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CONTENT AND STRUCTURE OF INFORMATION FOR DISTRIBUTED CONCURRENT ENGINEERING TEAMS

Requirements for computer systems supporting concurrent engineering teams are addressed. Information processed in concurrent engineering systems has been classified according to its semantics. A generic, object independent, characteristics of engineering data has been presented. Importance of features for product geometry modeling has been emphasized.

1. INTRODUCTION

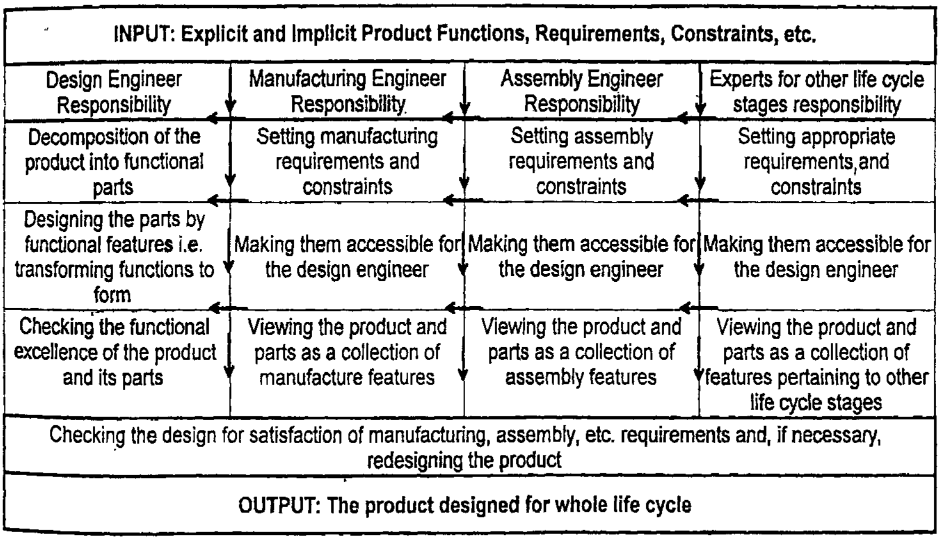
Difficult market and strong competition between producers enforce concurrent approach to the product development. This has dramatically changed the amount and structure of information to be considered in engineering design. To deal with not previously known issues of parallel processing of incomplete information not only a general view on the entire available information but also awareness of requirements for it effective management is necessary. Effective computer aided engineering systems must fulfill the specific requirements of concurrent engineering (CE). Concurrent engineering is based on parallel and collaborative actions of designers, production engineers, managers and other people involved in the product development. The concept of CE assumes that groups of experts of different fields, covering the product life cycle, work simultaneously to meet customer needs and market challenges. The requirements to computer systems become particularly demanding when teams are not co-located.

Synergy of multidisciplinary teams incorporating different aspects of the product life cycle into the final product makes the CE process more efficient than traditional, sequential procedures of product development. To bring the synergy into effect specific issues of information structuring, modeling, and management, must be solved, which is a prerequisite for streamlining information technology in CE systems.

In the next sections of the paper some results of an extensive study on information requirements for CE systems, including distributed systems, are presented [1]. Then information relevant to these systems has been classified. Furthermore, generic characteristics of engineering data have been identified and discussed. It followed that the data, which appear in engineering design problems, can be categorized into twenty groups, according to their role in the design. This categorization is generic, because it does not depend on the type of the problem. Eventually, the benefits of modeling the product geometry by features has been emphasized.

2. STATEMENT OF THE PROBLEM

Nowadays the need of introducing principles of concurrent engineering into product development process in manufacturing enterprises has generally been accepted. Despite of some communications of weighty impediments in accomplishing the genuine CE, most authors report of benefits that were gained due to concurrency [2]. It is acknowledged that a multidisciplinary approach to CE is indispensable for the entire life cycle of the product be included into the development process. Ideally, teams of multidisciplinary experts have to cooperate to make individual contributions to develop a new product, Fig.1. It gives rise to communication problems that become much more onerous in distributed organizations.



