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CONCURRENT ENGINEERING: Research and Applications

Development of New Products in Small Companies

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Abstract: Problems in the development of new products in small and mid-sized companies are analyzed in the following paper. Concurrent engineering methods known to date for the development of new products are tested within the framework of human and organizational capacities. The methodologies of 3-T looping and three-level team structure were especially tested. It was established that a two-level organization is more suitable for small companies. Due to requirements for product complexity, it was found that n-T looping methodology should be implemented. In the case of complex products (the methodology was tested on a mini-loader), it turns out that n is in the range of 7 to 9 members. Such a large team is still manageable and acts in an integrative manner to achieve the goal, product development. In the matrix analysis of activities, the use of a supplemented methodology was justified and proven for each phase of product development.

Key Words: concurrent engineering, development, design, iterative design process, small companies, project organization, mini loader.

1. Introduction

Due to their large degree of flexibility, small companies are very suitable for rapid and large developmental steps. However, a few conditions need to be fulfilled for this to happen. This paper will not address psycho-sociological conditions that additionally promote positive and developmental orientation within companies, since they should be the subject of other research, which has been especially intensive lately. The reason for this lies in the fact that in spite of large capital investments into materials and know-how, results in certain environments are achieved considerably more slowly than in others. In addition, preliminary research [1,2,3] showed that a positive orientation of the environment in the design-development process is one of the important elements; therefore, it needs to be especially considered. In the case of small companies, all product life cycle phases up to physical production are performed in the company. The following phases are thus merged at a single location: product conception, research and calculation, embodiment design, prototype, process planning and testing [4].

As a rule, successive product development has not been performed in small companies to date. Cooperation among employees engaged in product development was of an interweaving nature, which as a rule resulted in quasi-concurrent engineering. The review of some companies and literature [8,9] showed us that the claims of a better response of small companies and faster production management actually stemmed from the above-mentioned quasi-concurrent engineering. In the process, activities were performed in parts, as if concurrent engineering principles were observed.

Due to the introduction of information technology in small companies, undefined activities began to be manifested as interference. Standstills occurred. Activities were performed in the real world. The acquisition and provision of information in information systems of companies were not performed concurrently or were as a rule performed with large delays. Unreliable information appeared in information systems. Therefore such companies had to perform certain activities

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repeatedly. With the requirement of traceability (ISO) and definition of information flow, quasi-concurrent engineering proved to be a large obstacle.

In our case, the actual situation was analyzed for the same reasons as stated above and the existence of concurrent engineering was established. It is only when new information systems are introduced that problems will stand out in their true form. Due to a lack of understanding of the problem, management may even decide to return back to the previous status, to sequential production management. The company then becomes rigid, its response time is prolonged, and it slowly begins losing the opportunity to penetrate markets. The advantages of small size are lost.

Through a systematic approach to the study of concurrent engineering in specific conditions, we managed to ensure dynamics throughout the design-developmental and manufacturing processes in small companies that produce construction machinery. Their entire process was studied, and we recognized a special need for modelling their developmental groups, not as a random activity in their management and decision-making process, but as a constant in creating a concept for the dynamic organization of production. The organization of production in small companies is not permanent and unchangeable; it is subject to a certain process, which inevitably undergoes constant changes in the development of new products. This needs to be emphasized particularly because the need for dynamic cooperation needs to be presented to all employees in a small company. For this very reason, those who have a hard time accepting organizational changes do not remain in small companies.

The principles of concurrent engineering, which were deduced directly from the process of new product development and which as believed, have to be observed, will be presented in this paper. A solution is presented and its implementation is shown in the case of an actual concrete product.

2. Information Associations and Transfer in Concurrent Engineering Product Development

In recent years, product development, i.e., the design-developmental process, has been an essential element of competitive engineering, since individual phases have to be interwoven during the conceptual design of products. In the process of product development, successive performance of phases such as goal determination, conceptual design, embodiment design, process planning, preparation for production, manufacture, assembly and delivery as a rule acts as a blockage of the participants' activity. In each phase of product development or in each activity observed, data is built gradually. At the end of the activity, it is built in its entirety and passed on to the next activity or phase (Figure 1).

As a rule, such a work method prevents product improvement according to the principle of iterative procedures, which was recognised and established in the design-development process [10] and upgraded in [11]. The principle of an iterative process is shown in Figure 2. This process provides the possibility of adding improvements in every phase of product development. First, the process phase needs to be defined. On the basis of this definition, the required input data on the product are determined. On the basis of the collected data, a suitable n-th step is defined and then activated. In this model,

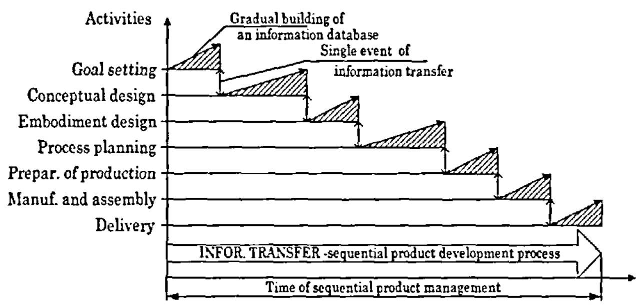


Figure 1. Sequential product development.

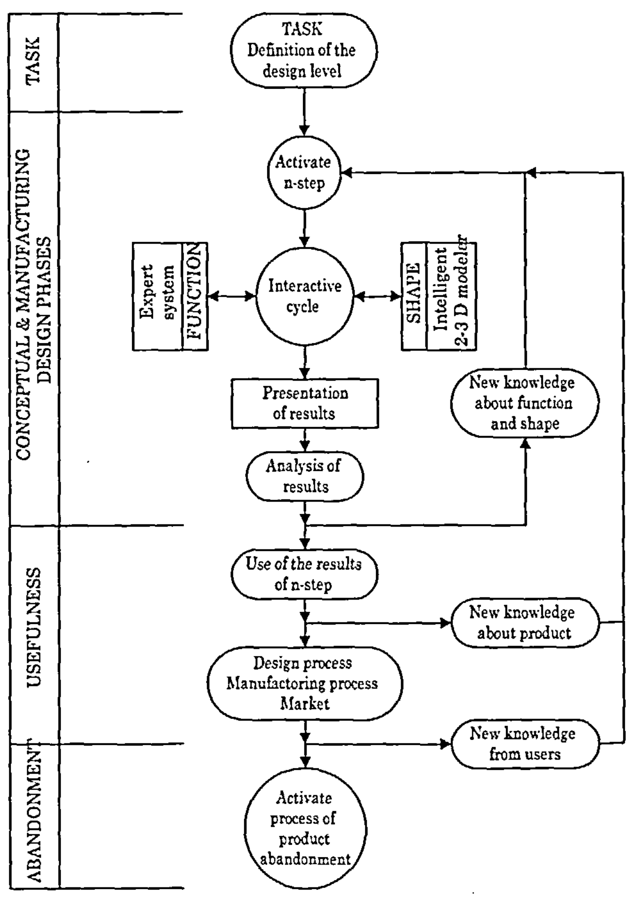


Figure 2. Iterative design process.

the basic characteristics of a product are recognized as function and form. Product characteristics are harmonized interactively up to a suitable level of perfection, which is then presented as a result. At each phase, results analysis includes additional knowledge, which is important for assessment based on the criteria used (e.g., economic, sociological, environmental, etc.).

The inclusion of analysis in the process of product supplementation enables new findings about the two basic product characteristics. The use of a loop as a prerequisite for iterativity is the essential characteristic of the presented model. The first part of the iterative model presents the conceptual and manufacturing design phases and, as its result in the real world, gives complete information on the product in a nonmaterial form. All other phases or steps represent a material product, which is presented in the design-development process. Then there are two characteristic types of feedback information, which enable a new process of improvement, i.e., information on the product from the production process (design and manufacturing process) and information from users from the market. Only all of the listed findings enable activation of the process of product abandonment.

In the iterative process, a product is supplemented with new findings in each phase of product development, but this is possible only at times when findings from another phase, one or several, are transferred to the studied phase. Findings are presented as information, which enables a more complete solution for the product.

If concurrent product development is used, possibilities are given for an iterative process, which includes new findings from various process phases. In successive product development methods with an iterative process, the process is lengthened after each phase, upon each instance of information transfer. For this reason, the iterative process could not be established objectively in successive product development.

In concurrent product development, information is transferred, as shown in Figure 3. The inclusion of information, e.g. from the embodiment design phase, into the process planning phase, simultaneously takes into account the relevant data enabling considerable acceleration of the process.

Figure 3 shows a partially built information batch during transfer between one phase and another. The overlapping of individual phases graphically indicates the amount of information in association with the generated information. In the analysis of information generation in an individual phase, it turns out that at the beginning the generation of basic data is relatively large, while in the middle the trend of generation decreases and at the end the amount of generated data increases. Since the amount of generated information is so variable, the most appropriate amount of generated data needs to be

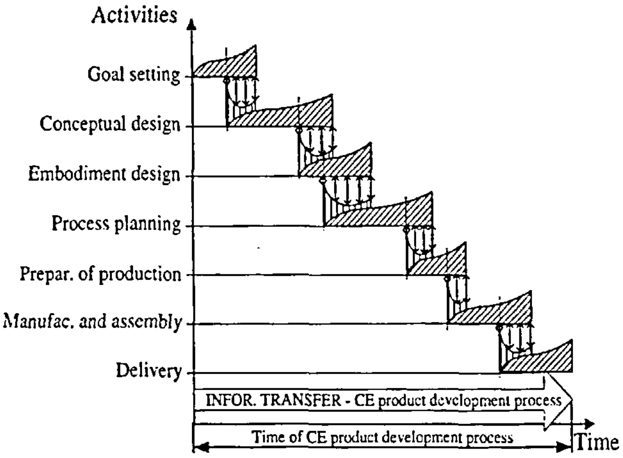


Figure 3. Concurrent engineering product development process.

determined for each phase. On the basis of the required amount of data, the time can be determined when the next phase can be activated. It can be seen that the activation of the next phase can take place only when all the relevant data is available for initiation. In the case that this information is not available, the next phase must not be activated. In Figure 2, the activation of an n-th step is marked in each loop of the iterative process.

