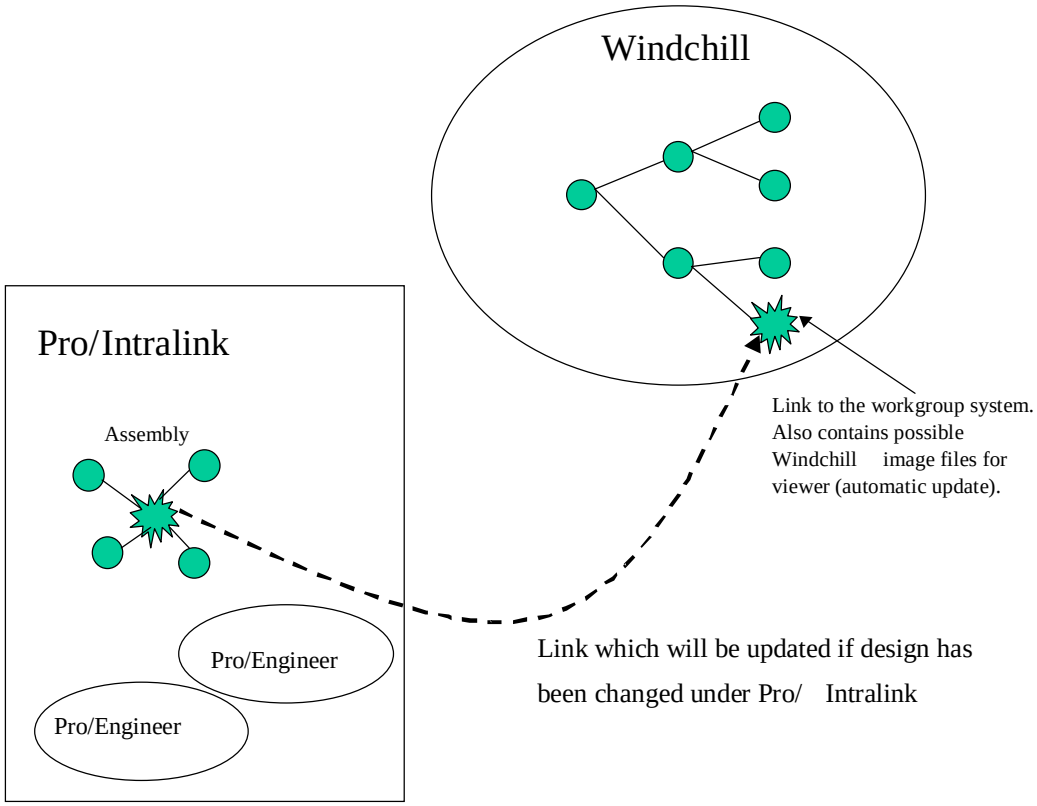

Figure 51. Team-level data management system integration to the EPDM.

Now Pro/INTRALINK is a data manager and Windchill only provides information to the enterprise-wide distribution. It creates links to the structure and parts managed by the team-level management system and it is possible to incorporate documents into the structure. When using a direct link to a design tool the EPDM system will be the application which manages data instead of the workgroup system (e.g. MCAD in Figure 40). Windchill doesn't support a direct link to CAD systems or office systems yet (it is possible to customise it). So, Windchill only offers integration to the MCAD tool (no integration with ECAD). However, there are customised links to ECAD systems. Info

Engine provides integration with e.g. Metaphase. Application launching is possible by using file extension association.

Image services:

By using the ProductView application (a stand-alone application) it is possible to view and mark up heterogeneous product information. A model may be viewed using a variety of display options (e.g. measurements).Windchill Enterprise Product Modelling (EPM) Gateways automatically generate ProductView images to the product structure and update them if necessary. ProductView is able to view e.g. Microsoft Office files, 2D drawings and 3D models.

Global access, notification, and communication:

Windchill uses Web-technology for distribution. It offers all documents available to authorised persons. Windchill allows automatic notification during workflow. The administrator defines default messages and participants. The participant definition is also possible through the use of roles. When the workflow is executed the system can automatically send mail to all participants (Figures 52 and 53).

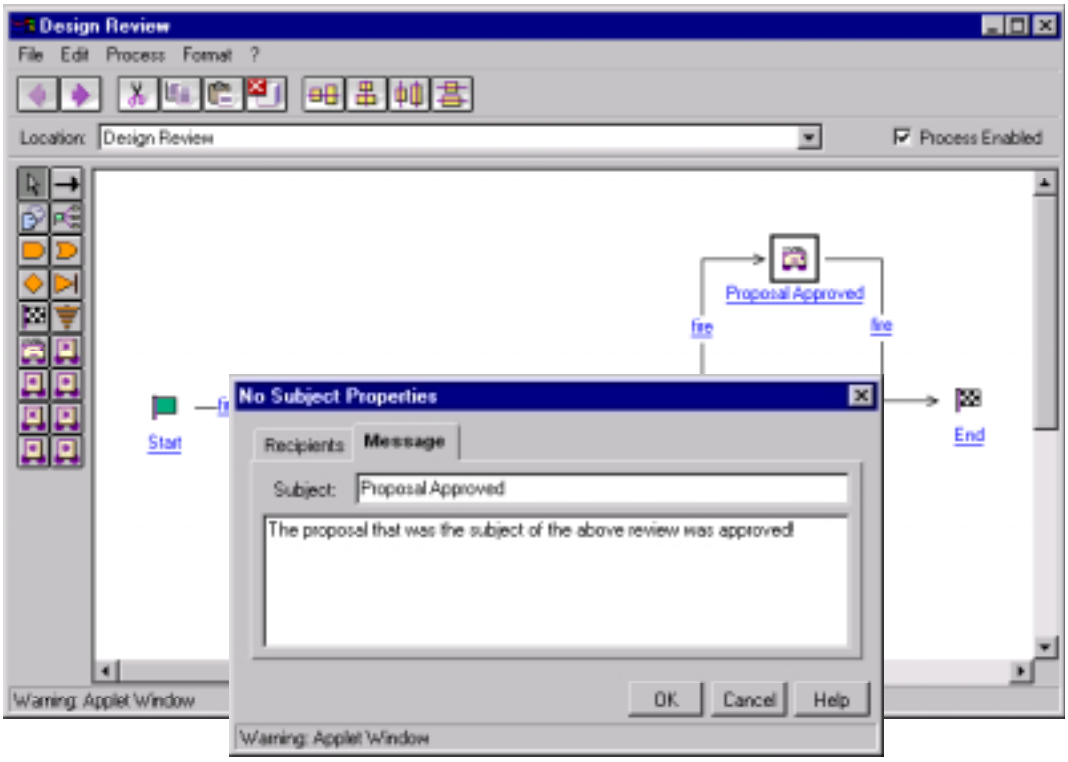

Figure 52. Notification definition during workflow design.

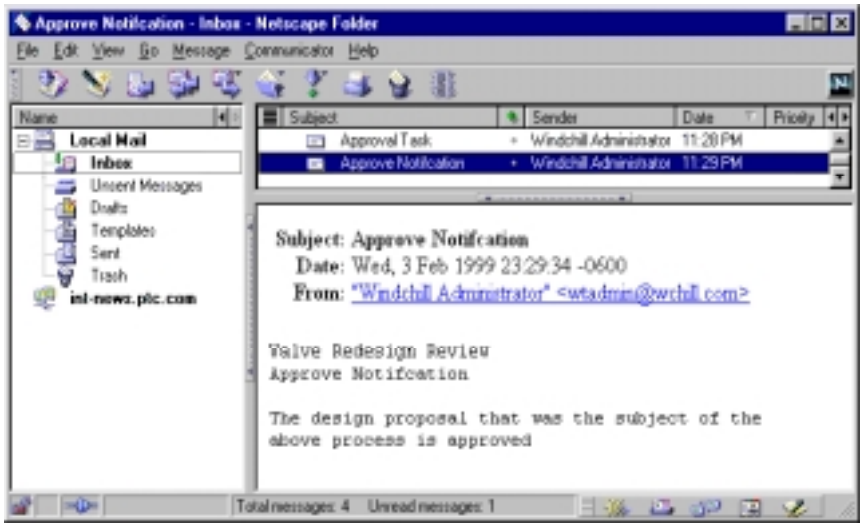

Figure 53. Automatic message from Windchill system.