<table>
<tr><td colspan="4">INPUT: Explicit and Implicit Product Functions, Requirements, Constraints, etc.</td></tr>
<tr><td>Design Engineer Responsibility</td><td>Manufacturing Engineer Responsibility</td><td>Assembly Engineer Responsibility</td><td>Experts for other life cycle stages responsibility</td></tr>
<tr><td>Decomposition of the product into functional parts</td><td>Setting manufacturing requirements and constraints</td><td>Setting assembly requirements and constraints</td><td>Setting appropriate requirements,and constraints</td></tr>
<tr><td>Designing the parts by functional features i.e. transforming functions to form</td><td>Making them accessible for the design engineer</td><td>Making them accessible for the design engineer</td><td>Making them accessible for the design engineer</td></tr>
<tr><td>Checking the functional excellence of the product and its parts</td><td>Viewing the product and parts as a collection of manufacture features</td><td>Viewing the product and parts as a collection of assembly features</td><td>Viewing the product and parts as a collection of features pertaining to other life cycle stages</td></tr>
<tr><td colspan="4">Checking the design for satisfaction of manufacturing, assembly, etc. requirements and, if necessary, redesigning the product</td></tr>
<tr><td colspan="4">OUTPUT: The product designed for whole life cycle</td></tr>
</table>

Fig. 1. Team activities during concurrent engineering design

Presently more and more companies have branches spread across several sites and even countries. Designers, manufactures, experts, professionals etc. are often deployed across large distances and it would be futile to bring them physically together to establish directly cooperating teams. Instead, individual team members may use new communications technologies thus creating a „virtual co-location" [3], that enables them to cooperate as if they were located in one place. To make it possible and effective new requirements are to be fulfilled by computer aided engineering (CAE) systems, which are far beyond those existing heretofore.

3. FUNCTIONAL REQUIREMENTS FOR CAE SYSTEMS

To make CE possible and efficient the computer system support is indispensable. Because of not previously met specific requirements it must be a new generation of computer systems, which would create the intelligent environment for engineers and managers who are involved in the product development. For effective supporting CE team functions the following functional requirements have to be fulfilled:

- implementation of knowledge based approach to effectively carry out domain specific rules and thorough recognition of the specific domain knowledge,
- separation of individual designer context from the collaborative design context,
- making possible an individual designer to navigate information of other designers,
- maintaining relationships between information spaces of different disciplines,
- defining the procedures and rules of sharing product information while keeping the information integrity,
- defining means of detection and resolution of conflicts arising in course of parallel actions,
- resolving issues of dependency tracking and propagation of change and constraints.

Relative importance of these requirements may vary depending on the designed object complexity and the enterprise organization. It should, however, be noted that they are object independent. Hence, it is possible to establish a set of generic rules to devising the computerized environment for CE.

In general, CAE systems must support differences in approach and style of individuals, teams and top managers. For this reason CAE systems should not impose a predefined procedure for design. Autonomy of teams should be, however, restricted, as many problems arise due to unavailability of a piece of information to all interested parties. Too much autonomy can cause conflicts and inconsistencies in the design process but, on the other hand, too little can detriment the result, hindering the use of individual knowledge. The need of duplication of information should be avoided as well.

For balancing the ***autonomy and integration*** following recommendations should be taken into account.

For team

- multiple stores of the same piece of information should be avoided;
- common information models should be accepted;
- both individual and collective decisions should be admitted;
- it is required to have a common source of consistent and accurate information;
- a common language is necessary to allow smooth exchange of information and knowledge. It limits the level of autonomy of team members;
- different viewpoints on the product should be maintained, but isolation should be avoided;
- trade-offs are required between different points of view on the product design;

For the individual agent

- all team members should have access to current details of the design and to knowledge of other team members;
- each team member should be allowed to use his (her) individual methods without restrictions;
- team members must be allowed to work individually when they want to;
- individual designers' perspectives should not put constraints each to other,
- agents are free to choose application programs, expert systems and the like aids,
- individual computer environment must be ensured.