In concurrent product development, activities interact. A track-loop technology was developed for the implementation of interactions [1]. Loop type describes the method of cooperation between overlapping activities. Winner [2] proposes the use of 3-T loops, in which interaction takes place between three activities of product development. Application of concurrent engineering to product development leads to a track and loop methodology. The phases as mentioned above are feasibility, design loop, process loop, production loop and manufacturing loop. When the output of each phase depends on input from the previous phase so that each phase is completely dependent on the previous track, the product development procedure is 'serial'. The proposed methodology improves parallelism achieved by overlapping. The main advantage of this methodology is the interaction between tracks. When teams that are overlapped work actively in their tracks the required information can be dynamically moved to other tracks with little effort. When the product moves through various tracks to attain the finished state from the inception state. The flaw in each state has to be checked and if there exists one the process goes back to the origin, thus the concept loop (Figure 4).

In each loop, transformation of inputs and outputs is performed on the basis of requirements and limitations, which is presented by the diagram of information flow in a track-loop process of product development (Figure 5).

Optimization and design improvement are carried out in an iterative fashion with alternatives further refined

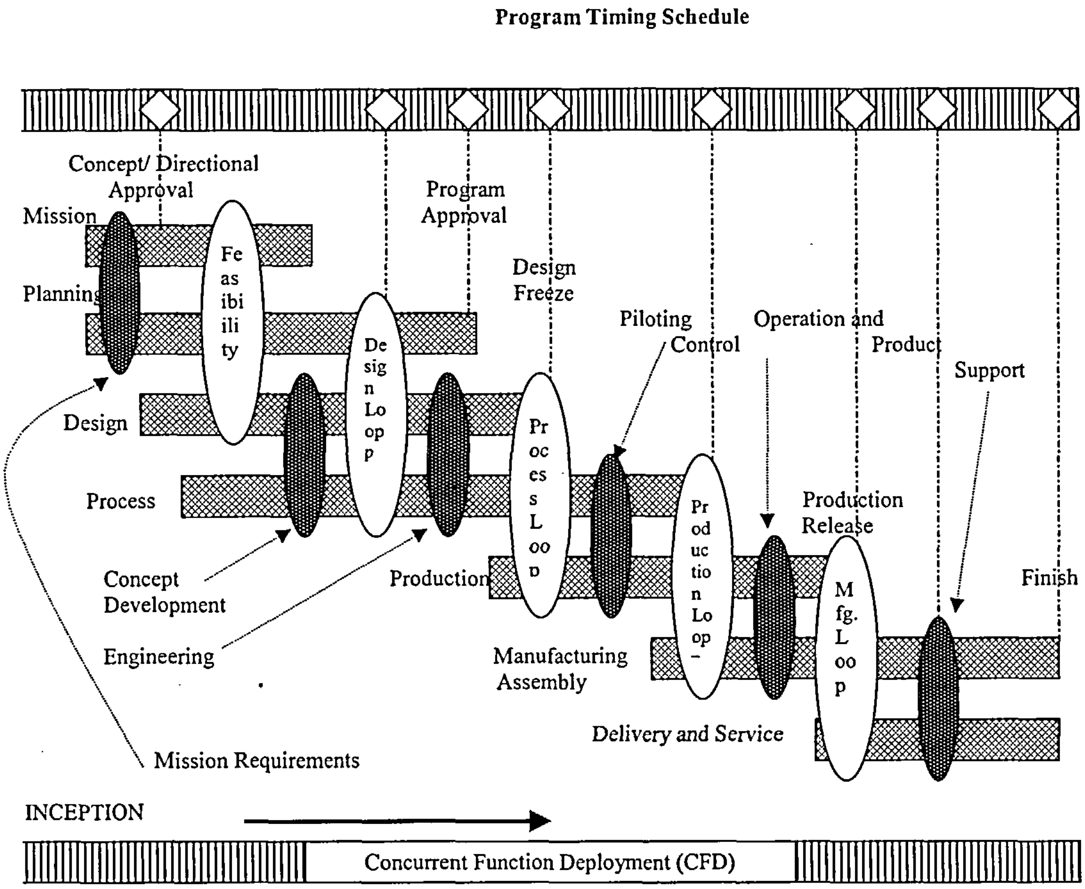


Figure 4. Overall product design and development (PDD) process.

through the process outlined in the concept development loop. The product engineering process has six activities to be performed (Figure 6).

- The voice of the customers help determine the specifications and to categorize them into different levels such as systems, subsystems, components and materials;
- Parts can be initially designed using a feature-based representation scheme, such as descriptive form features, etc.;
- An exploded view of the CAD model can be obtained from initial assembled model of the product using methods, such as rule-based or knowledge-based approach;
- The assembly process involves systematic introduction of parts or groups of parts to a fixture or to an assembled component. Development of assembly is one of its activities;
- Validation of the assembled design against the allocated specifications;
- The performance of the integrated system is optimised to derive a quantitative set of subsystem functional performances.

In adopting a loop for product design of parts that go into an assembly has its advantages. Parts designed and produced independently rarely go into mating without any tolerance problems. It is therefore required to adopt a loop methodology for assembling and disassembling parts that go into mating. This is a bottom-up approach where materials attributes and features is all we have to work with. This takes us to the design level to design mating parts in relation to each other. This requires forming subsystems and is followed by main system. Another half-loop is used to generate a disassembly sequence based on production requirements (Figure 7).

The product synthesis loop is an important activity, linking product design and manufacturing operations. At the beginning of the loop, the geometric shapes and sizes of a part, along with its functional surfaces are identified. The loop needs a basis for the identification of the parts function within the product and allowable process-type variations along with the exploded view from its initial assembled model. The second level taxonomy for the synthesis loop is shown in the figure. A previously five block schemata is followed with the synthesis loop in middle. It is surrounded by the inputs to its left, outputs to its right, requirements on its top, and constraints on its bottom. The developmental baseline state along with process information makes up the predictor. The cost/benefit verification model

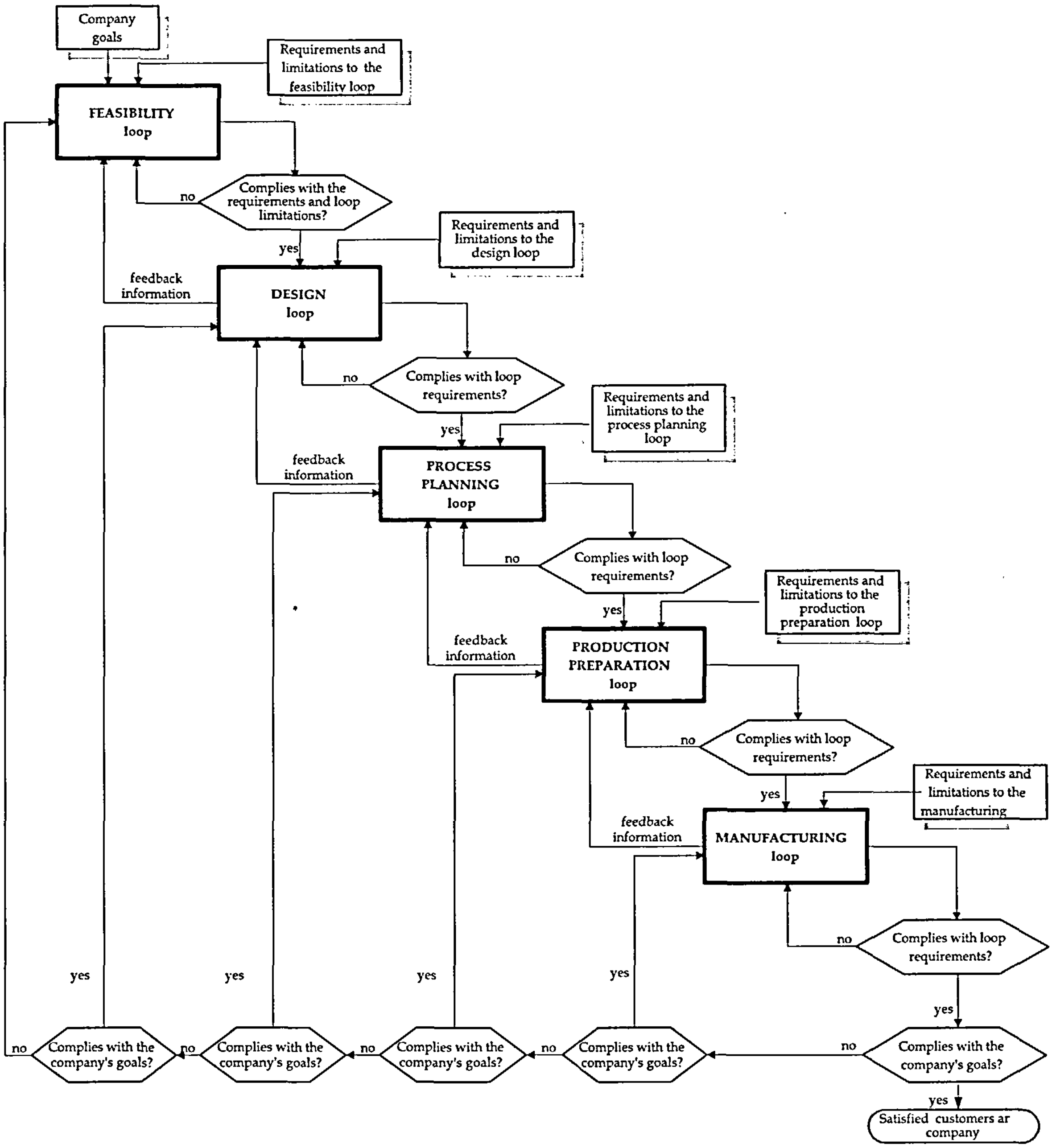


Figure 5. Information flow diagram for the track-loop process in product development.

serves as a corrector. Requirements are driven by processability and constraints are mostly imposed by facilities, tooling, capital funding. The output is a production baseline (Figure 8).