Methods

Design knowledge management:

The system supports knowledge management by providing all kind of information for enterprise-wide distribution. It is also possible to search for local and remote information.

Concurrent engineering:

The system enables the early release of information and preliminary information can be labelled with an appropriate status (e.g. concept). It also enables the user to automate processes and provides him/her with the possibility to make comments and notifications.

7.2 Metaphase EPDM system

Metaphase is SDRC's (Structural Dynamics Research Corporation) system for enterprise-level product data management (EPDM). The purpose of the system is to manage the data of a whole product (data from different disciplines, structure, and documentation) in a global business environment. This study represents the features of Version 3.1. This information is based on interviews and experiments provided by Ideal Product Data, the distributor of Metaphase in Finland.

7.2.1 Metaphase EPDM system

The typical application areas of the system are:

- product data management,
- document management,
- configuration management,
- workflow and change management,
- review/approval processes, and
- systems integration for concurrent engineering.

With Metaphase it is possible to use a database solution which allows organisations to share information but stay as independent as possible. Organisations can control their own servers (e.g. data access control). When connecting to the federated network, the organisation needs to define at least one of their own federated hosts that will manage communication. Then administrators modify local configuration files to identify remote sites which they want to federate with. After this, administrators define controls over external users who access their site's PDM information. Local administrators also control which local users are allowed to work outside the local site and which outside users are allowed to access the local site.

Metaphase Enterprise V2 contains:

- Metaphase Enterprise V1:
  - basic modules for EPDM
  - e!Vista
  - Integrator Toolkit
- Solution Series:
  - MetaDM (Document management)
  - MetaCM (Configuration Management)
  - MetaVPDM (Virtual Product Development Manager)
  - MetaSM (Storage Manager)

Metaphase Enterprise V1:

The Metaphase Enterprise V1 contains tools for managing all product-related information at the enterprise level. The system shares information created by multiple applications.

e!VISTA interface:

Metaphase defines the e!Vista interface (Figure 54) as follows:

e!Vista combines web delivery and Java technology to enable organisations to quickly build and deploy task-focused user interfaces for today's complex PDM environments.

So by using e!Vista organisations can create customised tasks. This feature allows the user to work with Metaphase without having to understand the Metaphases data model or PDM infrastructure. e!Vista provides an easy-to-use interface and amongst other things enables the defining of all the functions which the user needs in order to execute a task (use of terms which are familiar to the user are possible) (Figure 55). Metaphase provides many completed and ready-to-use tasks with e!Vista, which can be extended using Metaphase Java beans.

Figure 54. Metaphase e!Vista user interface.

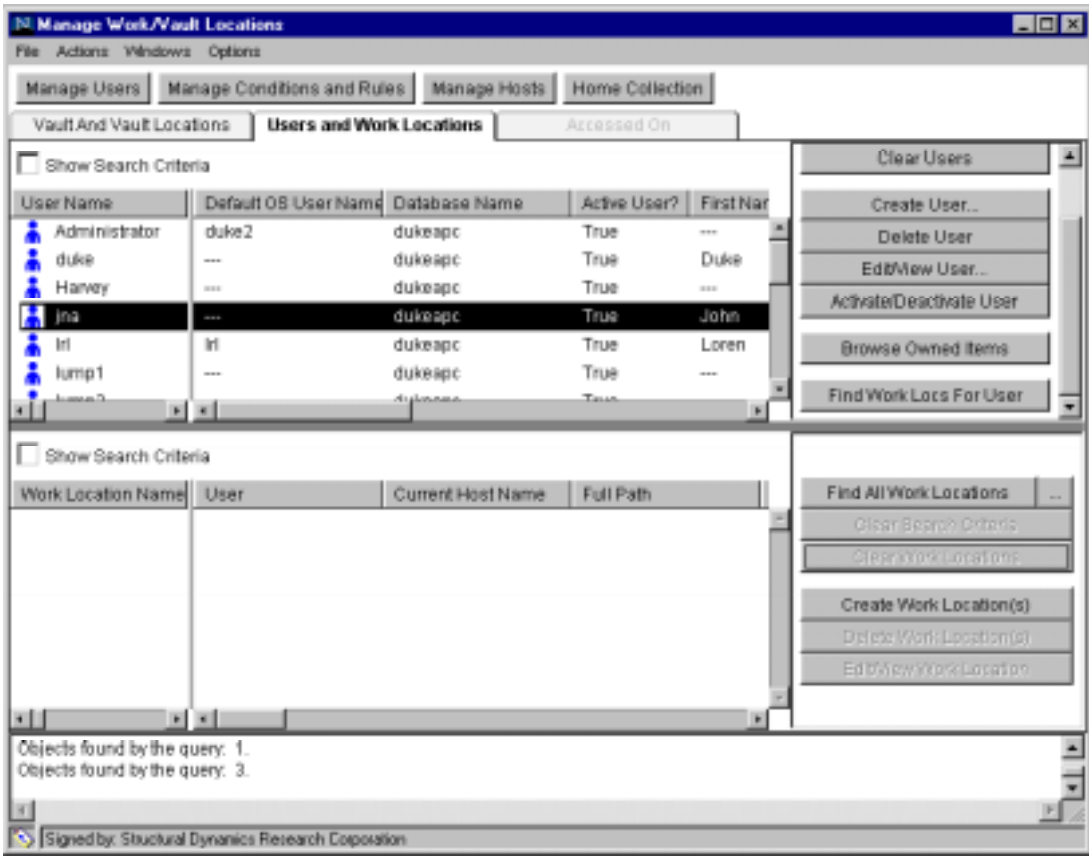

Figure 55. Administrator task example.

Integrator Toolkit:

The Integrator Toolkit provides tools for system customisation. It is also possible to create customised interfaces to external tools by using the Integrator Toolkit. The Toolkit contains application programming interfaces and graphical tools for customisers.

The Metaphase Solution Series contains ready-to-use packaged EPDM applications, which require only the minimum amount of tailoring.

Meta Document Management (MetaDM):

MetaDM is a solution which allows document management as part of its product definitions. This document management consists of identifying, storing, controlling, and distributing documents created by different applications. The solution offers the following basic capabilities:

Authoring services:

Users who create and modify documents use authoring services. It is possible to work with MetaDM in two ways: by using the authoring tool like Microsoft Office or by using Metaphase user interface.

Explorer-User services:

Explorer users are people who work with documents. Users use e.g. commercial Web-browsers to access MetaDM. Users can find, view and print these documents (Figures 56, 57, and 58).

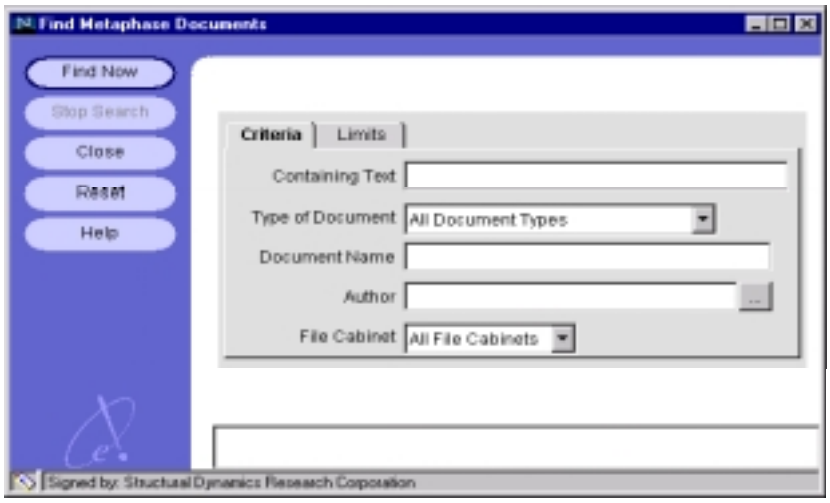

Figure 56. Document search.