3. 1. Specific requirements for integration of distributed CAE environment

Integrated environment to support communication between sites should ensure:

- For a co-located team:
  - single unit has a common goal;
  - regular team meeting and discussions take place;
  - communication and cooperation between team members are ensured.
- For distributed teams:
  - virtual co-location and virtual working environment are ensured;
  - important actions being taken in the system are announced to others;
  - variety of facilities supporting of social interactions are easily accessible;
  - team members should be aware of other members of the team.
- For individual agent:
  - easy exchange of knowledge between individuals (knowledge is inherently distributed);
  - easy access to experts systems and other application programs for individuals;
  - existence of many small individual knowledge bases.

4. CLASSIFICATION OF INFORMATION ACCORDING TO CE NEEDS

Information requirements for design within CE differ from those in sequential engineering. The fact that many engineers working parallel must proceed without all the information necessary for tackling the next step implies making many assumption as compared with traditional design process. It requires a particular care of consistency of the product data and continuing negotiation between design agents. This results in an extremely complex flow of information in the CE system. To deal with, the structured information model must be worked out.

Different points of view yield different structure of information relevant for CE. Because of space limitation only three classifications are considered here:

(i) According to phases and stages of the product life

Each phase of the product life, Fig. 2, involves some information which is specific for this phase, although it is also of importance for other phases. For example, information for feasibility study differs from information for production, and these two differ from, say, maintenance information, notwithstanding that they may be interrelated. Thus, a structuralization the body of information in accordance with the product life phases is natural.

(ii) According to various sources of information

Taking into account sources of data for CE we can distinguish:

1. data from previous projects,
2. data from similar projects,
3. trend data,
4. competitors data,
5. project specification data,
6. information about intent and assumptions being made by engineers involved in the project,

7. test data,
8. results of analysis,
9. process and manufacturing data,
10. other.

These data categories should be checked for consistency, stored in databases, and made easy to access for the design agents.

Initial phase		Product design phase				Process design phase			Production phase			Sales phase		Consumption phase			Wear and tear phase		
Market research	Feasibility study	Requirements analysis	Conceptualization	Embodiment	Detailing	Planning of manufacturing	Assembling	Testing	Manufacturing	Assembly	Testing	Advertising	Distribution	Operation	Service	Maintenance	Recycling	Retrieval	Disposal

Fig. 2. Whole-life product cycle

(iii) According to organization of CE system

Third possible classification of data reflects the hierarchical organization of CE within the enterprise. Seven categories of information can be distinguished:

1. information about designed product (product models),
2. information about manufacturing processes,
3. information of individual member of the team,
4. information of engineers' team,
5. information of related teams of engineers,
6. organizational information,
7. information covering multiple viewpoints on the design object.

First information category is concerned with product models, which are able to describe, communicate, handle, and store all the information related to the design process and designed product, primarily definition of geometry (compare e.g. STEP standard and ISO CD 10303-1), but also specifications, assembly problems, etc. Because computer methods of product geometry modeling has currently gained sufficient excellence, the emphasis of information modeling has therefore been moved to encompass information other than those directly related to product data. Recently dominant effort is paid on capturing the information of the product behavior throughout its life cycle [4].

The second category of information pertains the phase of bringing the product into reality, i.e. means and facilities for the manufacturing. Models of manufacturing contain information of manufacturing resources and processes which are related to manufacturing functions of the company and have substantial importance for the design process as well. The contemporary tendency in manufacturing modeling evidently focuses on the use of data on manufacturing facilities and resources to scheduling and planning of manufacturing processes. The latest developments of virtual manufacturing (or virtual factory) belong to the most impressive attempts in this direction.

For CE to be effectively supported both product models and manufacturing models are necessary [3]. They make possible making decisions regarding the product life cycle features during functional and process design development phases.

Information of the individual team member should provide for each member the assistance relevant to his/her needs. For the designer it will be some part of information from the first two categories completed with relevant application programs, expert systems individual data base, and so on. Information for CE team enables the members to cooperate smoothly and to detect possible conflicts of intents enabling them to ensure parameter consistency. This is extremely important because the product design team consists of members of diverse disciplines related to design, manufacturing, marketing, finance, production and management. Information of a group of teams is similar to this for one team complemented with mechanisms ensuring consistency in parallel group-work. These take into account interactions and exchange of information between different teams.

