Different Approaches to Concurrent Engineering

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Abstract
Technology and market changes introduce different problems in the product development arena, and firms are considering various structural relationships to help them cope with these changes. Concurrent engineering (CE) is a mechanism that can reduce these change effects and improve an organization's competitive capabilities.
This paper carefully defines CE, explains new product development methods by applying it, gives the tools for it, compares the CE with Sequential Engineering (SE) and also defines the organization structures in Big v.s. Small Companies in the application period of Concurrent Engineering.

Keywords: New Product development, Concurrent engineering

1. Definition of concurrent Engineering

Concurrent engineering, sometimes called simultaneous engineering, or parallel engineering has been defined in several ways by different authors. One of the most popular one is that by Winner et al. (1988), who state that concurrent engineering 'is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support.' This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.

Therefore, CE represents an organisation's ability to carry out product development as a series of overlapping phases, which delivers product on time, to provide customer satisfaction at the right price [7].

Therefore concurrent engineering can be defined as:

1) A philosophy of product development: Integrating multiple design issues
2) A method of product design: Integration of multidisciplinary folks into design team
3) A method to lead people: Design issues are represented in the people
4) What is not concurrent engineering:
    a) It is not the "over the wall"
    b) Nor "off the wall" (it's being used and is here to stay)

The goal of Concurrent Engineering is to improve the interactive work of different disciplines affecting a product. The following are some of the benefits:

a) Minimize the product life cycle - Eliminate the redesign procedure
b) Decrease production cost results from the minimization of the product life cycle
c) Maximize product quality - By spending more time and money initially in the design cycle and ensuring that the concept selection is optimized, the company can increase the prospect of delivering a quality product to the customer.
d) Teamwork - Human Resources are working together for a common product.

2. Concurrent Engineering vs Sequential Engineering

Sequential engineering, also known as serial engineering, is characterized by downstream departments supplying information to design only after a product has already been designed, verified and prototyped [1], in order to change what design engineering did wrong, or what could have been improved. A flow diagram of the serial engineering organization is shown in Fig. 1a.

In serial engineering, the various functions such as design, manufacturing, and customer service are separated. The information in serial engineering flows in succession from phase to phase. For example, the prototype model, verified by either simulation or prototyping or both, is reviewed for manufacturing, quality and service. Usually, some changes are suggested after the review. If the suggested changes in the design are made, there are increases in the cost and time to develop the product, resulting in delays in marketing the product. If the changes cannot be made because of market pressure to launch the product quickly, or the fact that the design is already behind schedule, then specialists in other functional areas or managers from manufacturing, quality, and service, among others, are informed of the impending problems. In sequential engineering a department starts working only when the preceding one has finished, and, once a department has finished working on a project, or part of a project, this is not planned to come back: information flow is only one way.

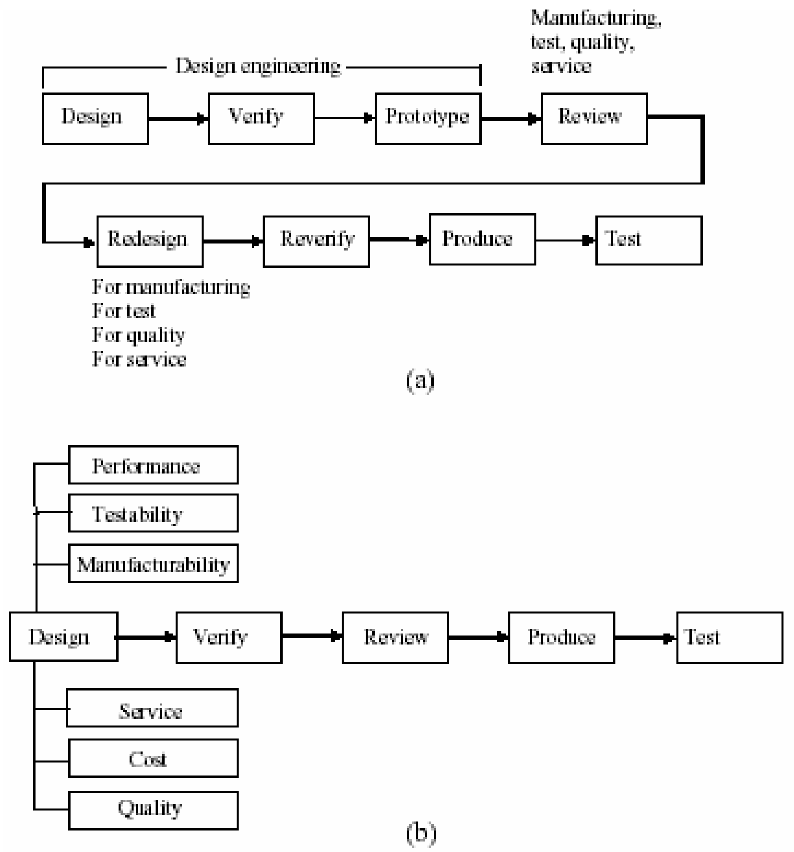

Fig. 1. (a) Flow Diagram of Serial Engineering Organization and (b) Flow Diagram of the CE organization