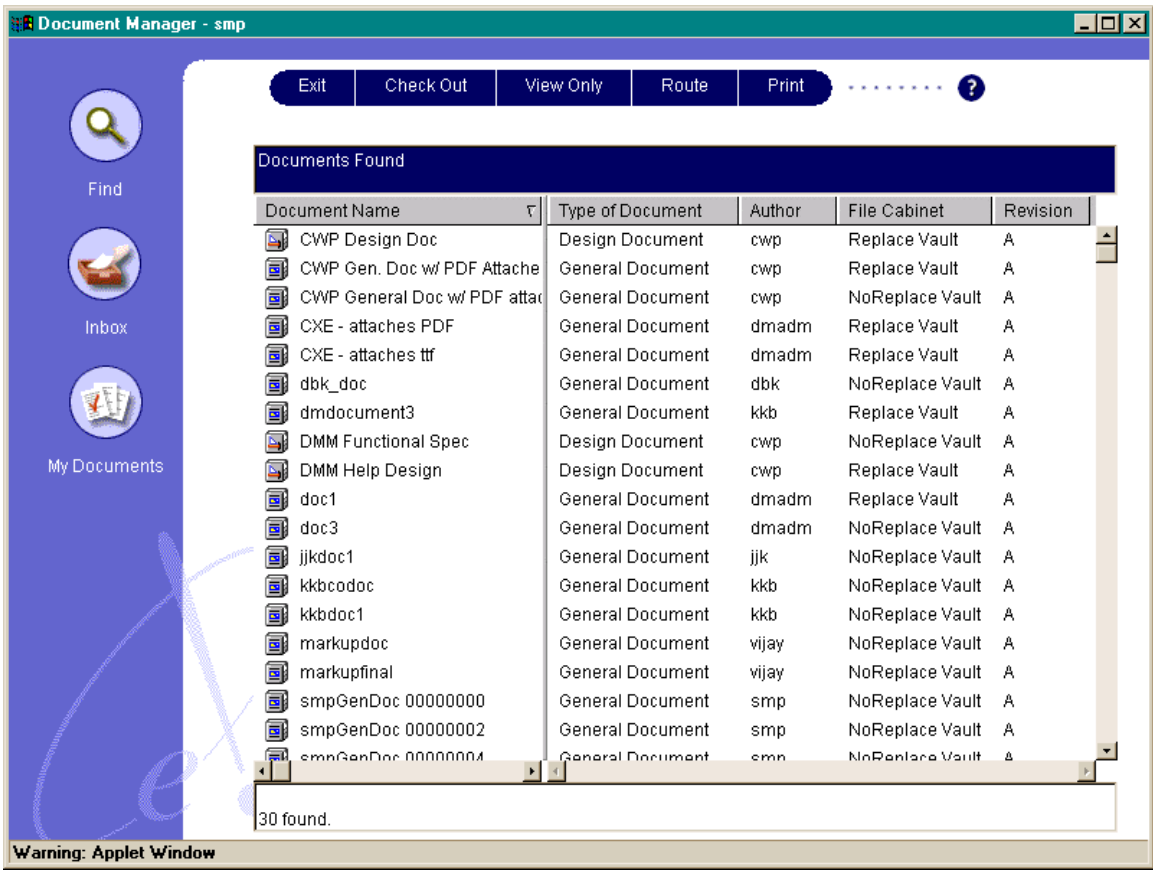

Figure 57. Results of document search.

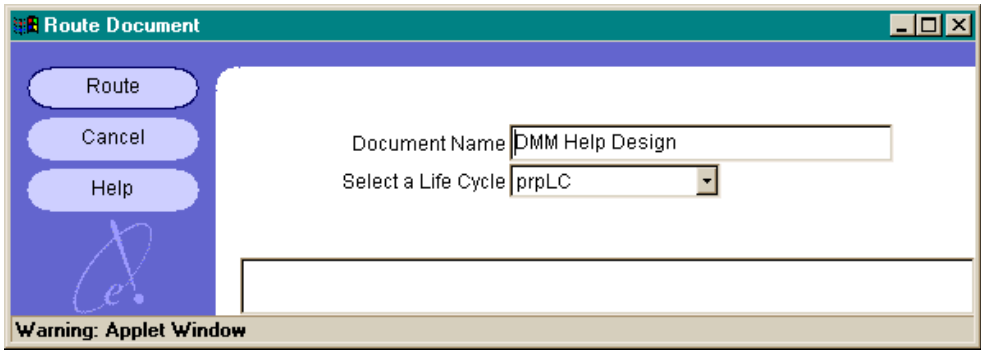

Figure 58. Route document dialogue.

Workflow services:

By using MetaDM and Enterprise PDM companies are able to automate workflows e.g. for reviewing and approving documents, typically based on the quality procedures (Figure 59).

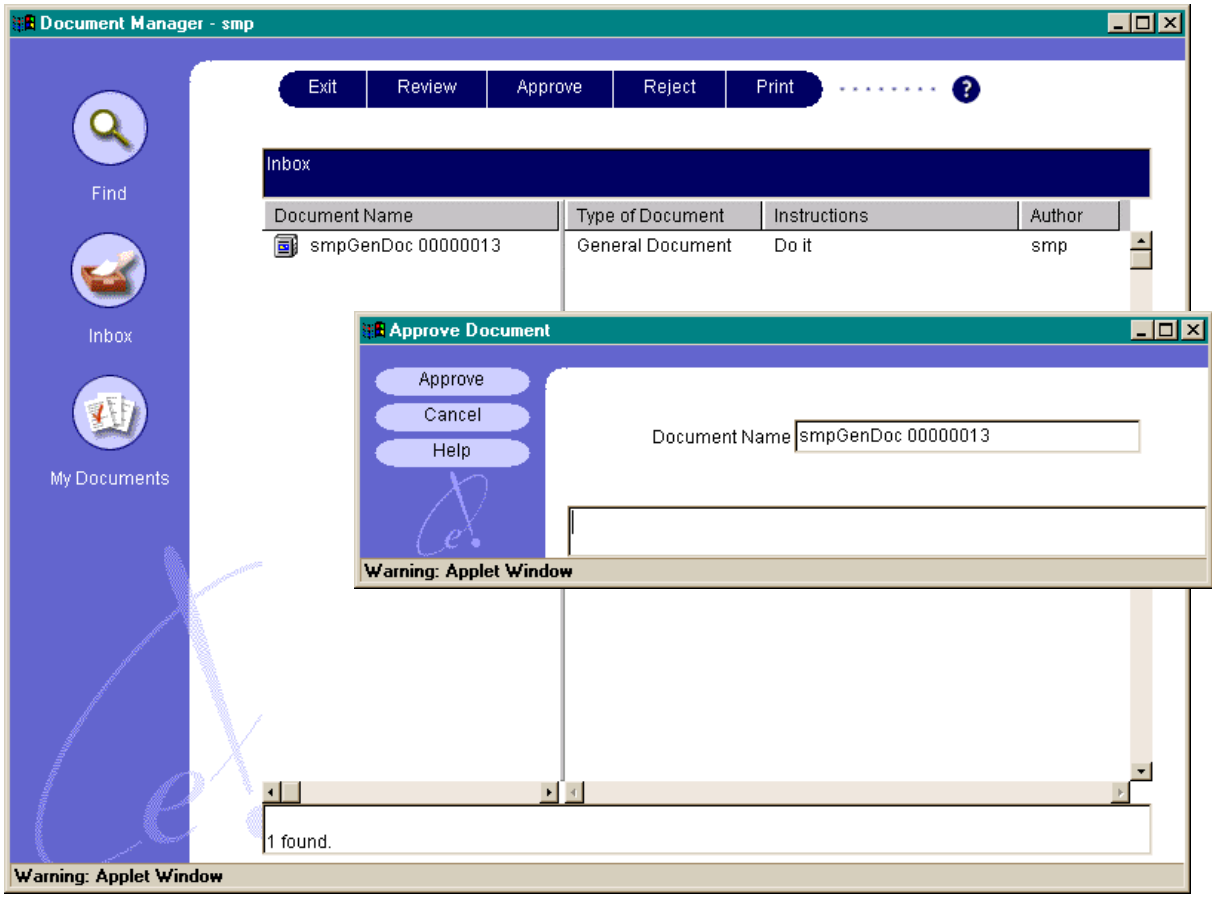

Figure 59. Approve document dialogue

Publishing services:

This service allows organisations to improve their publication process. MetaDM allows auditing and maintaining past versions and revisions of documents.