Organizational information category supports control functions and decision making of senior management. It can be further developed to embrace entire organization of the company.

Multiple viewpoints on the product may be included in product models. They can, however, be so diverse points of view of different experts that they go far beyond that what is regarded to be a product model. One of the reason for separating this category of information from the actual product model is the need of preserving information from the past, i.e. data of the product history.

5. GENERIC CHARACTERISTICS OF ENGINEERING DATA

To meet the functional requirements specified in section 3 and to enable agents to manage concurrently information in the product development process the data have to be mapped out in the computer system. Thus there must be a model of the data and a mechanism of operation the data. To be useful for various engineering objects and problems both the model and the mechanism have to be object independent. Following the thorough study of the problem [5] many real and hypothetical cases of engineering data structure have been analysed in respect to their generic characteristics [1].

About twenty different groups of data characteristics have been identified which are likely to appear in most of engineering design problems. The identification was based on comprehensive review of relevant literature as well as on the author's experience. The following categories of characteristics have been distinguished: Structural Representations, Operational Characteristics, Abstractions, Associations, and Historical Data. Each of the categories falls into sub-categories. They are described below.

1) Structural Representation

Complex structures. Complex structures of data have multiple levels with different data entity types. For example, data of geometry contain solids which contain surfaces which contain curves, etc. There are different structural elements in the model, which need to be closely associated because the complex structure must be treated as a single object. BOM hierarchies belong to this class of structures.

Meta data. These are data that characterize other data structure and content. While the latter can be processed in different manner and controlled by different processes, the meta data must be kept independent. Meta data are independent of the different applications and of the context in which the data are used. Another case when meta data are useful is when data that were originally meaningful in a single context only eventually turn out useful in other contexts; they need, however, to be adapted. So it is necessary to describe this information on a higher level of abstraction that is appropriate for each context.

Locally contained data. This data structure is useful only within the given contextual information. For example, description of geometry for FEM is not appropriate for other purposes. Yet sometimes a part of the information contained within the group of data may be useful outside that context. It is the case when in multiple representations (see characteristic of "fractional representation") the same data content appears. For instance, main dimensions of the engine are required in more than one context. In this case a part of locally contained data must be referenced to other groups.

Self Defining. It is the ability to describe the group of data by attributing it a defining name(s). It provides the information about the data (meta - data), which must be available to process the data. For example, in order to collect information for designing an assembly, the type of assembly should be indicated.

2) Operational Characteristics

Disclosing identities and similarities. If originally the same information has been represented in different schemes then it should be possible to identify this common origin. Also if the information at the beginning is represented roughly for a local usage and then the representation is refined and developed to a shared usage it is essential to associate these representations to one concern.

Rules. Rules contain information associated with data which is used in procedures that control the dynamics of information in the environment.

Views. Multiple views of the information gathered within a group mean using this information outside for different purposes. It requires an operational capability from the database or ability to data rearrangement according to each view.

Status of the design data. This characteristic describes different statuses the design data get during the life of a project.

3) Abstractions

Hierarchical decomposition. Hierarchical decomposition of a set of information is used in design when abstractions or refinements are necessary. These operations resemble filtering out the irrelevant information to extract what is needed. Hierarchical representation is an effective means for coping with complex information (provided it has some hierarchy). It is a discussion question whether derivations of information should be performed each time from the basic information or perhaps the derived forms should be retained.

Fractional decomposition. Fractional decomposition appears when information of an object is separated into different groups according to various points of view or using multiple representations. An example may be information for designers and manufacturers about the product or different representations of machine part geometry: *CSG, B-rep, etc.* Representations for different phases of the product life cycle also belong to this category. Problems may arise here with translation of one representation to another and with redundancy and consistency of information included in different groups.

4) Associations

Simple Association identifies an object as being of the same type as some other object(s), i.e. the objects belong to the same class.
Aggregate Association specifies that some objects are contained in other objects.
Actual Association states that an object is somehow associated with other objects.
Occasional Association establishes possibility of attributing an object with reference to other objects.
Derived Association appears when some object may be derived from other objects.