On the contrary, in CE all functional areas are integrated within the design process. In this case information continuously flows back and forth among all functions. During the design process CE draws on various disciplines to trade-off parameters such as manufacturability, testability and serviceability, along with customer performance, size, weight, and cost [1-2]. A flow diagram of CE is shown in Fig. 1b. The decision making process in a CE environment differs from sequential engineering in that at every stage decisions are taken considering the constraints and the objectives of all stages of the product life cycle, thus taking at the product design level issues that are usually addressed much later, thus giving the possibility to achieve a better overall solution [2,3]. The integration of other functional areas within the design process helps to discover hard to solve problems at the design stage. Thus, when the final design is verified, it is already manufacturable, testable, serviceable, and of high quality. The most distinguishing feature of CE is the multidisciplinary, cross-functional team approach. Product development costs range between 5% and 15% of total costs, but decisions taken at this stage affect 60–95% of total costs [4]. Therefore it is at the product development stage that the most relevant savings can be achieved. Examples of successful CE implementations are reported from all over the world:

- Suppliers involvement, a careful selection of team members, a hands-off management, a progressive development and the adoption of CE (through ‘‘design for y’’ methods) within ZETA and MTX75 programmes lead Ford Motor Company to dramatically decrease time to market, whilst increasing quality and decreasing costs [4].
- The support of management and the use of QFD, design for manufacture and assembly, a top-down approach and cross-functional teams were the keys to the success of the Hewlett Packard’s 34401 Amultimeter [5].
- In 1990 Bull Worldwide Information Systems Inc. improved manufacturers’ distributor performance using QFD; the key factors were maintaining employees’ motivation and involvement, continuing education for the work force, correctly anticipate and interpret customers’ expectations and emphasize prevention [5].
- An extreme example of fast product development, integrating customers, is the eBay company. Its product, a consumer auctioning website, evolves through suggestions from its customers. They are constantly monitored and their suggestions are turned into product upgrades in a matter of days.

The cross-functional design teams include all of top management, who is required to auction items themselves in order to share the customer’s experience.

Although results of CE can be impressive, the adoption rate and the completeness of implementation differ markedly between different companies and different countries. Moreover, CE is an integrated approach which consists of different tools, techniques, policies, etc. therefore the measures of such implementation is not straightforward.

When entering the global market the companies encounter several difficulties, the most important one being excessive time for new product development. This problem can be solved by transition from sequential engineering to concurrent engineering, [7]

3. New Product development in Concurrent vs Sequential Engineering

When developing a new product (here we are dealing with development of a product and its production process), it is necessary to harmonise all development stages—only in this way the product development time can be reduced

Concurrent product development time is reduced by 50% or more [10] due to the following reasons:

* activities run in parallel,

* team members have regular meetings which allow fast and efficient exchange of information,

* responsibility for all product features is transferred to teams (no time is wasted for searching the person ‘‘who is to be blamed for errors ’’).

Costs of integrated (or concurrent engineering (CE)) product and process development are lower than sequential engineering costs (SE), as presented in Fig.2.

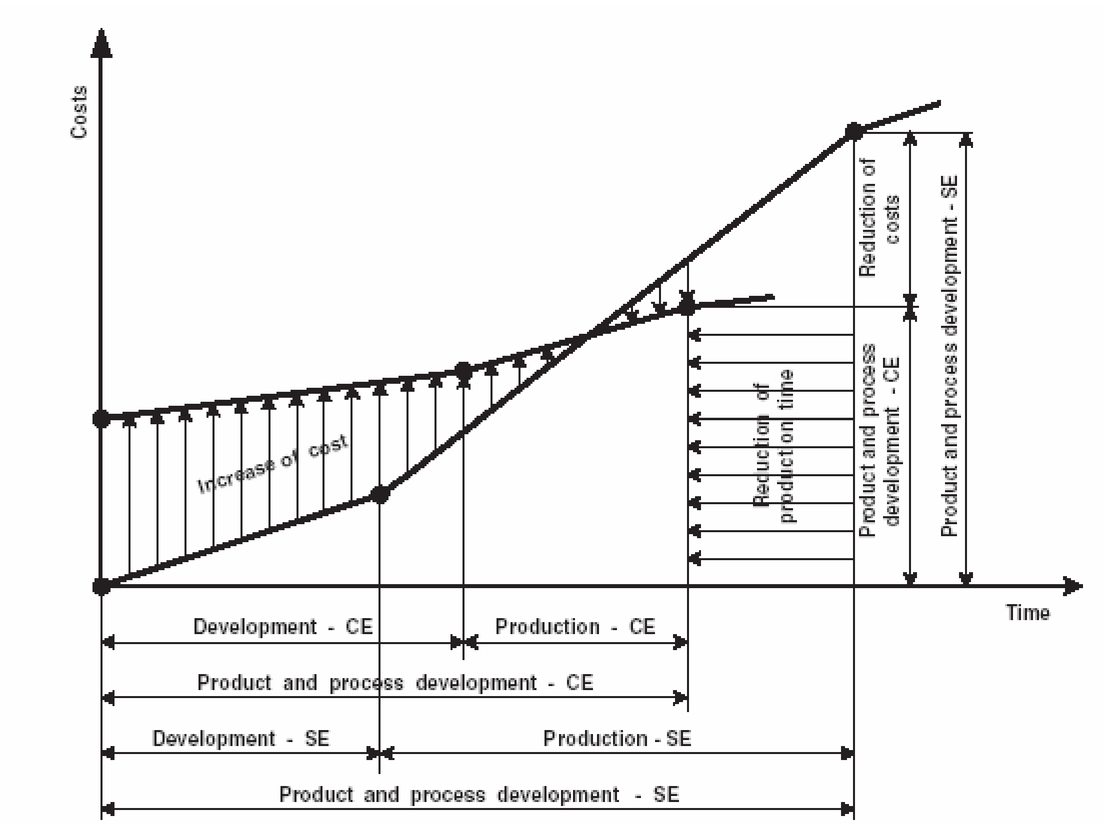

Fig.2 Costs of Sequential and Concurrent Product and Process Development

In sequential product and process development, product development costs increase slowly due to sequential execution of activities, while costs of manufacturing and use increase rapidly because of long iteration loops for execution of required modifications.