Enterprise PDM and MetaDM:

Enterprise PDM and MetaDM together provide enterprise level document management and PDM functionality. There are commonalities between these solutions but Enterprise PDM works on a broader scale. This combines documents, design geometry, and part/configuration information into the product's definition.

MetaVPDM:

MetaVPDM is a visualisation component of the Metaphase Enterprise solution series. This application tries to optimise the early stages of product design by providing visualisation tools together with other product data, for design teams to visualise new product ideas as CAD-neutral 3D models and product structures and meta-data (Figure 60). MetaVPDM uses commercial Web-browsers and e-mail applications to exchange product ideas and collaborate as product designs change.

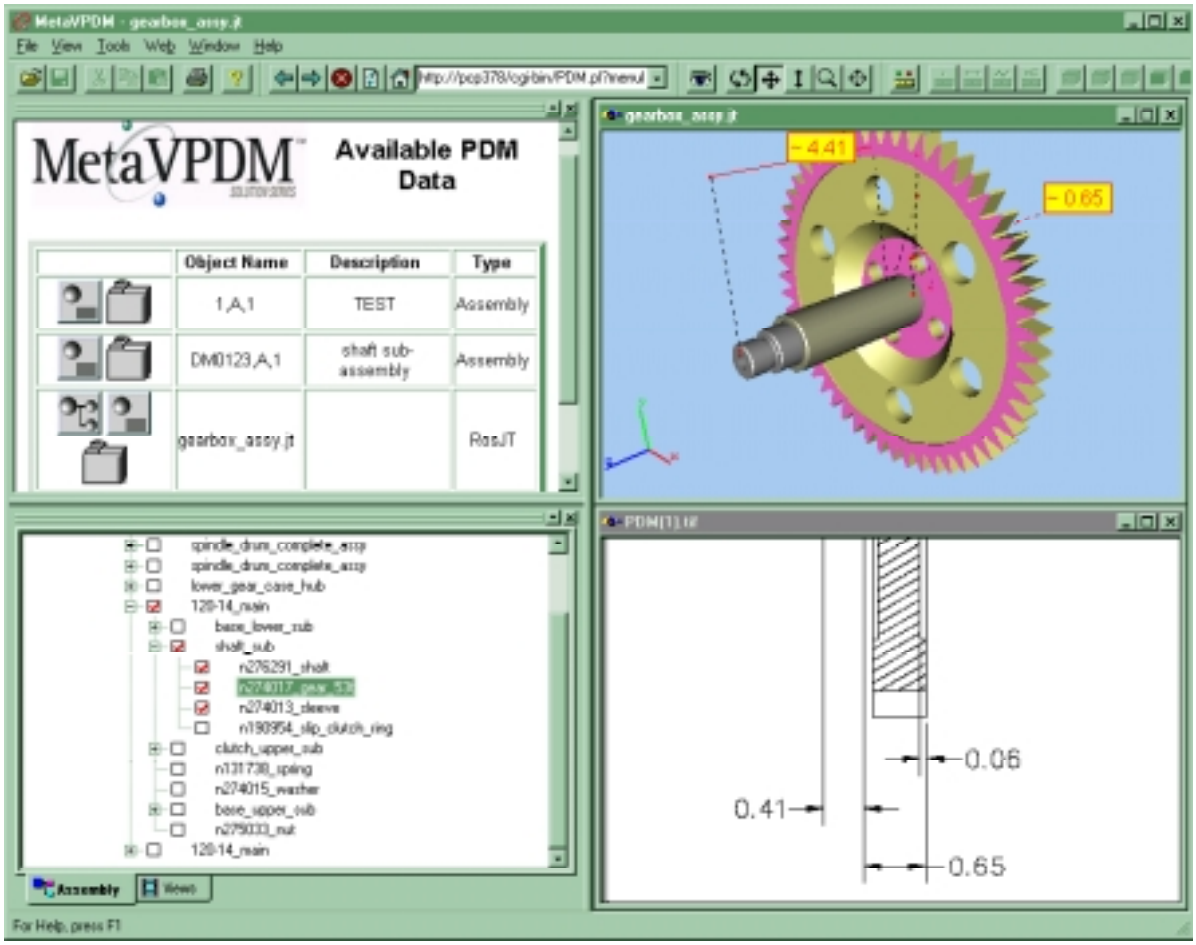

Figure 60. MetaVPDM.

MetaCM:

MetaCM is a configuration management tool which provides product configuration management during a product's life-cycle. It manages generic and specific features and product combinations to meet rapidly changing customer needs.

MetaSM:

MetaSM is a storage management component of the Metaphase Enterprise solution series. First the solution provides selective backup functions which also take into account the relationships that exist between the metadata and globally dispersed product

data. Secondly, it makes integrity checking when there are multiple PDM databases. Thirdly, it provides restore functions when the files that are lost need to be rebuilt.

7.2.2 Metaphase solution for design data management

Data Management

Data Vault and document management:

Vault support storage of all data (documents, components, assemblies, files, etc). The database solution is based on relational database technology, which has an external object model. The system supports a federated environment. This means that there are multiple repositories and the independent implementation of these repositories is possible. Check-in and Check-out functions prevent unauthorised modifications. Meta-data definition is possible as well as backup operations.

Metaphase has the MetaDM solution for document management. The solution contains version control, which allows one to follow changes and review a document history. It is also possible to copy the same document for several designers (parallel modifications) and decide after modifications which one to check-in (content comparison is also possible).

Product structure management:

Metephase allows the user to define and modify product structures. The system allows companies to incorporate documents, and design geometry and part/configuration information into product definitions. So the PDM and MetaDM together allow the configurations where the components have references to documentation (any type) (Figure 61). The user can navigate in the structure and see sub-assemblies and parts as well as define multiple views for the same product structure. The Metaphase product structure can be "virtual", which means that the whole product's structure can contain sub-structures from different design systems. The structure can contain alternate, substitute, and optional parts (Figures 62, 63, and 64). Metaphase supports the different variations of a basic structure as well as the creation of the complex one-kind-of structure (contains all variations) for highly specialised industries. It is possible to create and manipulate BOM as well as reconstruct past configurations and plan future configurations.