During the process synthesis execution loop decision-making is based on raw stock, tool selection, fixture etc. An assessment of time and cost standards are performed. This analysis involves the use of well-established process plan details, raw stock, and tooling information. By integrating processing knowledge with machine, tool, and fixture capabilities of manufacturing plant operations, many process planning constraints can be satisfied. During the process synthesis execution loop decision-making is based on raw stock, tool selection, fixture etc. An assessment of time and cost standards are performed. This analysis involves the use of well-established process plan details, raw stock, and tooling information. By integrating processing knowledge with machine, tool, and fixture capabilities of manufacturing plant operations, many process planning constraints can be satisfied (Figure 9).

Production Synthesis Loop Management

In any industry, the layout of that industry plays a vital role. For example, tooling and machine equipment is

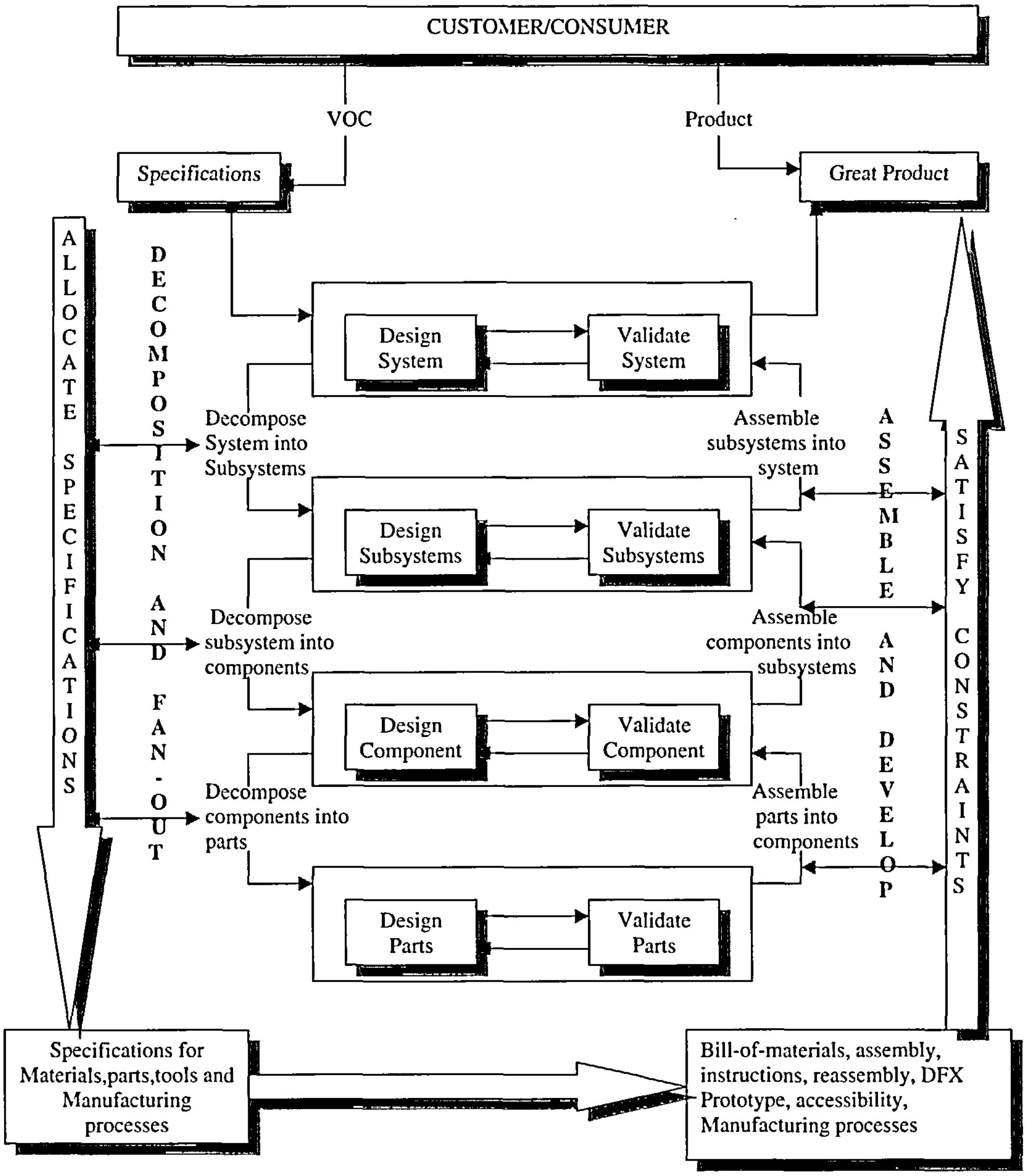


Figure 6. Steps in the product engineering loop.

organized according to the production schedule specifications to produce the product, which is necessary for the development of the product. It constitutes of two interconnected elements, a predictor and corrector. The production baseline state along with production information constitutes predictor and a cost/benefit tracking model serves as a corrector. The manufacturing baseline places various machines in the exact sequence required to process a family of parts, the machines are grouped on the basis of group technology. Cells are rearranged to reduce the material handling time and the movement between adjoining processes. Production Synthesis Loop Management includes a changeover reduction and quick setup strategies. Optimizing the production layout reduces the time required to convert the raw material into a finished product (Figure 8).

In the preceding paragraphs we have mentioned about the five different loops; in this instant we go in depth into the manufacturing loop. In general, as parts move from machine center to another, they will get some operation done at that center and move on to the other. This will in turn consume time, such as waiting in the queue and transportation time, depending on whether the industry layout is Product layout, Process Layout, Continuous Layout, or Fixed Layout. To minimize the handling and movement of parts the packaging of a finished part and assembly optimizes the material flow process of the supplier, manufacturing plant, and dealer.

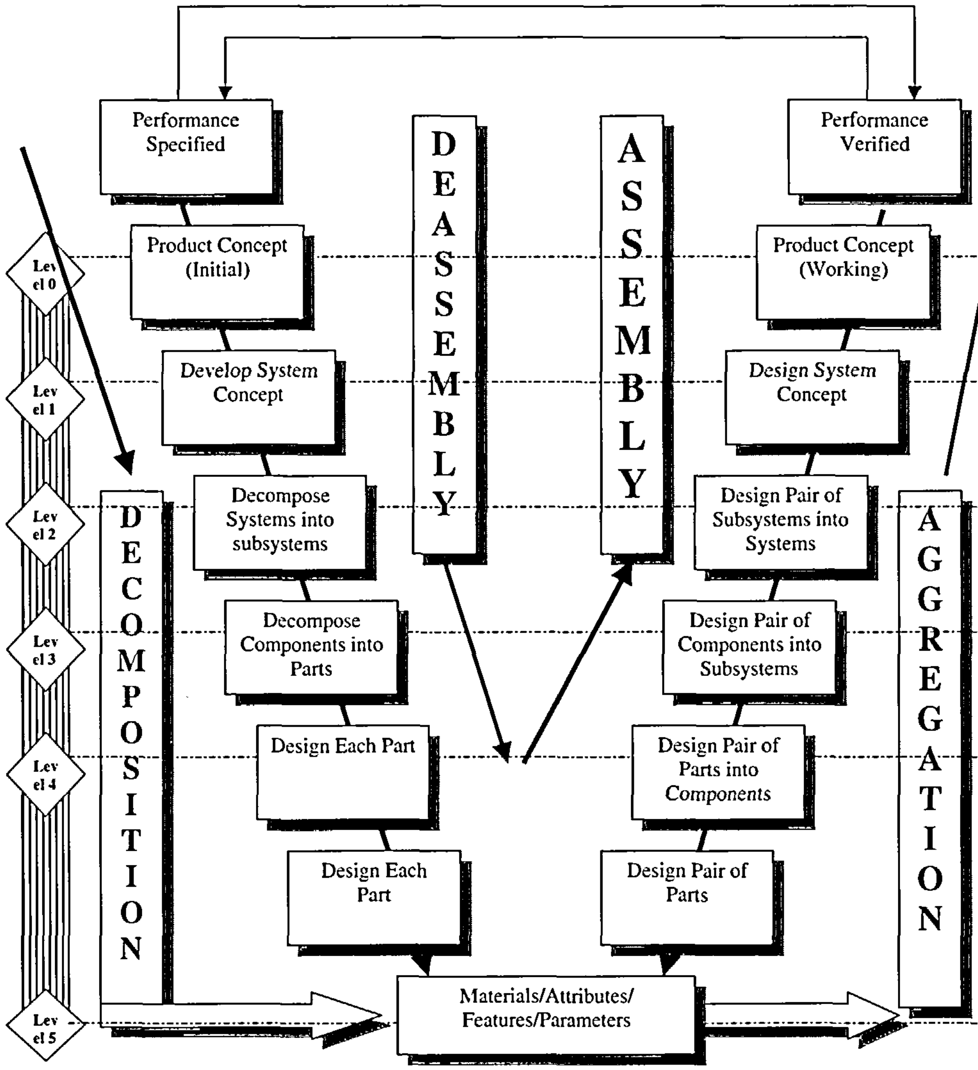


Figure 7. Steps in a product design loop.

This provides a balance between manufacturing, transportation and assembly needs.

The sub phases of the manufacturing loop are shown in the Figure 10.

The first step includes screening the initial process and manufacturing data using producibility analyses. The second step is component, prototype, and assembly testing. This step may utilize the process models depicting the generalized behaviour of the manufacturing processes and estimate variable costs associated with assembly and production. The other steps involve tooling and process design; parts and equipment procurement, production line set up and test for production runs. At the end of the production runs, results are reviewed to determine whether or not the product is production worthy.

A typical production system flow is illustrated in the figure. Inputs to a production system are raw materials, machines, equipment and capital while the resources are in the form of workforce, management, suppliers and tools. The resources are dependent on the requirements of the customer order and form a necessity in a production system.

The output, which is in the form of finished goods, services and hence profits is determined by the constraints that are to be considered which limit the production capability. Technology, information, resources, policies, inventory, human factors all form major constraints on a typical production system that determines its performance as a whole. The output performance is then fed back to the input to scale using CE metrics so that inputs to the system can be optimized.