In concurrent product and process development, costs increase rapidly in the beginning of development due to intensive activities during the early development stage, while costs of manufacturing and use increase slowly because of short iteration loops for execution of required modifications. Today only those companies can successfully compete on the market which can offer the customers the right products at the right time and price and of the right quality —therefore the companies which are able to adapt to the wishes and requirements of the customers.

Fig.3 presents an overview of the concurrent engineering tools; knowing and using these tools ensures better quality of products.

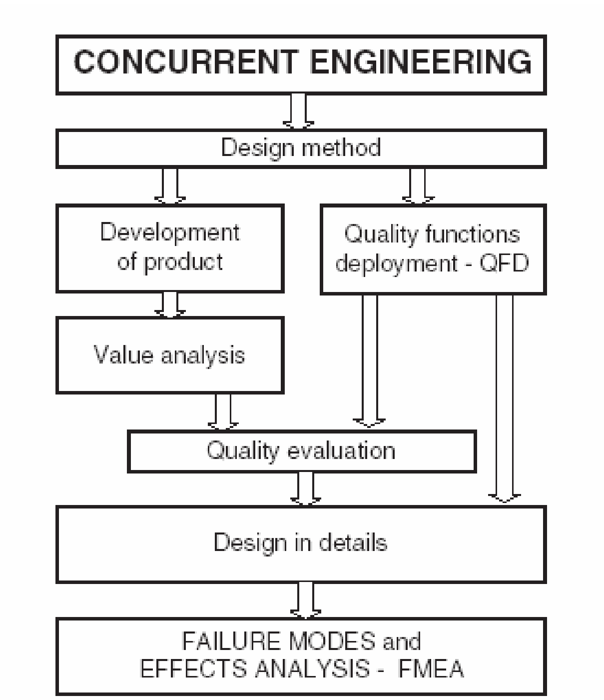

Fig.3 Concurrent Engineering Tools

From the tools listed the following two methods:

*quality functions deployment (QFD) method

*failure models and effects analysis (FMEA)method

present the methods which take care of transfer and fulfillment of customer wishes and requirements in all product development phases.

Quality function deployment (QFD)

QFD was developed in Japan in 1972 and introduced in the United States in the late 1983 (Akao, 1990). Using this method, Toyota was able to reduce the costs of bringing a new car model to market by over 60% and to decrease the time required for its development by one-third (Ullman, 1992). QFD consists of several activities supported by various tables and matrices. The basic idea is to translate customers' requirements into the appropriate technical requirements for each stage of product development and production. The procedures are divided into the following six steps;

Step 1: Identifying the customers.

Step 2: Determining customer requirements.

Step 3: Determining relative importance of the requirements.

Step 4: Competition benchmarking.

Step 5: Translating customer requirements into measurable engineering requirements.

Step 6: Setting engineering targets for the design.

The benefits of using QFD are:

1. The lead time of developing a new product is shortened.
2. The number of design changes is reduced.
3. The uncertainty of the design problem is reduced.
4. The designed product more fits the customer needs.

Failure mode and effect analysis (FMEA)

FMEA is an important design and manufacturing engineering tool intended to help prevent failures and defects from occurring and reaching the customer (Gordon and Isenhour, 1990). It provides the design team with a methodical way of finding the causes and effects of failures before the design is finalized. In performing an FMEA, the product and/or production system is examined for all the ways in which failure can occur. Typical failure modes would be:

1. Failures due to incorrect design or improper design.
2. Failures due to improper manufacturing method and incorrect assembly.
3. Failures due to bad quality management.
4. Failures due to incorrect operation.

5. Failures due to ill-considered aspects in safety design.

The implementation procedure for FMEA is shown below:

1. Identify the functions of parts.
2. Investigate the reasons of unsmooth operation.
3. Analyze the degree of influence and select key factors.
4. Propose the improvement strategy for the selected key factors.

For convenience to analyze the failure modes, four grades are divided as shown in Table1. From the relative values associated with pairs of activities, a set of weights are associated with individual activities. Failure modes of the parts deployed in the quality house.

The grades of failure modes

Grade	Degree of failure	Explanation
1	Extreme serious	Cause a huge lost in life and safety
2	Very strong	Have a large lost
3	Moderate	Nearly no lost
4	Light	Can be neglected

Table 1

Stages and activities of the new product development process

Concurrent and sequential engineering usually consist of seven stages of product development process [6]:

- definition of goals,
- feasibility study,
- development,
- design,
- process planning,
- manufacturing and assembly,
- delivery

In concurrent product development there are interactions among individual stages of product development process, while there are no interactions in sequential product development. Track-and-loop technology was developed for implementation of these interactions [7].

Type of loop defines the type of co-operation between the overlapping process stages. Winner [8] proposes the use of 3-T loops, where interactions exist between three stages of product development process.

When 3-T loops are used (Fig.4) new product development process consists of five 3-T loops. When developing a new product it is first necessary to determine its field of use, which corresponds directly to the target market. It is necessary to make a feasibility study which is the foundation for definition of the product development process.