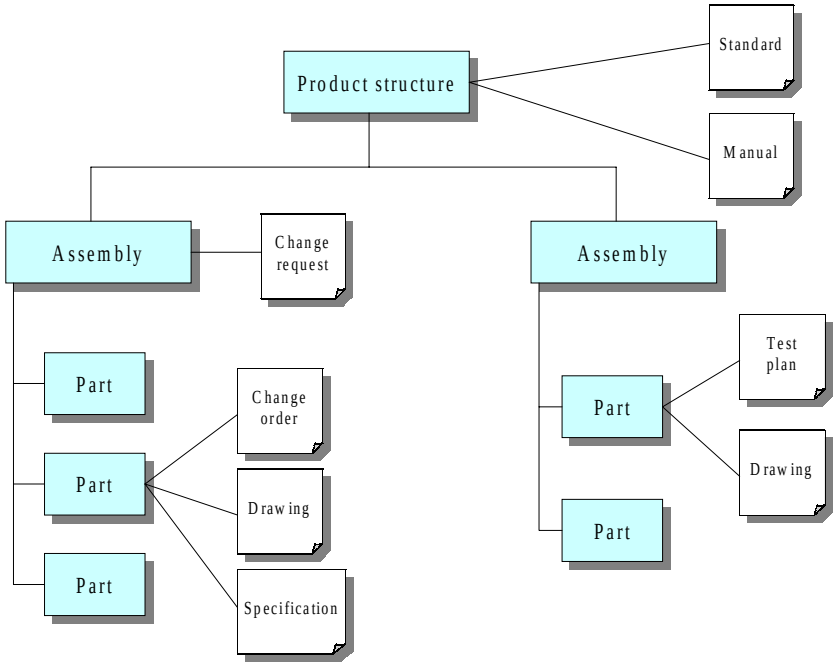

Figure 61. Documents within part/product definitions.

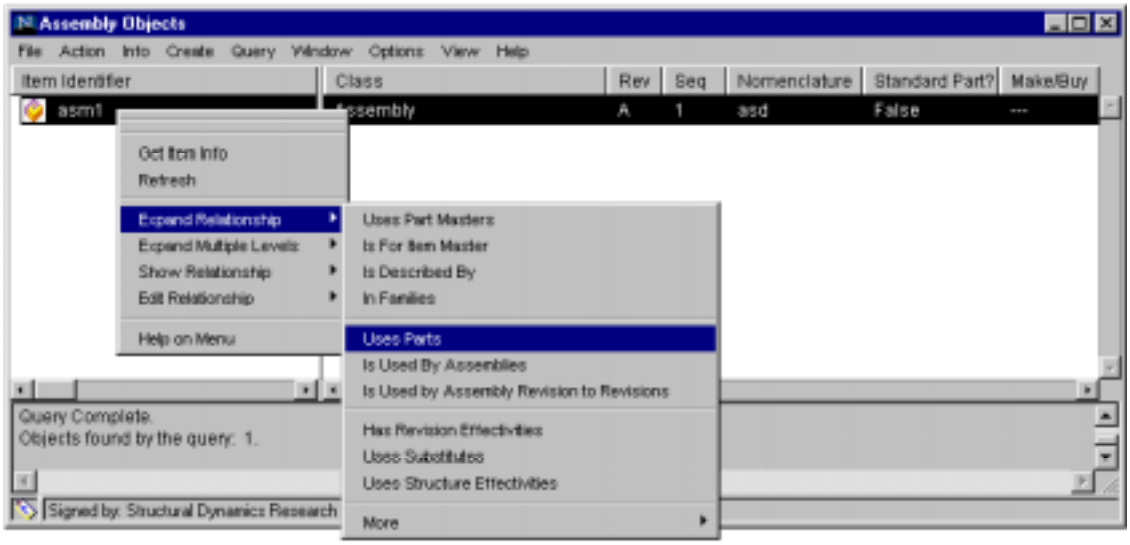

Figure 62. Expanding product structure.

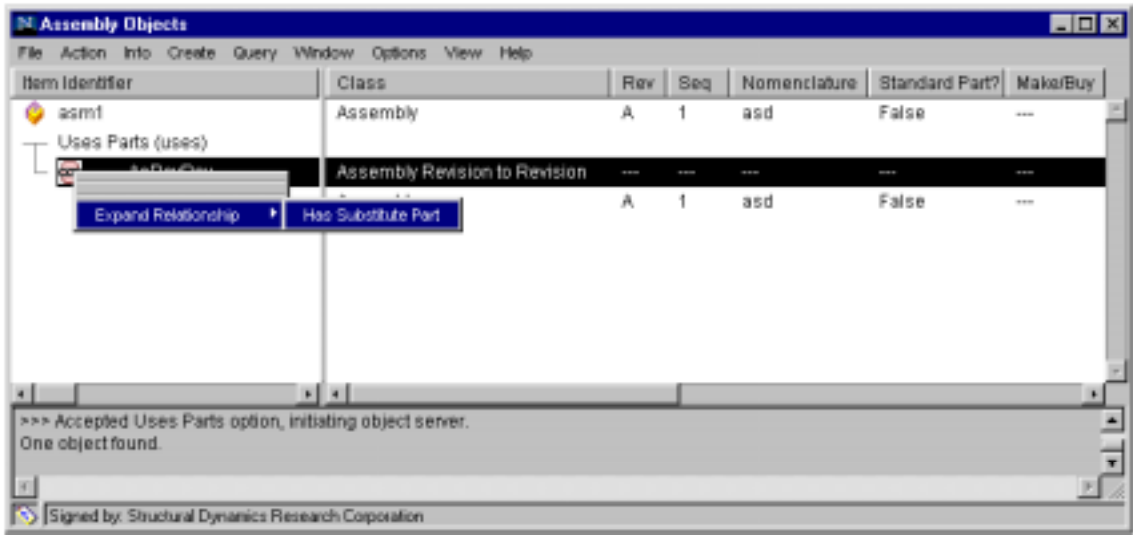

Figure 63. Viewing substitute parts.

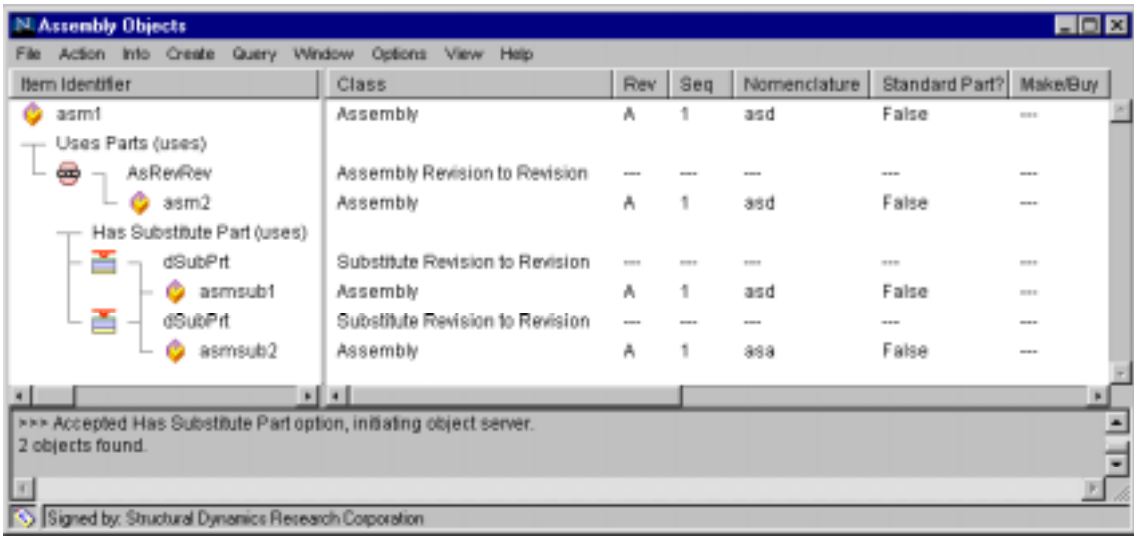

Figure 64. Product structure with substitute parts.

Classification and retrieval:

Relationships (see Figure 61) are possible between documents, parts and assemblies. This feature allows the user to attach supporting documentation to the product structure as well as find all related information about a document, part or assembly when a user is searching for information. Users can find, view and print all product-related documents. Searching is possible with the use of content-based requests (specific string) or by attribute based requests. After the search MetaDM provides a list of documents and a user can redefine his/her search. Once the user has located a particular document,

MetaDM specifies what version of the document s/he can view. Metaphase also provides the possibility to make part classifications which help to manage standard parts as well as existing custom designed parts. It uses part families and sub-families to group parts of similar design or function. This creates the hierarchical organisation of parts which can be browsed. This kind of feature also simplifies a component's reuse.