Organization of a process plays an important role in ensuring the effectiveness of the resulting production system. Concurrent Engineering is a problem of high complexity involving a variety of talents, tasks etc. Organization of industry can be achieved by carefully splitting the system level problem into its mutually separable transformation states, followed by modelling

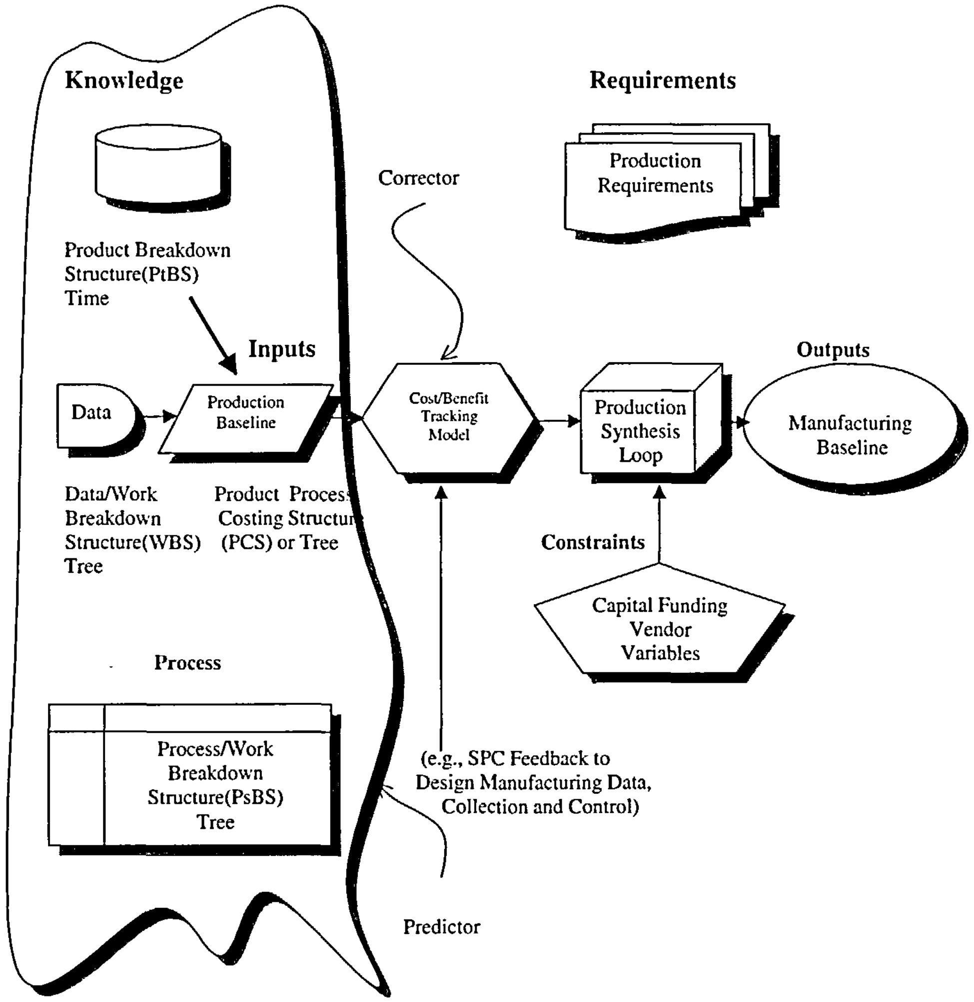


Figure 8. Product synthesis loop management.

of each state, then the reconstruction of a system definition from the aggregation of the definitions of its constituent states.

The inputs to the model can be classified as data inputs, knowledge description, and the processes at the states. The data inputs can be further classified as definition of detailed structural geometry, definition of electric cableway routing, definition of the HVAC duct routing, definition of the piping routes. The knowledge description may be comprised of scientific, technical, environmental, statutory etc. The process inputs may be constituted of information about manufacturing processes, tools required, team formulation, business strategies, and organizational infrastructure. The requirements or resources for this transformational model may be about functional requirements, safety rules, economic and ergonomic considerations. Various constraints are imposed on the model in order to narrow the choices, which may be of social, political, or economical type or Technological type (Figure 11).

Our attention all along is focused on the five loops. Distribution of the product lifecycle into loops provides an opportunity to view the process of design and development in a systematic manner. Now we can move on carefully viewing the different activities associated with each loop. In the planning loop we introduce the project we formulate to the team, which works on the project. We decide the time required in reaching the targets at any particular instant of time. At this stage we review the customer requirements and we establish a verification plan. An extensive competitive analysis is done on the plan and we finally establish functional requirements which are the attributes of the project. The last step involves approving the project implementation. Now the project is tested for feasibility, which includes checking whether it is economically and technically possible. At this instant it is required that we grade ourselves in terms of capabilities, identify the critical points and a develop a business strategy.

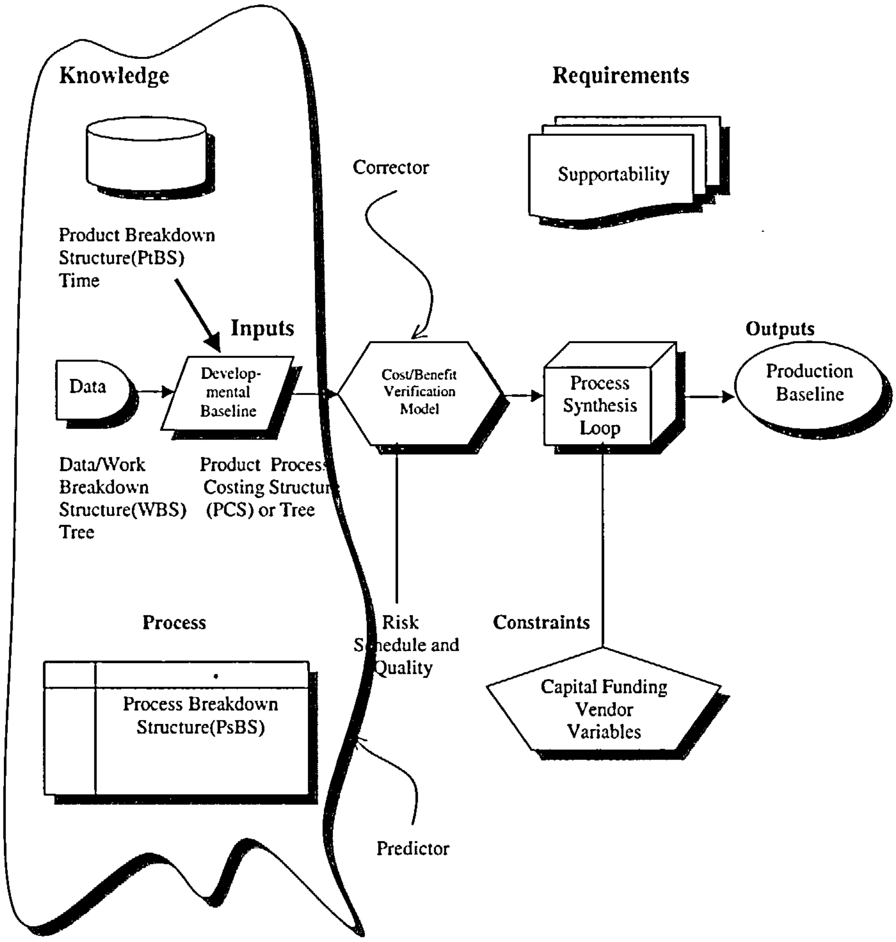


Figure 9. Process synthesis loop management.

Design, which is the heart of IPPD product process, comes into picture here. At this stage the customer requirements are reviewed once again, to decide on the technology to be implemented. The success factors are finalized and a final action plan is formulated. The materials to be used are decided, and some critical functions like System Analysis, specification and design, product engineers are plugged into it. Before the actual process starts, a flow chart is developed and the capability of the product is estimated. The fundamental step of Concurrent Engineering Process Engineering is applied. A pilot test is adapted to see if the plan can be implemented in the prescribed way. This then leads to the stage when, the prototype is manufactured and production Reengineering is applied leading to the manufacture of the product (Figure 12).

When reviewing and analyzing the process, we primarily strove for a parallelness of processes in normal conditions, which brings transparency and stability into the process. It was established that, in certain conditions, quality and synergy can be achieved by integration. On the basis of the above starting points, the following eight principles of production management were stated as follows:

- Early detection of irregularities and errors (problems detected early are easier to solve than those which are found late);
- Early decision-making (lower costs);
- Division of work (determination as to what is done by humans, what by machines and what by computers);
- Team work (not only connections within a team, but also connections between teams);
- Use of knowledge (decisions are adopted on the basis of expert knowledge, irrespective of the type of presentation – expert system, expert);
- General understanding (each team must understand what the others are doing);
- Ownership (the team is the author of work);
- Focusing on a common goal (convergence) (each team member must work towards the fulfilment of a common goal).