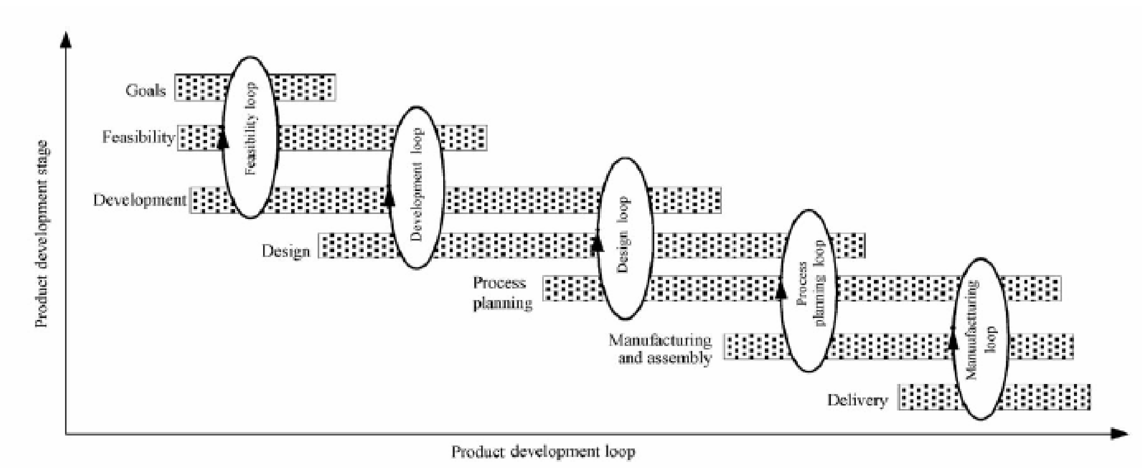

Fig.4 Track and Loop Process in New Product Development

Feasibility study consists of:

* concept of development and design,

* definition of commercial conditions for product development,

* definition of financial conditions for successful project implementation,

* definition of approximate organization model for project implementation, and

* definition of teams for product development process.

Results of this study are the foundations for definition of the basic plan of the new product development process. In the product development process, it is necessary to ensure dynamic execution of activities as additions to the concept. If these additions reach such an extent that it is difficult or even impossible to achieve the goals, it is necessary to repeat the feasibility study, taking into account the changed conditions.

There is an inter-loops partial information exchange which allows for parallel execution of individual activities in stages of new product development process.

Fig.5 presents the information how and connections between 3-T loops in the product development process.

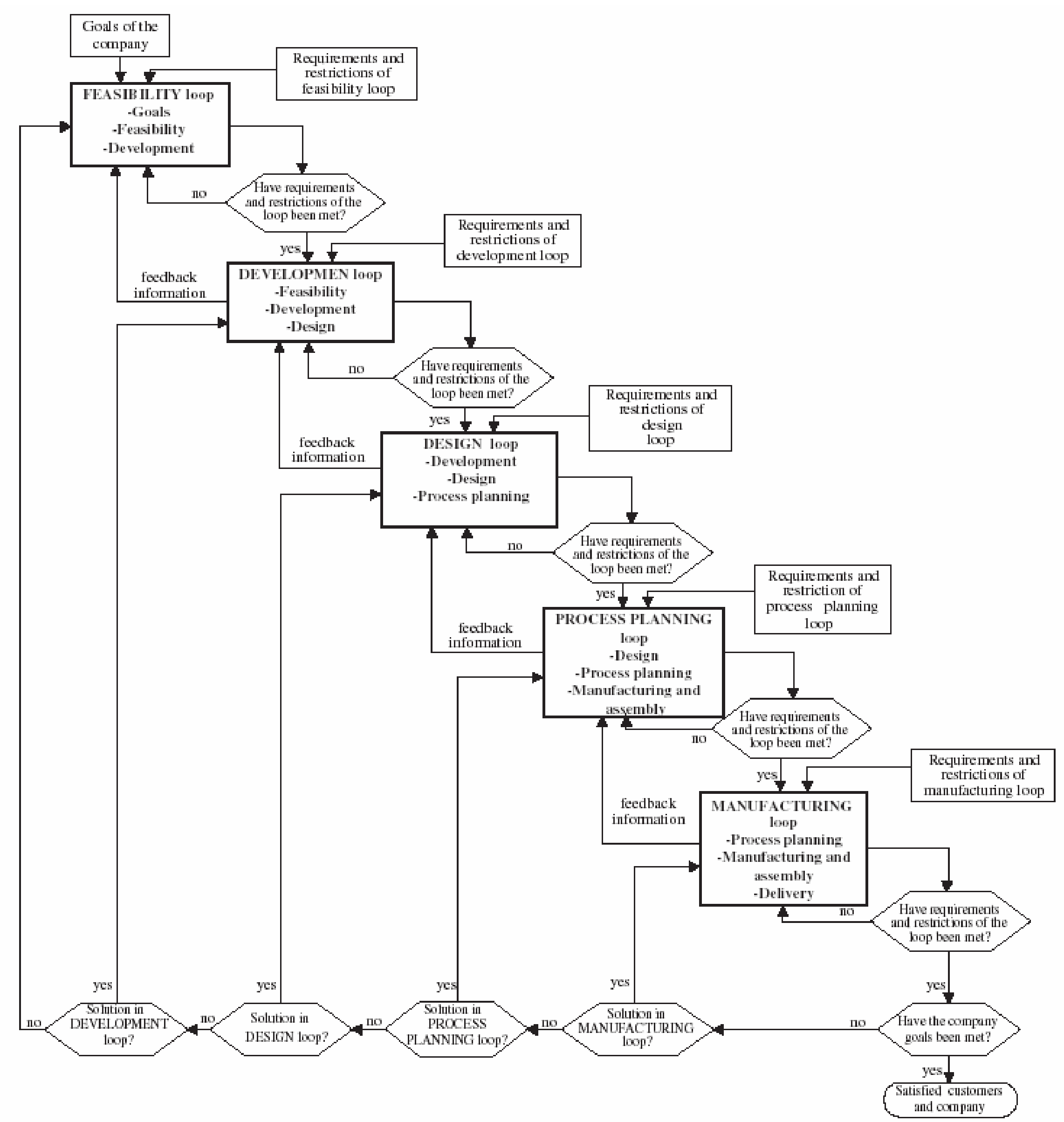

Fig.5 Information flow between 3-T Loops in the product development process

Output data of a particular loop are the input data for the next loop.