Process and life-cycle management

Process management:

It is possible to define and automate workflows for e.g. document review and approval. Organisations also can incorporate any objects into other workflows. It is possible to define workflow rules, which define people who participate in a certain process, what sequences pertain to document routing, and what happens if someone does not approve a document. Workflow participants perform tasks like routing documents for approval, reviewing documents, annotating comments, and approving or rejecting documents. Workflow capabilities also provide automatic notification features when important events take place in the workflow. The system also allows the company to define other unique processes to meet their own requirements but it does not contain extensive project management (it does contain some features).

Workflow capabilities, together with the product structure views (e.g. as-designed, as-manufactured, as-maintained) enable the full life-cycle management of products, typically together with ERP systems.

Change control solution supports the electronic release and change processes and for example it allows document incorporation to the change proposal. The change management provides complete change history, which can be useful when considering future changes.

Life-cycle management:

In Metaphase terminology, a life-cycle represents a process that involves a series of interconnected workflows that move objects through their various life-cycle states. Therefore, the difference between process management and life-cycle management is not strict. Metaphase provides the definition and execution of workflows that allows the management of an object (part, structure, etc.) from concept to obsolescence. When the object has been submitted to these processes, the user can graphically view the object life-cycle state as well as get details about any step. Automatic notification is possible when the life-cycle state changes.

Data capture & distribution

Data exchange:

Metaphase takes part in data exchange standardisation. It provides a MetaSTEP module for the data exchange and support for CORBA (see Section 6.3). The MetaSTEP provides a standards-based application interface that allows data exchange among diverse computer-aided design (CAD), product data management (PDM), and enterprise

resource planning (ERP) systems. The module allows Metaphase EPDM systems to exchange product data with any design or data management system that supports PDM Schema (see Section 4.2). It is also possible to save files manually into the system.

The system contains the following interfaces:

- I-DEAS interface,
- Pro/ENGINEER Interface,
- AutoCAD Interface,
- FrameMaker Interface,
- Mentor Graphics Interface,
- SAP Interface,
- OracleManufacturing Interface,
- Unigraphics Interface, and
- Microsoft Office interface (Figures 65 and 66).

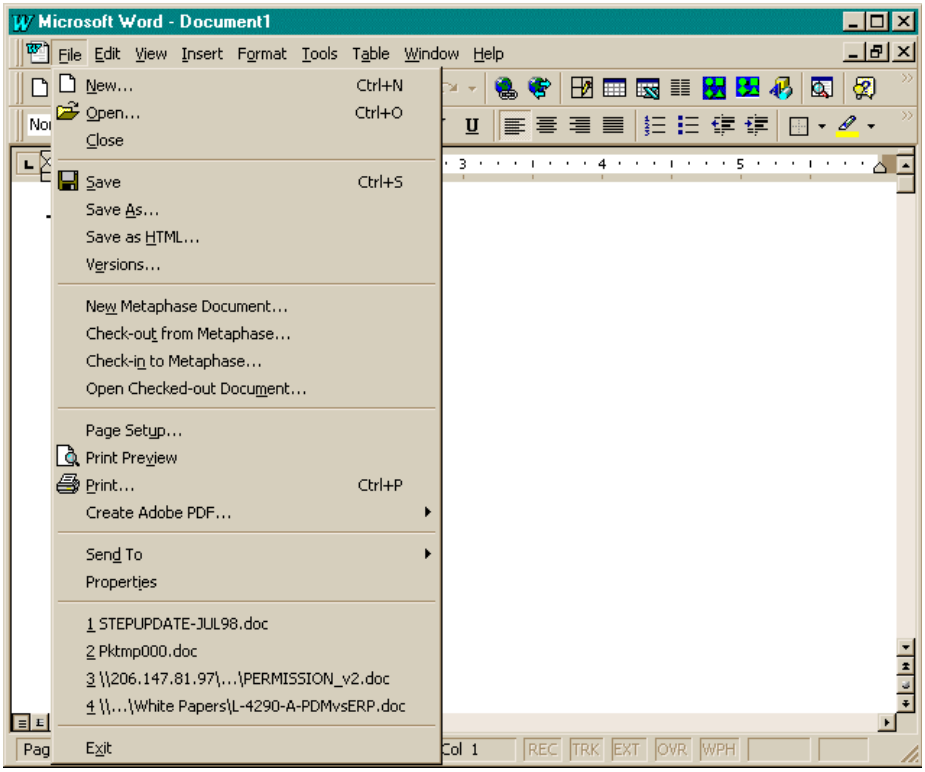

Figure 65. Microsoft Word interface containing e.g. check in and out functions.

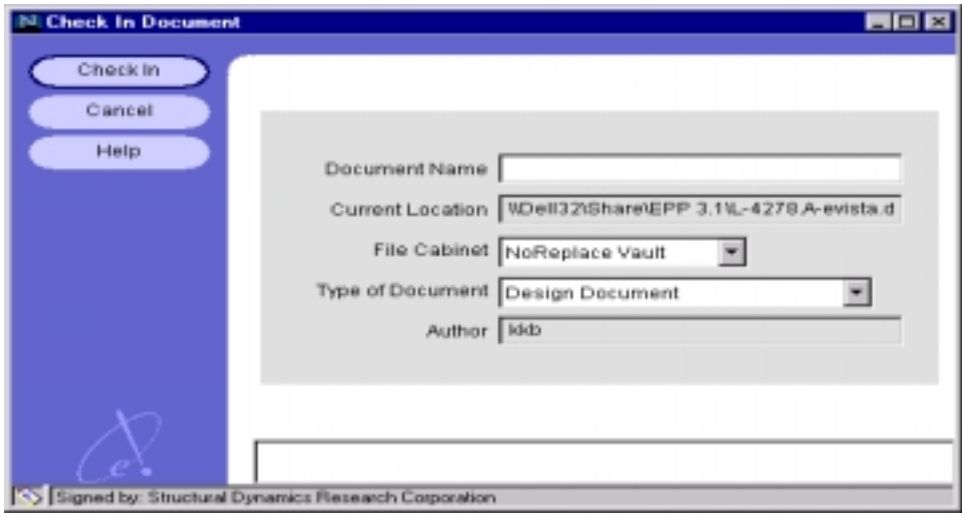

Figure 66. Document Check in dialogue.

Thus the system contains integration with MCAD and ECAD design systems, and interfaces/integrations with software design systems are underway. Nowadays, the Software Configuration Management system typically manages software product design and configuration, and released software product versions are then registered in Metaphase for the publishing of results outside the programmers' group (see Figure 40).

The I-DEAS interface connects the I-DEAS Team Data Management system and Metaphase-EPDM system. So this interface connects the team level system to the enterprise level system (see Figure 40). Items (such as assemblies, parts, and drawings) created and then put into I-DEAS libraries can be transferred to and from Metaphase. These items become Metaphase data items (item registration) when they are transferred to the Metaphase. This transfer moves items and all related sub-assemblies (relations defined in team level system) to the Metaphase. The connection can be further customised for individual needs.

Mentor Graphics interface connects the Mentor Design Manager (team level data management system) system and the Metaphase-EPDM system. This interface connects the team level system and the enterprise level system like in the I-DEAS interface. Figure 67 illustrates the schematic design by using Mentor and Metaphase. During the design process the electronics designers use registered standard components contained in Metaphase. These components can be browsed from Mentor and placed into the schematic with a single menu choice. If there is not a certain standard component it is possible to register new components to the Metaphase and then use these components in Mentor. Designers can register entire Mentor configurations including all data files and relationships to Metaphase. The designer assigns part numbers to the top-level assembly and other new components (or lets Metaphase automatically name them), and registers the design in Metaphase. Metaphase product structures may be created from the data and relationships contained in a Mentor design configuration. After that the designer

signs off his/her assigned tasks and data is transferred to the vault. It is worth noticing that a design's life-cycle state changes during design process and this can cause automatic notification. The engineer who is responsible for the simulation task receives notification about the simulation task. The engineer checks out the schematic design from the vault and performs simulation activities. If there are no problems the engineer signs off his/her assigned task and the process continues with layout design.