A decision on concurrent product development is, therefore, in principle also a decision and a qualification

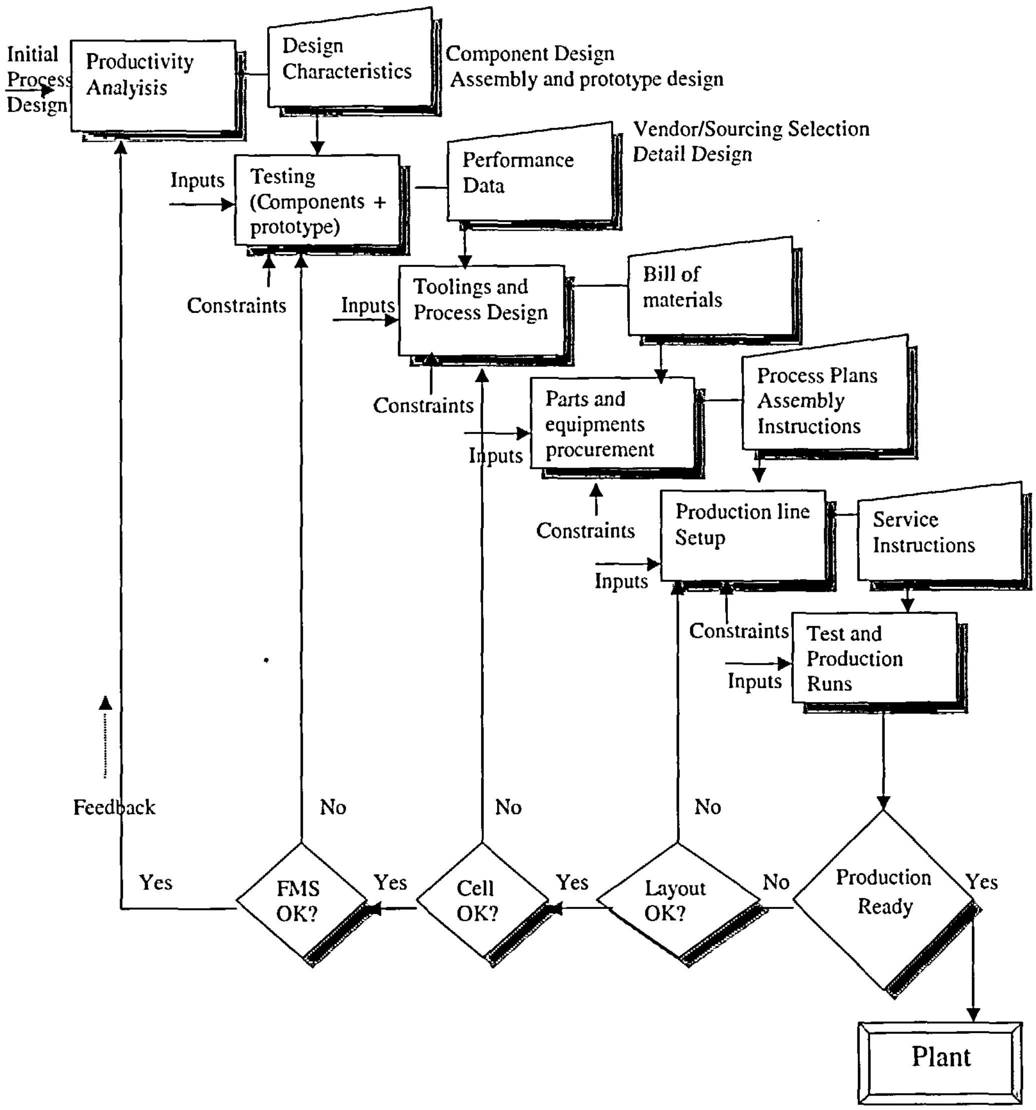


Figure 10. Information flow through a manufacturing loop.

of each individual team member for teamwork. In the case that an individual does not have the above-mentioned properties, he or she is not a suitable candidate for a team member. According to literature [1] the following is necessary for teamwork:

- Cooperation (the ability to accept the requirements for flexibility, unpredictability and constancy);
- Responsibility (feeling of obligation to achieve the set goals);
- Communication, (i.e. exchange of information);
- Rationality (ability to make compromises);
- Pragmatism (agreement in spite of disagreement);
- Harmonization (harmony in the implementation of interdependent activities);
- Creativity (permanent improvement in order to rationalize costs);

It is understandable that individuals cannot have all of the above-mentioned properties. However, the team leader must diversify the exclusivity of these properties in individual team members as much as possible.

3. Conception of Team Work in Small Companies

It was found during previous studies [4,5] that concurrent product development is based on a multidisciplinary team, which must include both professionals from various services within the company, as well as representatives of strategic suppliers and customers, as shown in Figure 13.

Team members must be linked up in a communication network, which enables them to access the local

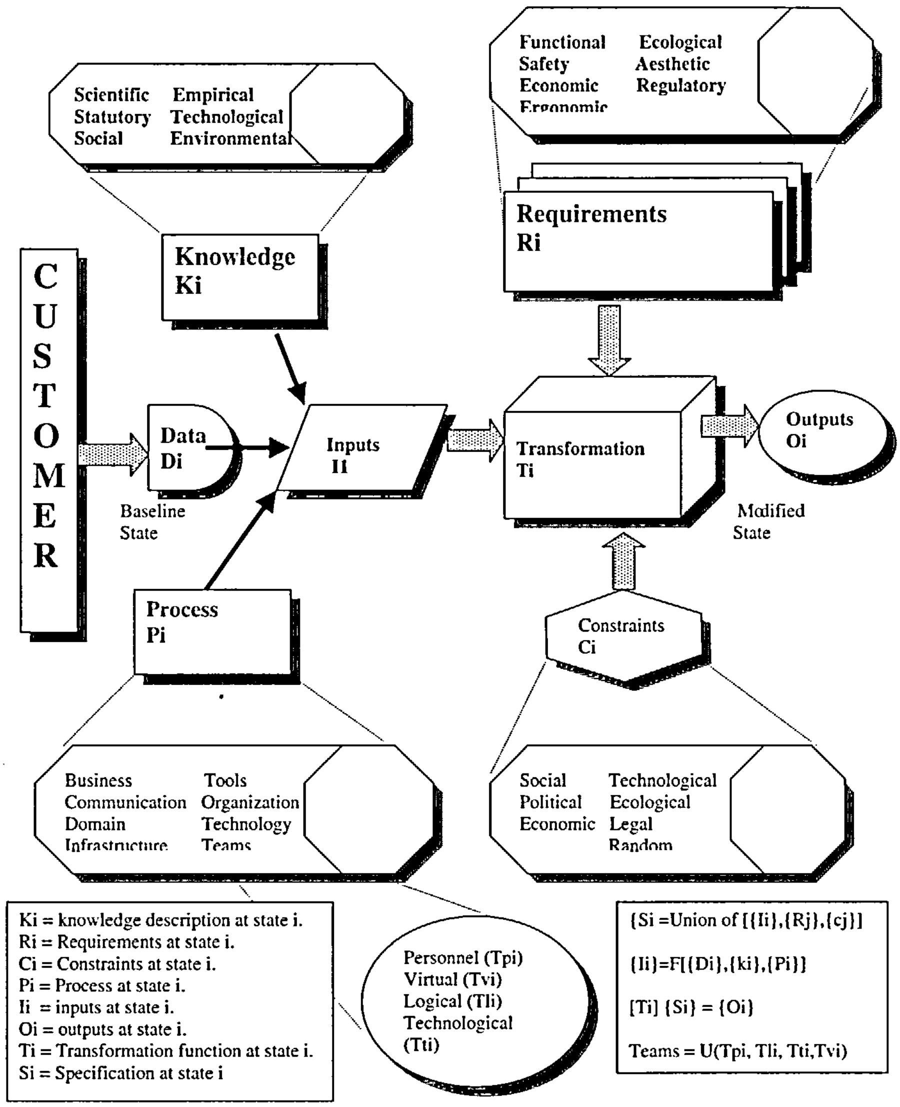


Figure 11. Basic terminology in a transformation process.

information system that provides data on the company's processes and existing products. Due to distance, the representatives of strategic suppliers and customers participate in the team only virtually, using Internet technology that enables them to employ the same tools and technologies available to team members within the company. Harmonization of communication standards is important for active communication.

For large companies, it is recommended [1] that their multidisciplinary teams be composed of the following four subteams in each phase of product development:

1. Logical subteam, which should ensure that the entire process of product development is divided into logical units (operations) and should determine their mutual links and associations;
2. Personnel subteam, which should provide the necessary personnel and is in charge of their training, motivation and appropriate salaries;
3. Technological subteam, which should generate the strategy and concept;
4. Virtual subteam, which functions in the form of Internet modules and provides the required information to other team members.

It follows from this that large emphasis is put on information exchange. One can anticipate that those team members who cannot master modern communication techniques will have a hard time participating in team work. If they are included, though, their response times will be longer.

The basic objective of concurrent engineering product development is to achieve the best possible cooperation between the above-mentioned four subteams.

On the basis of a review of published papers in the structure of team planning in large companies [1,3,6], a conclusion was made that a three-level structure of multidisciplinary product development teams is best for