Input data of the feasibility loop are:

* voice of the customer (market analysis results, feedback information on products, experience of teams),

* strategy of the company (target price of the product, estimated investments and costs, available and required resources),
* knowledge of the product and techniques,
* reliability of the product (planning the product 's life-cycle, possible repairs, re .ts),and
* special wishes and requirements of the customer.

Output data of the feasibility loop are:

* development goals,
* goals regarding quality and reliability of the product,
* plan and execution of quality control,
* list of materials,
* draft of special requirements of the product and process, and
* draft of the process organization.

Output data of the development loop are:

* FMEA of design (an analytical method which tries to predict errors in design, frequency of errors and their influence on design),
* DFM/DFA (design for manufacturability and assembly),
* approval of the product concept, and
* building the prototype.

Output data of the design loop are:

* drawings and CAD models,
* technical specifications,
* material specification, and
* requirements regarding measuring and testing equipment.

Output data of the process planning loop are:

* evaluation of the process quality,
* plan of the manufacturing process,
* FMEA of the process,
* quality control plan,
* instructions for work, plan for analysis of measuring equipment capability,
* test series,
* analysis and estimation of measuring equipment capability,

* analysis and estimation of the process capability,
* approval of the process and product,
* approval tests, and
* control plan for regular production.

Output data of the manufacturing loop are:

* reduction of defects,
* customer satisfaction, and
* supply and service.

Analysis of the track-and-loop product development process, as shown in Figs.4 and 5, reveals that the concurrent engineering is not possible without a well-organised team work.

New product development is costly. For example, Booz et al. (1982) found that only one of seven new product ideas are carried to the commercialization phase. This means that the successful product must not only return its unique development cost, but cover the costs of the other six products that received attention but were not introduced. The high failure rates and the high costs make new product development risky. But new product development can be managed so that the risks are minimized and the profit maximized. The failure rates can be reduced if high-quality products are produced. Quality Function Deployment (QFD) tool plays an important role here (Erikkson and McFadden, 1993 and Graessel and Zeidler, 1993). More recently, Lester (1998) argues that the success of a new product development effort hinges on 16 critical factors in five areas:

(1) senior management commitment,
(2) organizational structure and processes,
(3) developing attractive new product concepts,
(4) forming a venture team, and
(5) project management.

Products have characteristics that describe their performance relative to customer requirements or expectations. The quality of a product is measured in terms of these characteristics. A basic principle of Total Quality Management (TQM) is that quality must be built into the development process. If the process is not controlled the quality of the products is random and has to be tested post facto. If the process is controlled it is possible to predict the quality of the products. Simultaneous Engineering is important in present industry (Gordon and Isenhour, 1990). The theory behind Simultaneous Engineering is to create the 'perfect' design. In this instance 'perfect' stands for the best design possible in terms of its aesthetics, efficiency, practicality, easy assembling and manufacturing qualities as well as lowest overall cost.

Concurrent engineering and team work

We are dealing with team work when a team is oriented towards the solution of a common goal. Team work is an integral part of concurrent engineering as it represents the means for organizational integration.

There are seven elements (7Cs) in team cooperation philosophy [7]:

* flexible, unplanned and continuous collaboration,
* commitment to meet the goals,
* communication (exchange of information),
* ability to make compromises,
* consensus in spite of disagreement,
* coordination (managing interdependencies between activities),and
* continuous improvements in order to increase productivity and reduce process times.

4. Organization Structures of CE in Big vs Small Companies

Team composition in big companies

Concurrent engineering is based on a multidisciplinary product development team (PDT)[6,8]. PDT members are experts from various departments of a company and representatives of strategic suppliers and customers (Fig.6).

PDT members communicate via central information system (CIS) which provides them with data about processes, tools, infrastructure, technology, and existing products of the company. Representatives of strategic suppliers and customers —as they are located away from the company —participate in the team just virtually, using the Internet technology (Internet information system (IIS)) which allows them to use the same tools and techniques as team members in the company [9].

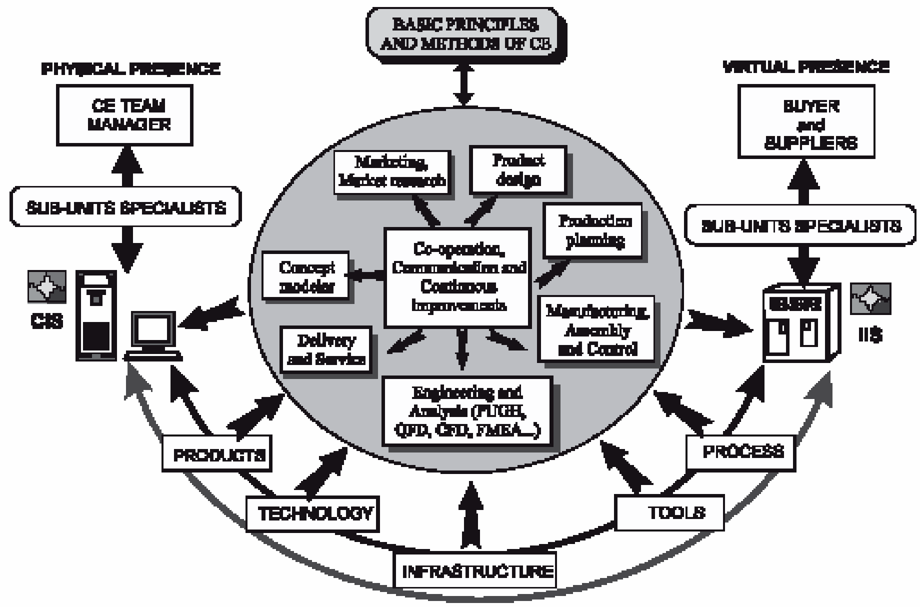

Fig. 6. Product development team [8].