5) Historical Data

Duration. Technical data need to be available for a longer period of time that the length of the life cycle of the product. For example, in the aircraft industry, technical data may need to be available for twenty years (in the nuclear industry about fifty years).
Versions. During the life of a project it may be necessary to preserve data about different versions of the design. It would not be thoughtful to get rid of the older data because older versions of design may be still necessary e.g. when a part of the design was only slightly altered or when reasons for the changes are of interest.
Variations. Variations concern maintaining different values for the same data. These different values may be the result of project evolving during some time. It is necessary to keep these different values in the data base.
Three types of databases: files, relational, and object oriented, have been compared as to their capability to represent the listed characteristics. Particular attention has been paid to the object oriented database. The results obtained are similar but not identical to those from [6]. Summarized results have shown that object oriented databases are more applicable for modelling of data than files or relational ones, but even they do not fully satisfy all needs of engineering data modelling [1]. Object oriented databases are capable to model abstractions, associations and structures but not operational characteristics. Thus, some additional infrastructure is required to support the lacking operational capabilities. This may be a form of data dictionaries in conjunction with appropriate control technology.

5.1. The role of features in modeling the product geometry

Geometric data of the product are a core of CAD/CAM/CAE systems. There are many ways of geometry representation in computer systems, each of them is based on a structuralization of the information about the product geometry. Two information categories may be distinguished: syntax and semantics. The syntax refers to the mathematical and topological information of geometry. The semantics refers to the meaning of the geometrical data in the real world. Different representations of the 3D geometry differ in their suitability to expressing the syntax and the semantics of geometry and to mathematical computation. The basic techniques for the geometry representations are:

- Two-dimensional views,
- Wireframe models,
- Surface models,
- Boundary representations,
- Constructive solid geometry,
- Parametric representations,
- Variational geometry,
- Feature-based representations-

It has been proved that there is no ideal method of representation. Feature Based Representation, Boundary Representation and Variational Geometry are the most promising ones if all categories of information are necessary. Boundary representation is particularly good for mathematical calculations while features are most suitable when representation of both: syntax and semantics, comes in question. Thus, representation by features is particularly promising tool for product geometry representation in CAD/CAM environment. Most researchers share the opinion that a feature is an abstraction of low-level design information to a high-level modelling primitive which encodes engineering significance of the primary property attributes. From among of many definitions we quote two, which perhaps are the most relevant to the subject of the paper [7]:

"A feature is any geometric form or entity that is used in reasoning in one or more design or manufacturing activities".

"A feature is a partial form or a product characteristic that is considered as a unit and that has a semantic meaning in design process planning, manufacture, cost estimation or other engineering disciplines".

Features are viewpoint dependent. One can have multiple feature models for a part or assembly. This arbitrariness in interpretation of features is a weakness of the concept but, on the other hand, it agrees well with the way engineers reason about the designed object. On general, features are not limited to being geometric entities nor are they limited only to design and manufacturing although most of the research to date has been on geometric features for design and manufacturing.

6. CONCLUSIONS

CE team working in the computerized environment can be seen as a very complex, inhomogeneous cybernetic system which is aimed at the development of competitive product. Computer systems for concurrent product development processes have to meet specific functional requirements, addressed in section 3, which are crucial for capability of supporting concurrent functions. The issues of devising, establishing and operating these systems pose a new challenge for developers of computerized environments.

Three basic groups of information relevant to concurrent engineering needs have been identified.

Twenty object independent characteristics of engineering data has been addressed. Information about capability of different databases to model these characteristics has been mentioned. Object oriented data bases were found the most satisfactory. Although there are some characteristics that can not directly be represented in object oriented paradigm, this drawback can be overcome by some additional programming. Moreover, object oriented approach is well fitted for operation with features.

Modelling the product geometry needs the ability to represent the syntax and the semantics of geometrical information. Various methods of geometry representation have been evaluated. Feature based representation was found the most suitable for computer representation of product geometry for engineering purposes.

The results presented in the paper contribute to better understanding of information processing within CE systems and may also be useful at the conceptualisation of computer supporting systems.

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