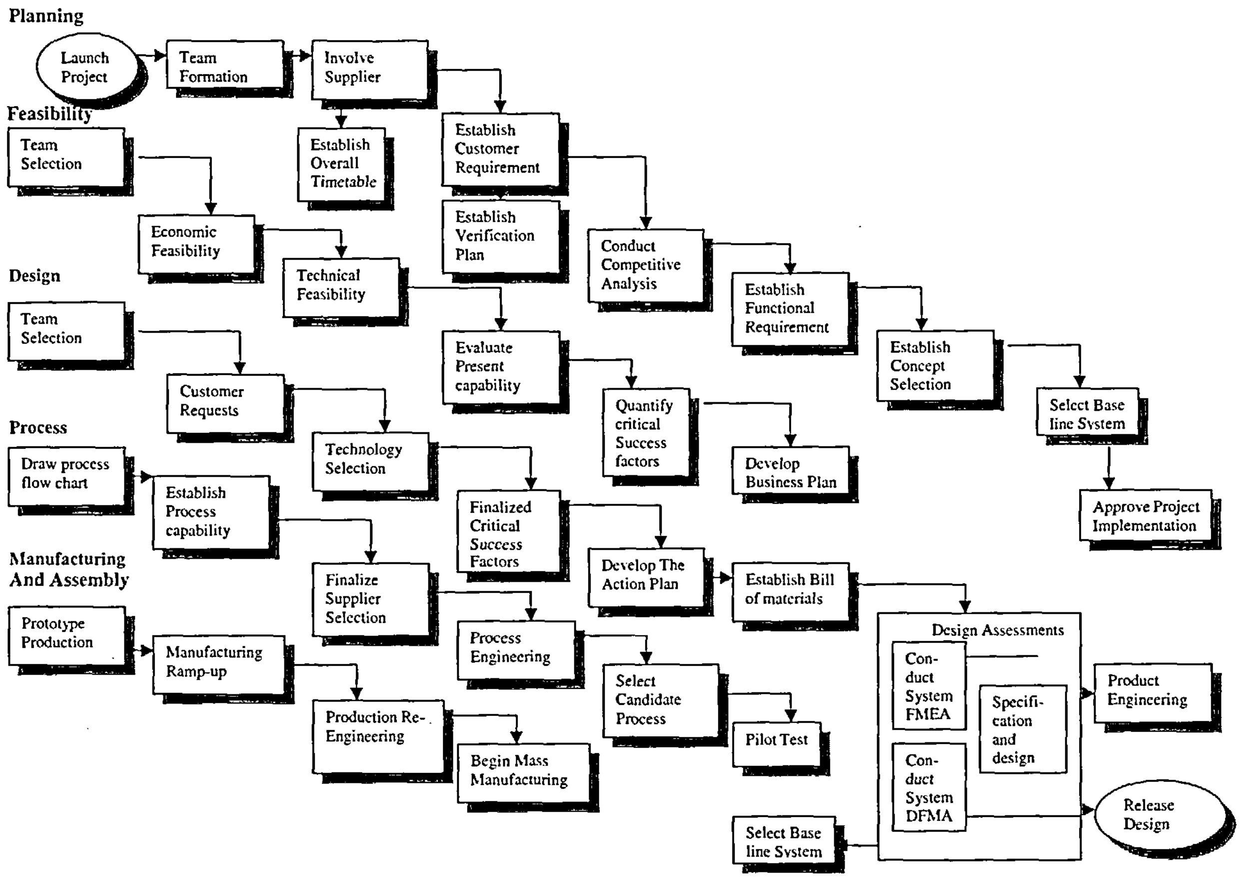


Figure 12. Activities and metrics associated with each loop of the IPPD process.

large companies (Figure 14). At the first level is the core team, which consists of the company management and phase team leaders. At the second level, there are several phase teams, the task of which is to coordinate and harmonize partial goals and activities of the functional teams and ensure a smooth transition to the next phase of product development. Each phase team consists of the team leader and leaders of the participating functional teams.

At the third level, there are several functional teams, which are in charge of the execution of the planned scheduling, financial and personnel tasks. Each functional team consists of the leader and professional from various fields of the company activities, as well as the representatives of its suppliers and customers.

The analysis of results of forming multidisciplinary teams and of their structure and organization showed that the concepts proposed for large companies are not acceptable for small ones. To begin with, small companies cannot support large organizations. Requirements concerning team composition, structure and organization in small companies are as follows:

- The number of subteams in a multidisciplinary team should be as low as possible.
- Active participants must have as much broad and integral knowledge as possible.
- Specialists are included in the team on a part-time basis.
- The number of team levels should be as low as possible, because this promotes direct cooperation.
- The company organization should be appropriate, i.e., it should enable external associates with specific knowledge to work on a part-time basis through their virtual participation in various company activities.

Taking into account the above requirements, elimination of the personnel subteam and virtual subteam from the multidisciplinary team structure seems to be the first of several possible solutions for small companies. As a rule, this is easy to do in the case of the personnel subteam, since decisions concerning personnel are limited to the company's upper management or the project team leader. However, the elimination of the virtual subteam is a special problem, because this depends on the personnel structure of the other subteams. Since there is a need to provide information to customers and suppliers, elimination of the virtual subteam is possible only if the members of both other teams are properly trained in communication using

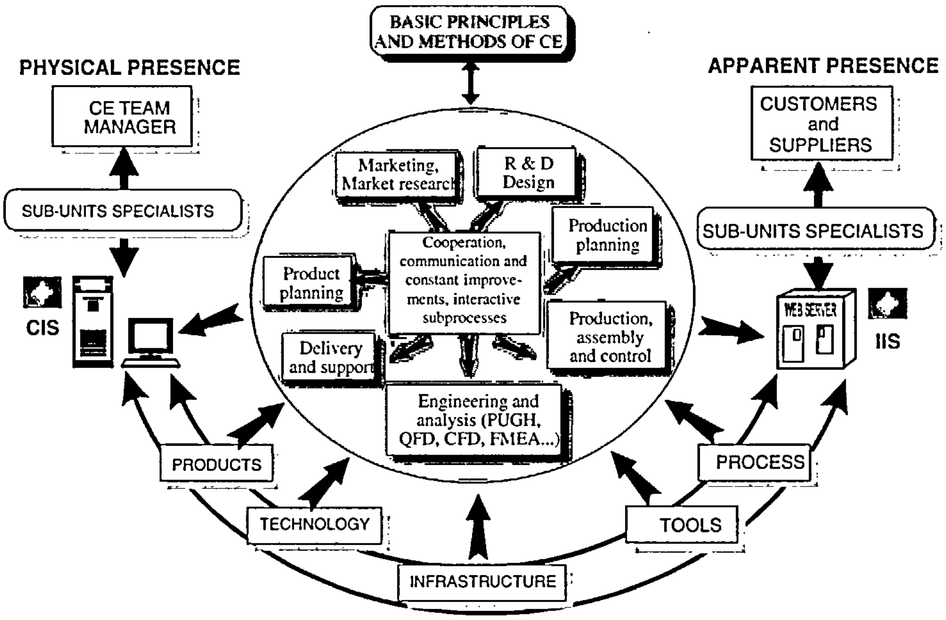
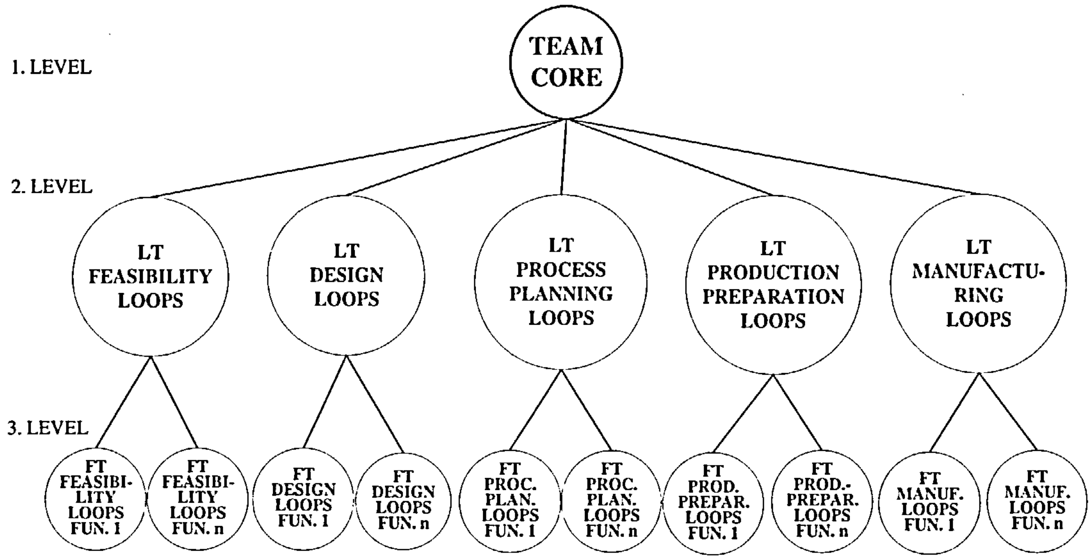


Figure 13. Multidisciplinary product development team.



LT- Level's Team
FT-Functional Team

Figure 14. Three-level structure of teams in a large company.

modern technology. A special study [12] showed that the virtual team can replace the knowledge of individual members of both necessary teams in environments consisting of personnel which is able to actively use modern technologies. On the basis of our research, it can be concluded that, in the future, virtual teams will supplement the knowledge of all members of both active teams, i.e. the logical and the technological subteam.

The logical subteam is in charge of dividing the entire process of product development into logical units. The technological subteam generates the strategy and concept.

On the basis of the above considerations, the transition to a two-level multidisciplinary team structure in small companies can be made as shown in Figure 15.

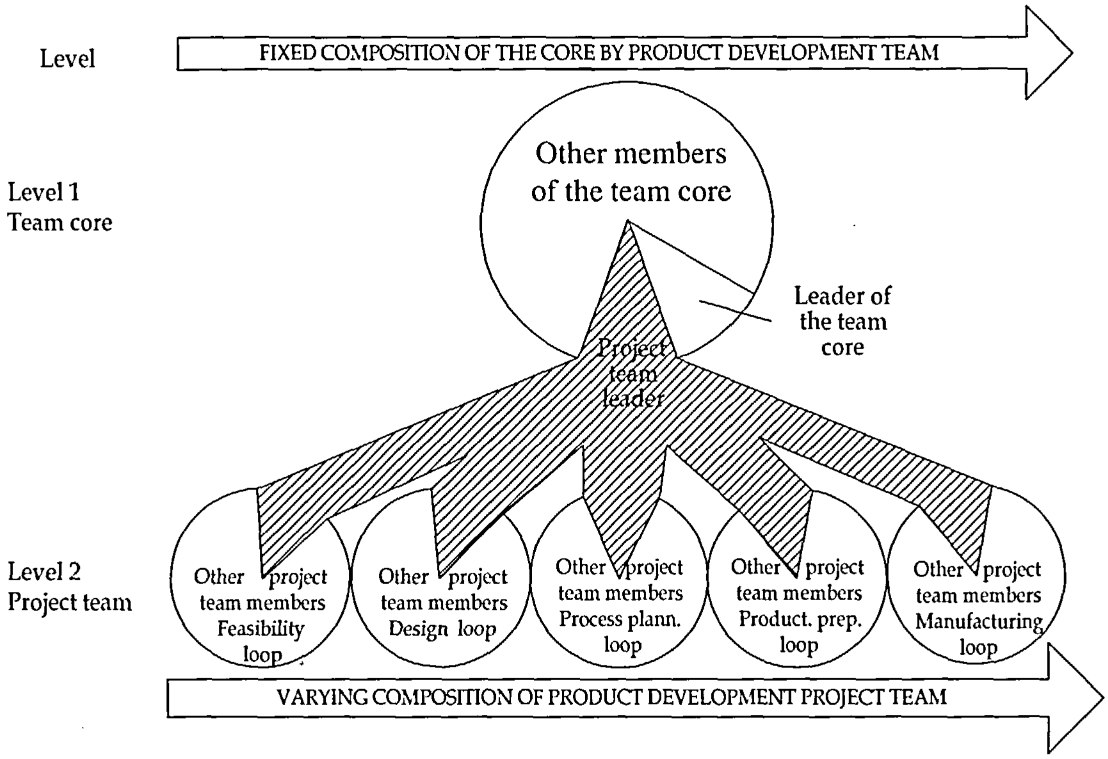


Figure 15. Two-level structure of teams in small companies.