In big companies the PDT composition changes in different stages of product development. The team consists of logically composed workgroups in various phases of product development, and each workgroup consists of four basic teams [7]:

* **Logical team** breaks up the whole product development process into logical units (operations, activities, tasks) and defines their interfaces.

* **Personnel team** has to find the required PDT members, it trains and motivates the personnel, and provides proper payment.

* **Technology team** generates strategy and concept. Its focus is on assuring the highest product quality at the lowest inherent cost.

* **Virtual team** is in a form of computer software and provides other PDT members with data required.

Fig.7 presents the composition of a workgroup in a big company. The goal of concurrent engineering is to achieve the best possible co-operation among the four basic above-mentioned teams of a particular workgroup.

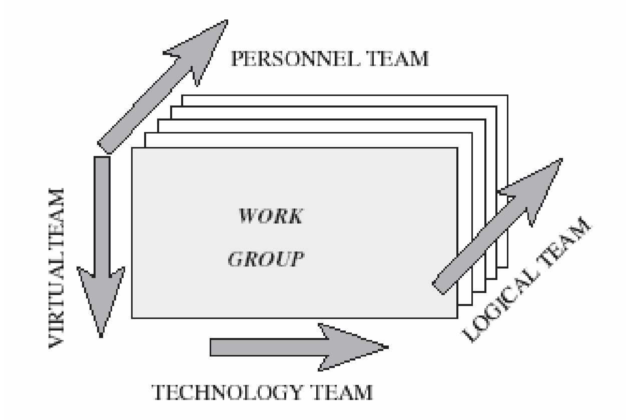

Fig. 7 Workgroup in a Big Company

As a general rule, the multidisciplinary teams for product development should have such a structure that the following goals are achieved:

- clear definition of competence and responsibility,
- short decision paths, and
- identification of team members with the product being developed.

A survey of the published works in the field of team structure planning in big companies [7] has revealed that a three-level PDT structure is recommended in big companies, as presented in Fig.8.

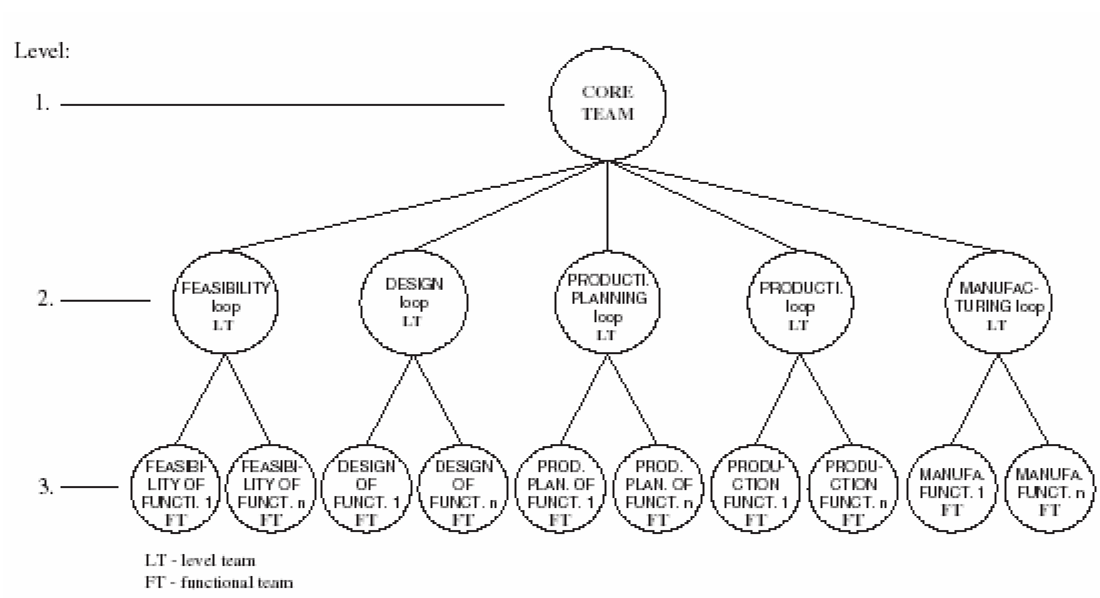

Fig.8 Three-level team structure in a big company

Core team consists of the company management and the manager of the reference level team; its task is to support and control the product development project.

Level team consists of the level team manager and the managers of the participating functional teams in the reference stage (loop); its task is to co-ordinate and tune the goals and tasks of functional teams and to ensure a smooth transition to the next level of product development.

Functional team consists of the functional team manager, experts from various fields in the company, and representatives of suppliers and customers; its task is to carry out the tasks given, taking into consideration terms, finance and personnel.

Team composition in SME

Analysis of results regarding setup of workgroups and team structure in big companies has shown that the proposed concept for designing workgroups, and structure of teams cannot be used in SMEs (there are too many teams in a workgroup and too many team levels).