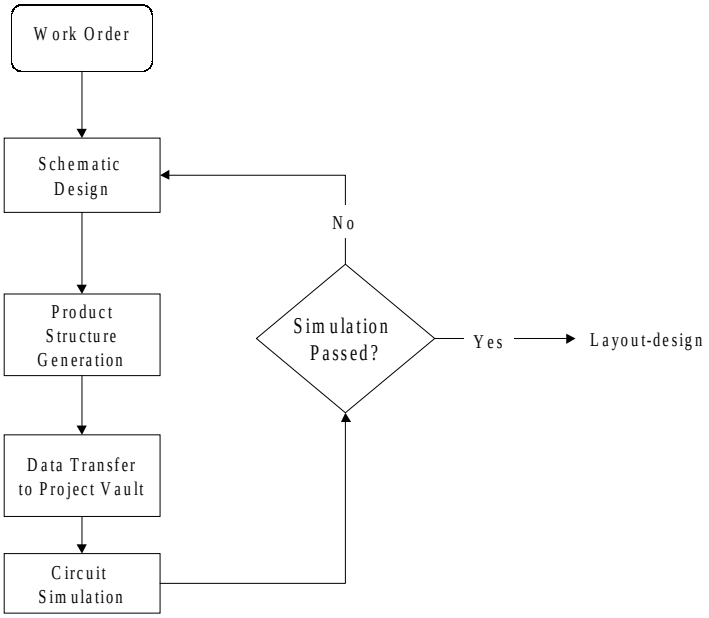

Figure 67. Schematic design using Mentor and Metaphase.

Image services:

The system provides the possibility to view, comment and redline files. In the review process documents get copied to a local machine, and after review, possible redlined comments are related to the original file. Users can view the content of document and comments in a universal format (e.g. PDF). The system automatically generates neutral viewing formats when the original information changes (e.g. PDF format). The MetaVPDM solution allows designers to visualise the product ideas as well as perform virtual prototyping.

Global access, notification, and communication:

Distribution is possible via the Web or traditional client-interface: e!Vista provides full functionality in Java, MetaWEB gives viewing and restricted editing capabilities in html/CGI, so-called classic client provides full functionality to non-Web clients. Server load can be shared between workgroup and enterprise servers. Servers can be distributed and/or federated or stand-alone. The system offers automatic notification on any event. This is useful e.g. during a review process. MetaVPDM allows easy communication during early stages of the design. It also offers the possibility to add annotations to visualised material. MetaDM provides a "Document Inbox" that contains all the things which the person has to complete.

Methods

Design knowledge management:

The system supports knowledge management by providing all kinds of information for enterprise-wide distribution.

Concurrent engineering:

The system enables companies to automate processes and provides the possibility for concurrent working. It enables early release of the information. It is also possible to create parallel revisions and choose which one to check-in. MetaVPDM supports concurrent engineering, allowing for the exchange of product ideas and for design teams to collaborate. Some features of MetaVPDM are under construction but it provides solutions for the early engineering and design evaluation (visualisation with prduct structures and meta-data, virtual prototyping, and simulation). MetaCatalog is coming out to further help design re-use and standard part utilisation integrated with 3-D geometry libraries.

7.3 PVCS Dimensions

PVCS Dimensions is a product data management solution provided by Merant. PVCS Dimensions has been chosen as part of this consideration because it has a strong connection to the software design, which is one of the main technologies in an embedded product's design. The following information is based on interviews and experiments provided by Software Engineering Center SEC, the reseller of PVCS Dimensions in Finland.

7.3.1 PVCS Dimensions system overview

PVCS Dimensions is a process-based solution for product data management. It provides features for:

- version management,
- configuration and workspace management,
- parallel development,
- distributed engineering,
- archive and retrieval,
- make and configuration build,
- change and problem management,

- impact analysis and traceability,
- process management and product structuring.

7.3.2 PVCS Dimensions for design data management

Data Management

Data Vault and document management:

PVCS Dimensions is based on industrial-standard relational database technology, implemented using the Oracle RDBMS (Relational DataBase Management System). This provides SQL access to the data and reports. PVCS Dimensions provides a central meta-database (object repository) and supports distributed development (multiple repositories and central metadata). The system offers the possibility to check-out multiple revisions and merge them when checked-in. It also supports role-based access control (e.g. certain files are available for persons defined as a Programmer). PVCS Dimensions has the following object classes:

- product: a composite object made up of all the object classes and object instances, which identify the controlled objects;
- part: a basic building block which is a group of objects that supports change control, version control, software building and access control. These blocks form a hierarchical tree structure;
- item: a physical file which is in relationship with parts. Each item is owned by a single part and may be used by one or more parts (reuse without physical duplication);
- workset: a container for all the item revisions needed to complete the allocated task;
- baseline: a baseline captures the status and the content of a workset at a milestone point in a project;
- release: a tested baseline which is ready for the customer;
- change document: a document which is used in conjunction with product items to support change control and with product parts to support change tracking.

PVCS Dimensions provides a version management tool which also allows parallel development. The tool manages all files and also manages the data that does not reside on the file system (paper documents, books, etc.). All these versioned objects are stored under a product configuration and the version-tree can be viewed graphically and reported textually. Versioned parts have attributes and relations embedded in them.

Product structure management:

The configuration in PVCS Dimensions is either dynamic or static. The dynamic configuration is a workset which is the collection of item revisions needed to complete a particular task. The content of the workset is continually refined until the baseline is reached. The baseline is a snapshot which represents a development milestone (current state of a product) within a project's life-cycle. So it is a formally accepted useful configuration at a certain moment (frozen configuration). It captures the structure and details and is used to build the configurations of the product for test and release purposes. So, a selected sub-tree of the product is captured, including parts, relationships (e.g. the "is-design-spec-of" relation between specification document and source code) and status of each item. PVCS Dimensions does not allow any modifications to the baselines (of course a new baseline is possible). PVCS Dimensions provides several types of baselines:

- release baseline: captures the details of product release. Contains only single revisions (e.g. source-code modules which are ready for the test);
- archive baseline: archives all revisions of certain items;
- merged baseline: contains selective items from the multiple release baselines;
- revised baseline: a release baseline which contains one or more related change document;
- design baseline: the structure of the product, which contains all related items.

Release is the configuration of the product, which is based on the release baseline. It is possible to track what kind of design documents relate to the certain release and who has bought that product. PVCS Dimensions also contain SW-build capability. Build, release and distribution features connect the customer's configurations and the customer's information.

When constructing product configuration the relationship between the items can be both hierarchical and non-hierarchical. This feature, therefore, enables e.g. relations as "is-affected" between items. The users can view the structure to find particular objects. PVCS Dimensions also allows the creation of a "made of list" which represents the Bill-Of-Material and is available for navigation and reporting. The system also offers an option to substitute component definition (Design Part Variant concept).

Classification and retrieval:

PVCS Dimensions allows system and user-defined attributes, which can be used when retrieving objects. The system offers querying facilities to find certain objects. It also uniquely identifies items and the user can access them by using different filtering criteria (item type, object status, time-stamp, etc.).

Process and life-cycle management

Process management:

PVCS Dimensions allows the definition of unique process models to meet a company's requirements. For example, it is possible to define one’s own change processes or use supplied change management process models. The system provides reporting facilities and automatic routing of change documents as well as pending lists which contain change documents for which the user has some responsibility. The user can use change document templates, which specify the layout for all change documents. The template can contain any fixed text and it is applied dynamically each time the change document is browsed. This means that template can be modified and modifications are updated automatically. The change document can be related to other change documents (e.g. a parent change document cannot be closed unless all of its daughter changes are implemented and approved (parallel changes). The system offers impact analysis, which announces which other items have been built from the item, for example. The system does not contain project management (but it does contain some features like process definition).