The core team, which supports and supervises product development projects, is composed of:

- Core team leader (permanent member);
- Managers of the company's professional services (permanent members);
- Project team leader (permanent member);

The project team, which implements tasks stated in the scheduling, financial and personnel plans, is composed of the following elements:

- Project team leader (permanent member) and
- Professionals from various fields of work and representatives of strategic suppliers and customers (temporary members).

Project teams in small companies have a similar composition to that of functional teams in large companies, the major difference being that there is only one such team, but its composition changes during the period of product development. The project team composition for each feasibility loop will be discussed below.

In the feasibility loop, in which the project team determines the customer requirements and the team's goals and prepares suggestions for various product variants, such a team consists of employees from the marketing, planning and design departments and the representatives of strategic suppliers and customers.

In the design loop, the project team is in charge of outline solutions for the product and conceptual and embodiment design of the product itself and of its assemblies and parts, prototype development and selection of the best variants from the standpoints of function, form and technology. This team consists of employees from the planning, design and manufacturing technology departments.

In the process planning loop, the project team is in charge of the selection of the most appropriate technological procedures for the manufacture of components and assembly (determination of the sequence of operations and microtimes; selection of machines and tools to be used). This team consists of employees from the design, manufacturing technology and production preparation departments and representatives of strategic suppliers.

In the production preparation loop, the project team is in charge of task assignment (workshop, cellular or product work process) and selection of optimal disposition of work implements. This team consists of employees from the technology, production preparation, manufacturing, assembly, logistics and shipping departments.

In the production loop, the project team is in charge of prototype testing, purchasing of necessary equipment, disposition of work implements and zero series production and testing. This team consists of employees

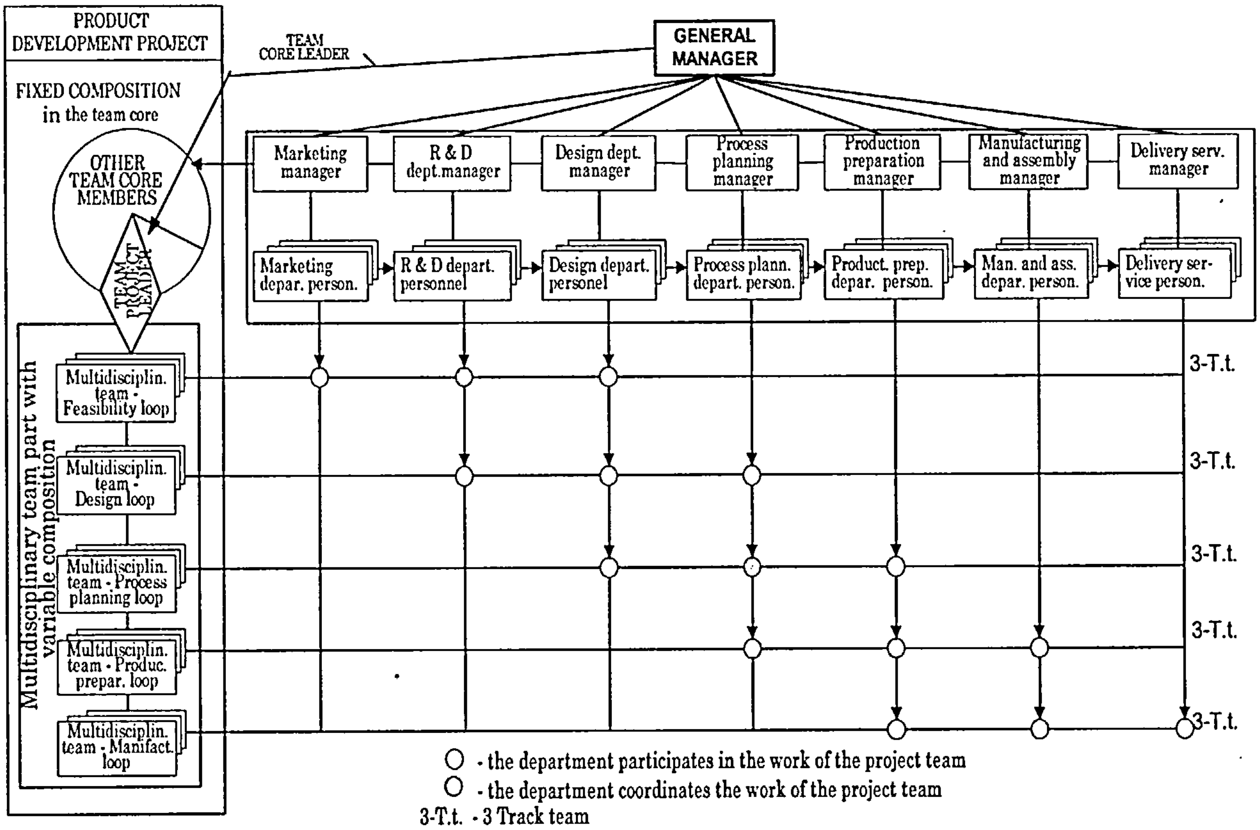


Figure 16. Proposal for matrix organization of small companies.

from the production preparation, manufacturing, assembly, quality assurance, warehousing and shipping departments.

In a small company, tasks otherwise performed by phase teams in large companies, are taken over by the project team leader, who coordinates the work and harmonizes goals and activities between the project team and the core team and ensures an unimpeded transition from one phase or loop to another in product development.

The analysis of various organizational schemes in companies showed that matrix organization (of the company, or of the core team and project teams) is best for small companies. In this manner, individual core team members, with the exception of the project team leader, spend part of their working time performing work for their department and are responsible for this work to the company's general manager, while the remaining part of their working time is dedicated to the project of product development, for which the employee is responsible to the core team leader. This work method is called CPJT (Company Part-time Job) and is an important tool of dynamic production. Project team members, with the exception of the project team leader, also use part of their working time to perform tasks in their department and are responsible for their implementation to the department manager, while the remaining part of their working time is dedicated to the product development project, for which employees are responsible to the project team leader.

During the entire product development project, the project team leader ceases to participate in the work of his department and works full-time exclusively on the project (Figure 16). After project completion, he will return to his department. The project team leader should be an appropriately qualified and experienced person who is familiar with the activities of all company departments and trained for the use of computer tools and information technology.

The transition from sequential to concurrent product development should be performed in the following two phases:

- Preparation for concurrent engineering product development and
- Implementation of concurrent engineering product development.

In the preparatory phase, the company must first decide on the composition of the multidisciplinary team, the structure of subteams and the overall organization of the company. This must be followed by training of team members for successful teamwork at several creativity workshops [7].

Successful completion of the preparatory phase for concurrent product development is a condition for the beginning of the implementation phase of concurrent product development, i.e., implementation of a 3-T track-loop process of product development.

4. An Example of Team Formation in Small Companies

A small Slovene company that has developed and now manufactures mini-loaders in small batches, decided to participate in the application of the concept presented in Section 3.

The company has 182 employees. In addition to company management (general manager, assistant to general manager), it has the following eight departments:

- Marketing Department, which is in charge of marketing and sales and has 7 employees;
- R&D Departments, which is in charge of product development, planning and design and has 11 employees;
- Technological Department, which is in charge of production planning and logistics and has 12 employees;
- Purchasing Department, which is in charge of purchasing and cooperation and has 5 employees;
- Production Department, which is in charge of operative preparation of production and production itself and has 136 employees;
- Financial Department, which has 3 employees;

Figure 17. Team core composition for mini-loader management.

- Quality Assurance Department, which has 3 employees, and;
- Information Unit, which has 3 employees.

The management of this company recognized the need for an organized approach to product development early on. It enlisted the help of external experts, including our team from the Faculty of Mechanical Engineering of Ljubljana.

Two creativity workshops were organized for the company's general manager and eight department managers.

The results of the first creativity workshop (Figure 17) showed that the core product development team should consist of the following ten company employees:

- General manager (also the core team leader),
- Eight department managers, and
- Project team leader.

The topic of the second creativity workshop was project team composition in each individual phase or loop of mini-loader development. This workshop was expected to bring answers about the necessary number of product development loops, activities to be performed by the project team in each individual loop, and departmental responsibilities for the implementation of planned activities. The results of the second creativity workshop are shown in Table 1.

The results of the second creativity workshop, shown in Table 1, and the management's decision regarding the project team leader enabled the formation of project teams for individual loops of mini-loader development, as shown in Table 2.

The project team leader is a permanent team member, while professionals from various fields of company activities and representatives of suppliers and customers are temporary team members.

The known compositions of the core team and the project team for mini-loader development enabled the determination of the matrix organization of the company and the composition of both teams, as shown in Figure 18.

As can be seen in Figure 18, the core team members should use a part of their working time to perform tasks for the department and are responsible for them to the general manager, while the other part for working time is earmarked for working in the core team, for which they should be responsible to the core team leader, again the general manager. Project team members should use a part of their working time to perform tasks in their departments, for which they should be responsible to department managers, and the remaining time for work within the project team, for which they should be responsible to the project team leader.