When developing a workgroup concept, structure and organization in an SME, it will therefore be necessary to propose:

* as few workgroup teams as possible,
* as few team levels as possible, and
* appropriate organization of the company.

In the University of Ljubljana, in the Production Systems Institute we made several versions of workgroup, team, and organization structure of a company, and decided — after evaluation of the proposed versions —that the following seems advisable for SMEs:

* transition from four workgroup teams (personnel, logical, technology and virtual)to two teams (logical and technology),
* transition from the three-level team structure to two-level structure ,and
* transition from project to matrix organization of the company.
* In an SME a workgroup therefore consists of two basic teams (Fig.9):
* **Logical team** ensures that the product development process is divided into logical units and that interfaces and junctions between process units are defined.
* **Technology team** is responsible for generating strategy and concept.

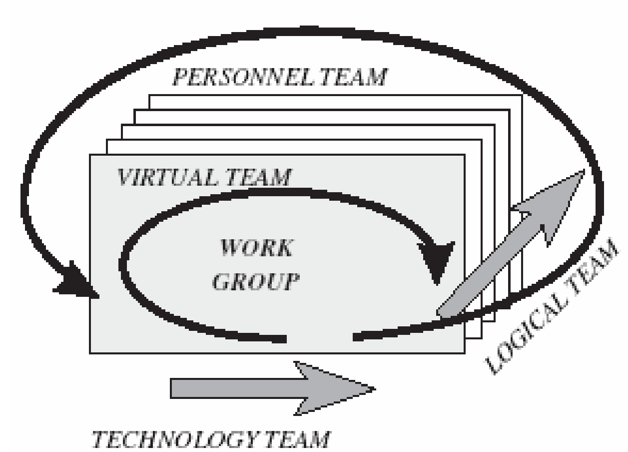

Fig.9 Workgroup in SME

- Software in the CIS performs the role of the virtual team (workgroup members should be properly trained to use the software) and project team manager carries out the personnel team tasks. For an SME, the transition from a three-to two-level team structure is planned, as presented in Fig.10.

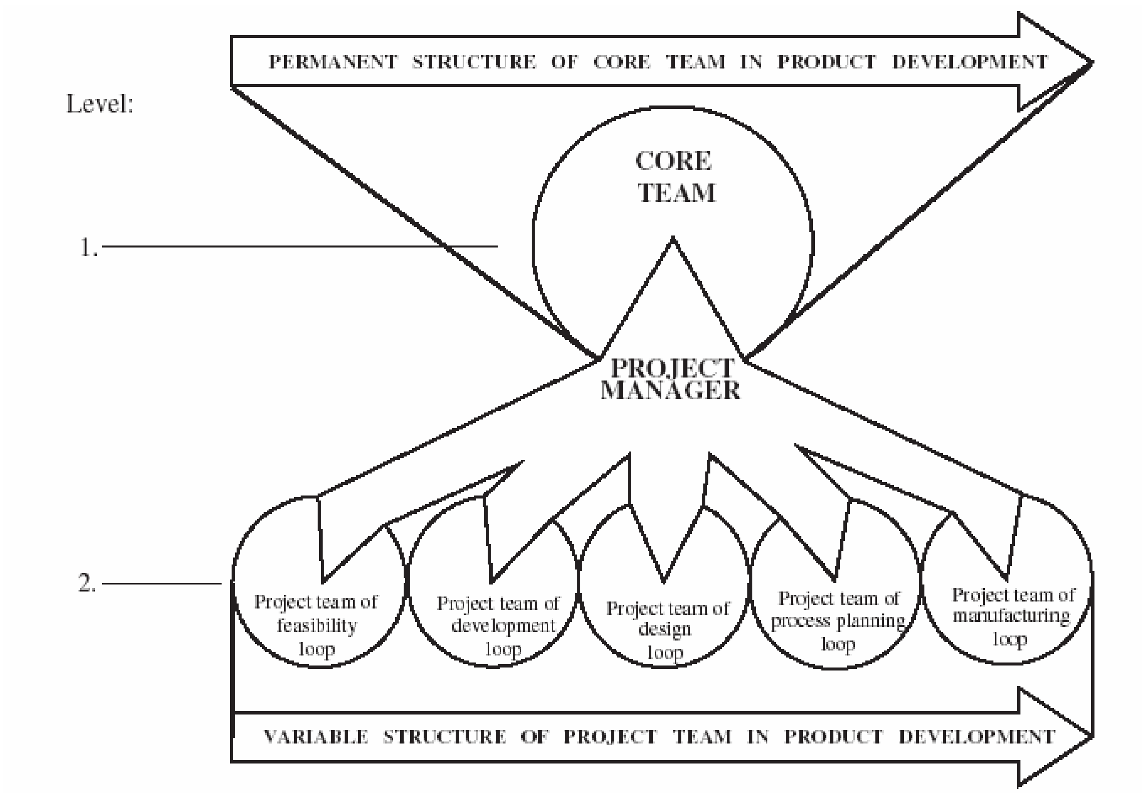

Fig. 10. Two-level team structure in an SME

Core team, which supports and controls the product development project should consist of:

* core team manager (permanent member),
* department managers (permanent members),and
* project team manager (permanent member).

Project team, which carries out the tasks given, taking into consideration terms, finance and personnel, should consist of:

* project team manager (permanent member),
* experts from various fields in the company and representatives of strategic suppliers, and customers (variable members). The project team in an SME is therefore designed similarly as a functional team in a big company, the difference being in that there is just one team and its composition changes in different phases (loops) of product development process.