Life-cycle management:

The life-cycle feature is available for items, change documents, parts and baselines. The life-cycle contains a number of states and each transition between these states is associated with one or more roles (e.g. project manager, programmer, etc.) and the user must possess these authority roles in order to perform the transition. These roles also define access to the life-cycle object. The life-cycle correlation rules allow the definition of state-defined functions that are available in a certain state (e.g. the user can define that when an object has a "frozen" status it is not possible to attach change-documents to the objects). It is possible to track the life-cycle of the object. The system also allows document incorporation with the objects.

Data capture & distribution

Data exchange:

Using the data migration wizard it is possible to migrate existing data into PVCS Dimensions (directories and/or files). PVCS version control commands offer code and document migration from SCCS (Source Code Control System). It is also possible to save files manually into the PVCS Dimensions.

The system offers integration to several software tools (PDM functionality is available to the user from within the software tool) but integration to ECAD or MCAD is not supported. However, PVCS Dimensions provides an application programming interface whose functions support access to the PVCS Dimensions data structures and the ability to call PVCS Dimensions commands. These functions can offer customised connections to design and management tools (MCAD, ECAD, and ERP). Application launching (opening a file in a correct application) is possible by using e.g. the operating system's file extension association. This association can be overwritten.

Image services

The PVCS Dimensions does not provide any image services. However, it is possible to use commercial viewers.

Global access, notification and communication:

Client/Server architecture allows the sharing of data anywhere on the network. PVCS Dimensions also provides an Internet client for Web browsers but this feature offers only a subset of the version and change management functionality. PVCS Dimensions provides the possibility for automatic e-mail notifications and pending lists (change control).

Methods

Design knowledge management:

The system supports knowledge management by providing all kind of information for enterprise-wide distribution.

Concurrent engineering:

The system supports the early release of information as well as the file's status feature (preliminary information can have e.g. "concept" status). PVCS Dimensions supports concurrent working allowing parallel modifications and version merging. Figure 68 illustrates the use of parallel worksets.

When the code changes don't overlap the merging can be done automatically. If overlapping exists the conflicts must be solved using a graphical tool. PVCS Dimensions also supports workset synchronisation. This means that the projects can have integrated workset, which is automatically updated from nominated worksets according to replication rules (automatic and continuous). Distributed parallel development is the extension of workset synchronisation, which provides replication over a network.

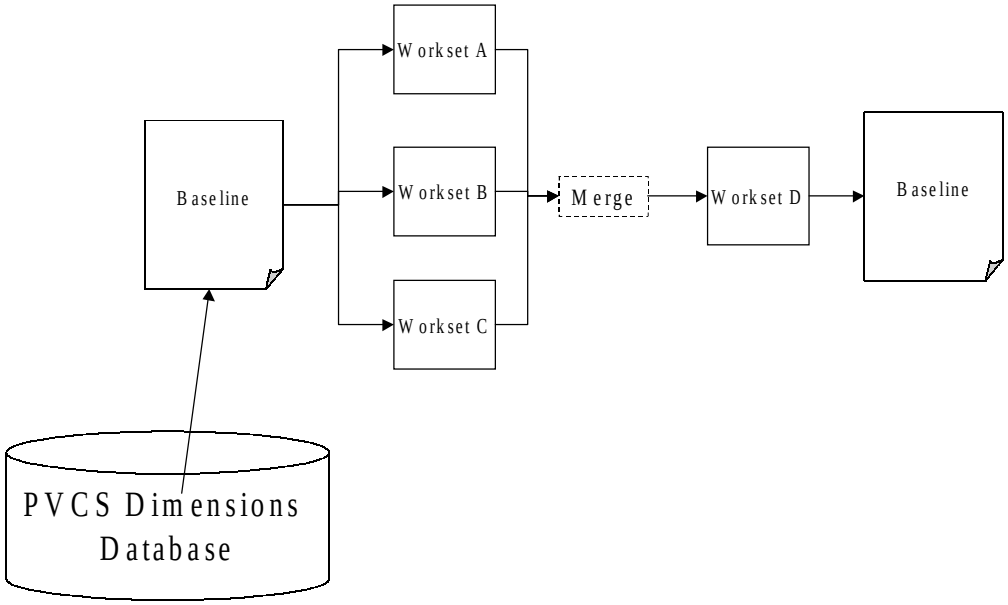

Figure 68. Parallel development of worksets A, B, and C.

7.4 Observations

The classification which is represented in this report can be used when considering the capabilities of a product data management system in the electronics industry (the report emphasises embedded product design). According to this requirement classification, three commercial PDM systems (Windchill, Metaphase, PVCS Dimensions) were considered. These systems offer many solutions for design data management although none of them supports all the requirements defined in Chapter 5. The capabilities of systems depend on the PDM product vendor's different interests, backgrounds and technologies. Basic features like the data vault is well supported. The main feature, which is not fully supported, is tool integration, although the systems offer good capabilities for customised connections, for example by using application programming interfaces. Other features whose capabilities depend on the system are:

- image viewing capabilities,
- project management,
- SW-build management,
- support for neutral data formats and data exchange, and
- support for concurrent engineering.

This report does not contain system comparison because the possibility of customising a PDM system makes it difficult to compare the capabilities of two systems. Some PDM systems offer the possibility of using third-party programs for some specific tasks (like document viewers) which also complicates the comparison between PDM system features.

8. Conclusions

The management of design data in the electronics industry in a global environment is complex. The design of an embedded product requires management of all design data containing different technologies, for example, software and electronics. Design documents, product structure and company's processes are strongly connected and this requires consideration which combines all these aspects.

This report describes the requirements for design data management in the electronics industry. These requirements are divided into three categories, although overlapping occurs between categories. These categories are data management, process and life-cycle management, and data capture and distribution. However, this classification needs further consideration before it can be used as a comprehensive framework for examining an embedded product's design data management solutions.

The solutions for design data management can be divided into three categories: enterprise-level, team-level, and design tool level. All these levels contain data management features, and the features of every level can be exploited when enterprise-level management is considered in a company.

The system review section indicates that current systems do not meet all the requirements of the embedded product's design data management. Features which are not fully supported, or depend on the system, are:

- tool integration (however, customised connections are possible),
- image viewing capabilities,
- project management,
- SW-build management,
- support for neutral data formats and data exchange, and
- support for concurrent engineering.

The electronics industry nowadays needs solutions for the enterprise level management of design data. These solutions should be suitable for the management of complex products’ data and they should also support a company's work. However, companies’ requirements vary and therefore different companies can end up with different kinds of solutions.

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Title

Product Data Management (PDM)
Design, exchange and integration viewpoints

Abstract

The electronics and electrical industries have become an important branch of industry in Finland. They produce products which are used in health care, industry, and every-day living such as mobile phones, industrial instruments and automotive electronics.

In the global markets there are many competitors and companies seeking new ways to decrease costs. This hard competition forces companies to specialise and focus on a certain market-segment. Products are containing more functionality, and product development is a continuous process to fulfil customer needs. Developers have to master a range of technology and the total amount of product data is increasing.

This report describes the requirements of the embedded product's design data management. Analysis covers different product technologies as well as development processes. The challenge of the design data management is to manage the total set of data related to the structure of the product during the product's life-cycle.

The result of the analysis is the framework which represents the requirements of the design data management of the embedded product. This classification contains three subsets: data management, process and life-cycle management, and data capture and distribution.

This framework is used to evaluate three commercial PDM systems. This consideration brings out the fact that the current solutions do not meet all the requirements of the embedded product's design data management.

Keywords

design data management, embedded product design

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