The tasks were then observed in detail, procedure after procedure, including the members assigned to each

Table 1. Loops in mini-loader management with a description of activities and department responsibilities

Loop no.	Loop description	Department / Personnel / Loop activity planning	SALES		R & D			TECHN-OLOGY		PURC-HASING		MANU-FACT.		FINANCES	QUALITY ASSURANCE	INFORMATION UNIT	DELIVERY	INDUSTRIAL DESIGN
			MARKET-ING	SALES	RESEARCH	DEVE-LOPMENT	DESIGN	PRODUCT. PLANNING	LOGISTICS	PURCHA-SING	COOPERA-TION	OPERAT. PREPAR.	MANUFA-CTURING					
1	FEASIBILITY LOOP	Goals definition	///		///	///												
		Scheduling plan	\\\	\\\	\\\	\\\		\\\		\\\						\\\	\\\	
		Financial plan		///										///		///		
		Preliminary calculation		\\\		\\\		\\\		\\\				\\\		\\\		
		Target market	///	///						///								
2	DESIGN LOOP	Preliminary design	\\\		\\\	\\\												\\\
		Assembly outline concept			///	///	///											///
		Product conceptual design			\\\	\\\												
		Modules design			///	///	///									///		
		Manufacturing drawing			\\\	\\\	\\\	\\\								\\\		
		Bills of material				///	///	///	///	///						///		
3	PROCESS PLANNING LOOP	Material requirements					\\\	\\\	\\\	\\\						\\\		
		Technological procedures						///				///				///		
		Control procedures						\\\	\\\			\\\			\\\	\\\		
		Preparations					///	///				///						
		Tendered documentation						\\\								\\\		
		Review of available stokes							///						///	///		
		Creating of orders							\\\	\\\						\\\	\\\	
		Ordering of materials							///	///		///				///	///	
		Acceptance and warehousing							\\\	\\\					\\\	\\\	\\\	
4	MANUFAC-TURING LOOP	Preparation of materials							///			///	///			///		
		Preparation planning						\\\				\\\	\\\			\\\		
		Production of components and assemblies						///			///	///	///			///		
		Assembly						\\\				\\\	\\\					
		Testing						///				///	///					
		Testing and control										\\\			\\\			
5	SALES LOOP	Conclusion of contract		///			///	///				///	///	///	///	///		
		Product preparation					\\\	\\\				\\\	\\\					
		Final control		///	///							///	///		///			
		Delivery		\\\				\\\					\\\			\\\		

Table 2. Project Team Composition in Individual Product Development Loops

Loop No.	Loop description	PROJECT TEAM MEMBERS																	TOTAL NO. OF PROJECT TEAM MEMBERS IN THE LOOP
		PROJECT TEAM LEADER	MARKETING	SALES	R & D	CONCEPTUAL DESIGN	DESIGN	PRODUCTION PLANNING	LOGISTICS	PURCHASING	COOPERATION	OPERATIVE PREPARATION	MANUFAC-TURING	FINANCES	QUALITY ASSURANCE	INFORMATION UNIT.	DELIVERY	INDUSTRIAL DESIGN	
1	FEASIBILITY loop	▨	▨	▨	▨	▨		▨		▨				▨		▨	▨		10
2	DESING loop	▨	▨		▨	▨	▨	▨	▨	▨						▨			10
3	PROCESS PLAN-NING loop	▨					▨	▨	▨	▨		▨			▨	▨	▨		9
4	MANUFAC-TURING loop	▨						▨	▨		▨	▨	▨		▨	▨			8
5	SALES loop	▨		▨	▨			▨	▨			▨	▨	▨	▨				10

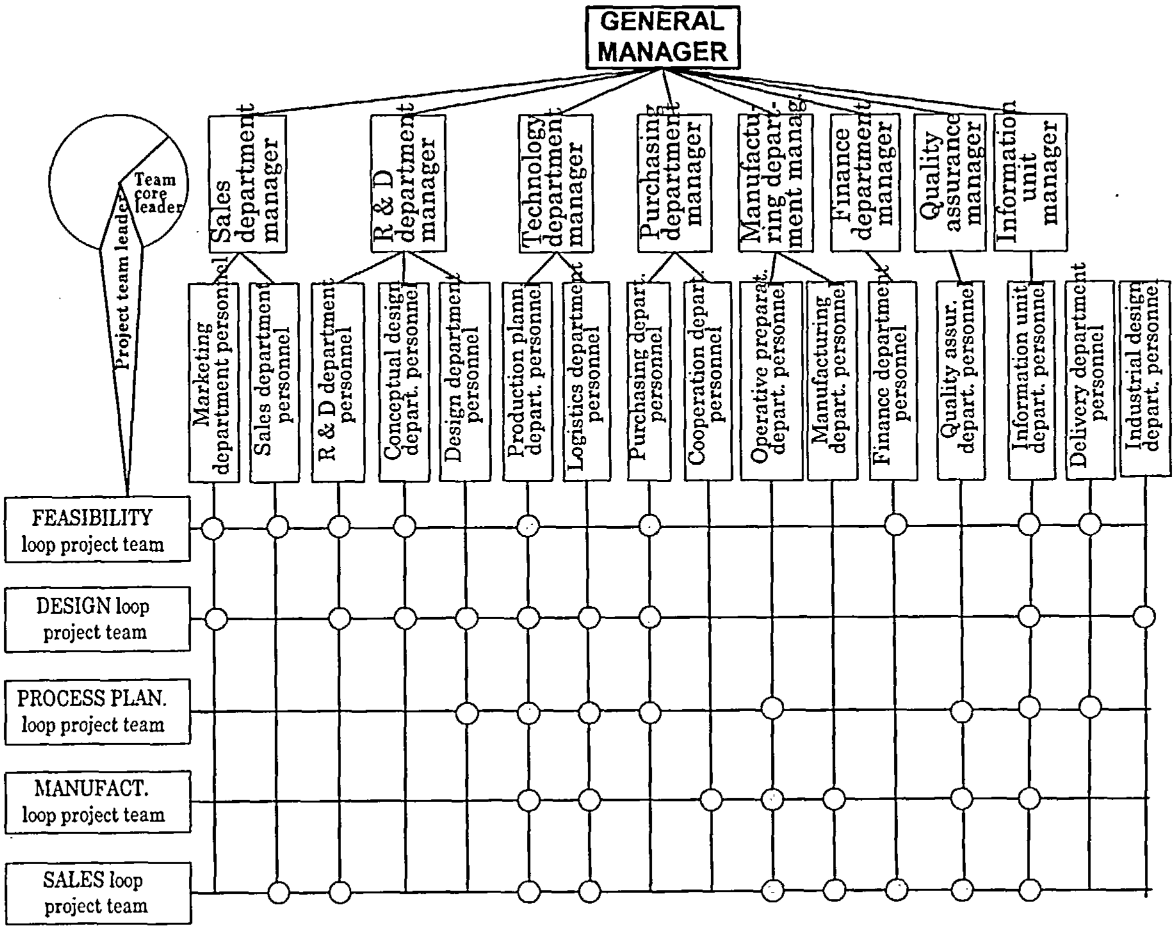


Figure 18. Example of matrix organization of small company.

project subteam. External experts monitored work in groups and with occasional random visits to the company. Any information blockages were overcome on the basis of human relationships. The process and established deviations were recorded. Minor deviations were promptly supplemented as necessary.

The presented case has led to the following conclusions:

- A three-level core team structure is less appropriate for small companies.
- A two-level core team structure provides a good basis for the dynamic cooperation of all those involved in new product development.
- Findings from the literature confirm that a 3-T loop structure is a limiting factor in concurrent engineering technology in small companies. It limits complete treatment of problems by not being able to use a wide range of knowledge. For this reason, project teams need to be supplemented by members from various departments with a wide range of knowledge.

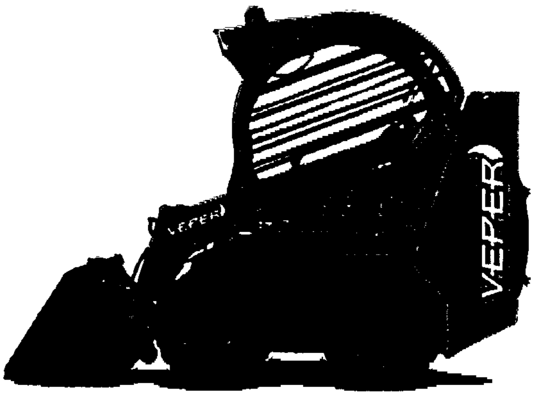


Figure 19. Mini loader which was development with presentation model.

- Expansion to n-T looping will serve to integrate the necessary knowledge and departments at each product development phase. Therefore, the iterative process of product development is integrated into the organizational model and will enable the use of naive descriptions according to the principle of heuristic product development.
- The size of n-T looping is determined specifically for each product development phase, depending on product type.

On the basis of the presented concept, a mini-loader was developed up to the prototype phase within 10 months of the decision (Figure 19). The prototype was tested at a construction site for 30 days. The research and development work included external experts in the fields of mechanics, power engineering and hydraulics. Finally, the documentation was supplemented and improved, and this enabled the production of a zero series of 25 mini-loaders.

The 3-T loop known from the literature proved to be too rigid for small companies. On the basis of the presented model and its use in practice, an n-T loop is proposed for use in each individual phase. This means that n needs to be determined separately for each phase. The matrix structure of knowledge and departments also needs to be determined for each individual product. There is no general model for selecting the required knowledge. However, the described findings present various matrix compositions for knowledge and departments for individual groups of products. This method of work is very suitable for the formation of ad-hoc design-development teams in large companies (those which are assigned to develop a specific group of products).

5. Conclusions

The market requires short product development times, which forces even small companies to move from sequential to concurrent product development.

Since team work is the basis for concurrent engineering product development, special attention is paid to the formation of teams in small companies. Our research has led to a conclusion that in small companies the multidisciplinary team should not be composed of four, but of two subteams (logical and technological subteam). A two-level team structure is suitable for small companies (permanent core team and variable project team) and matrix organization of the company.

An n-T team was introduced for each individual phase of product development, as these are much more efficient in supplementing the required knowledge in individual phases.

The proposed concept of team formation in small companies was tested on an example of team composition planning in a company that manufactures mini-loaders.

It was found that not all companies have all the tools required to support concurrent engineering. However, this can be said of a company only after a model for organized approach to new product development has been implemented in it. The management of the company described in this paper decided to use the formed teams for the introduction of the basic tools that support concurrent engineering. With the assistance of external team members, the tools and knowledge were then supplemented in order to improve the entire process.

Successful introduction of the basic tools and methods that support concurrent engineering is a condition for a later transition to concurrent engineering development of a new type of product (e.g., mini-loader).

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