In the *feasibility loop* the project team should define customer needs, mission, and make several versions of the product concept; the project team should consist of the employees from the marketing, planning and design departments, and representatives of strategic customers and suppliers.

In the *development loop* the project team should provide general solutions regarding the product, product planning, and design: the project team should consist of the employees from the planning and design departments, customers ,and suppliers.

In the *design loop* the team designs the product parts and components, development of prototypes, and selection of the most suitable versions regarding manufacturability; the project team should consist of the employees from the planning, design, and process departments.

In the *process loop* the project team should select the best technology for manufacturing of parts and assembling the components (definition of sequence, operations, selection of machines, tools, and standard times).The project team should also define production type (workshop, cell or product-oriented type of production)and select the optimal layout of production means; the project team should consist of the employees from the design, process, production, manufacturing and assembly, logistics, and delivery departments.

In the *manufacturing loop* the project team should take care of prototype tests, supply of required equipment, layout of production means, manufacturing and test of the null series; the project team should consist of the employees from the production, manufacturing and assembly, quality assurance, warehouse and delivery departments.

The tasks which are performed by level teams in big companies should be carried out by the project team manager in an SME and he should coordinate and tune the goals and activities between the project team and core team and provide smooth transition from one loop of product development process to another.

In big companies the members of the core, level and functional teams usually use project type of organization. This type of organization cannot be used in SMEs as they have too few employees.

Analysis of various organizational structures of companies or teams has shown that in SMEs matrix organization would be the most suitable for core and project team members. Therefore, a member of the core team (with exception of the core team manager) would carry out tasks in his/her department part of his/her working time (for this work (s)he would be responsible to the general manager of the company), and the rest of his/her working time (s)he would work on the product development project (for this work (s)he would be responsible to the core team manager).A member of the project team (with exception of the project team manager)would carry out tasks in his/her department part of his/her working time (for this work (s)he would be responsible to department manager),and the rest of his/her working time (s)he would work on the product development project (for this work (s)he would be responsible to the project team manager). The project team manager would be excluded from his/her department throughout the duration of the product development project and (s)he would work full time on the project. When the project is finished the project team manager would return to his/her department. Project team manager should be properly trained and experienced person who knows in detail the work in all departments of the company and has the skills to use computer tools and information technology.

Fig.11 presents the proposal of an ideal matrix organization in an SME.

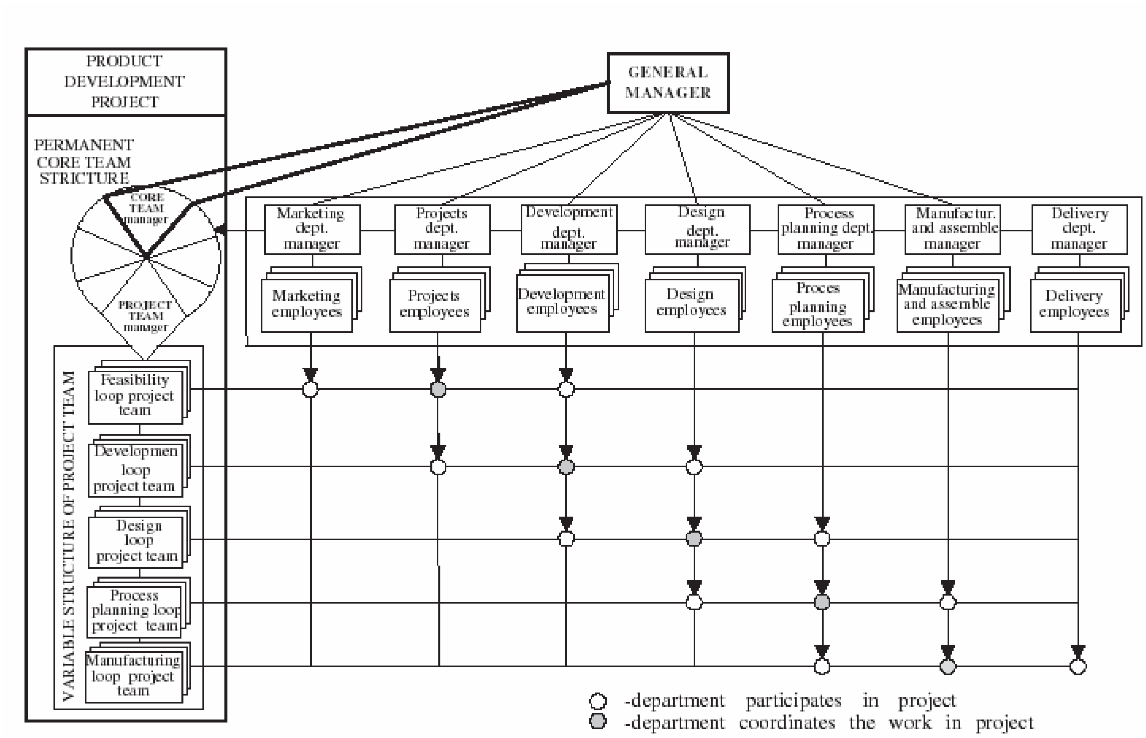

Fig. 11. Ideal matrix organization in an SME

5. Conclusions

Global market requires short product development times, and so all kinds of organizations are forced into transition from sequential to concurrent product development. The basic element of the concurrent product development is team work. So the formation and structure of teams in organizations gain special importance. Moreover the tools (especially QFD) used for CE are really important in order to develop a new product in the modern industry.

For more research and interest the web site of West Virginia University; ‘CE Research Center’ – www.cerc.wvu.edu - can be investigated.

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