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Modelling of Concurrent Development of the Products, Processes and Manufacturing Systems in Product Lifecycle Context

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1. Introduction

The process planning is a phase of the Product Life Cycle realized within the production preparation, which significantly influences the phases of the production and usage of the product. Therefore, the process planning should be examined in the context of the life-cycle of the product and with the consideration of new development strategies. This part presents the directions for increasing the level of integration and automation of manufacturing production preparation with the possibilities offered by PLM solutions. In the area of functional integration, the analysis of CAx and DFX systems used in the implementation of the product development strategies, processes and manufacturing systems are carried out. In the area of information integration, the application of PDM system and the development of the workflow diagrams are discussed. The BPMN notation is used for the modelling of development processes occurring in the product lifecycle in order to implement the workflow diagrams. The conception and example of integrated process and manufacturing system planning in PLM (Product Lifecycle Management) environment are presented.

2. The trends in strategies and computer systems for concurrent product development

According to the new development strategies (Eigner, 2004), (Chlebus, 2000), the product development focuses on Fig.1:

- as much as possible parallel execution of all development related product life cycle phases, thus creating CE (Concurrent Engineering) environment. CE strategy assumes the development of resources and production facilities at the early product design phases to shorten the production start-up time.
- incorporation of the relations between business and engineering activities CEE (Cross Enterprise Engineering), securing also the access to the resources of cooperating enterprises. The parallel execution and the integration of products and processes start on the early product development stages and cover suppliers, clients, as well as internal and external IT solutions. CEE means that product components, parts, assemblies, systems and functional sub-systems are designed and developed across the local

business and engineering boundaries. Intranet and internet are here used as the means for the communications and the information exchange.

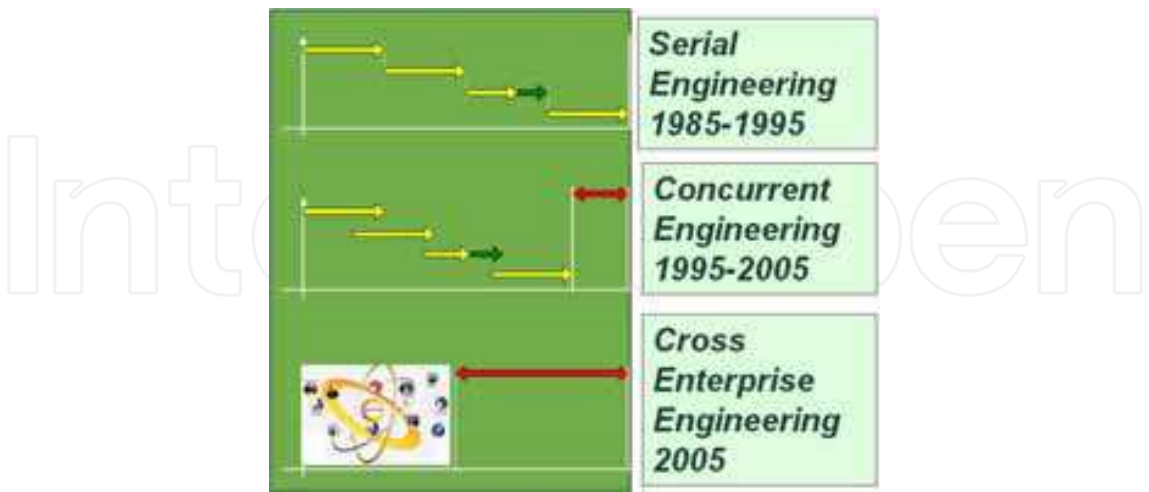


Fig. 1. Product design strategies

3. Development of CAD/CAM systems

The key condition for the efficient process planning, especially in the CE environment is computer integrated design and planning - the common platform for the CAx systems used during the product development.

The works (Dybała, Oczóś, Chlebus, & Boratyński, 2000) (Duda, 2004), presents the use of the CAx systems in the various phases of the product lifecycle fig.2.

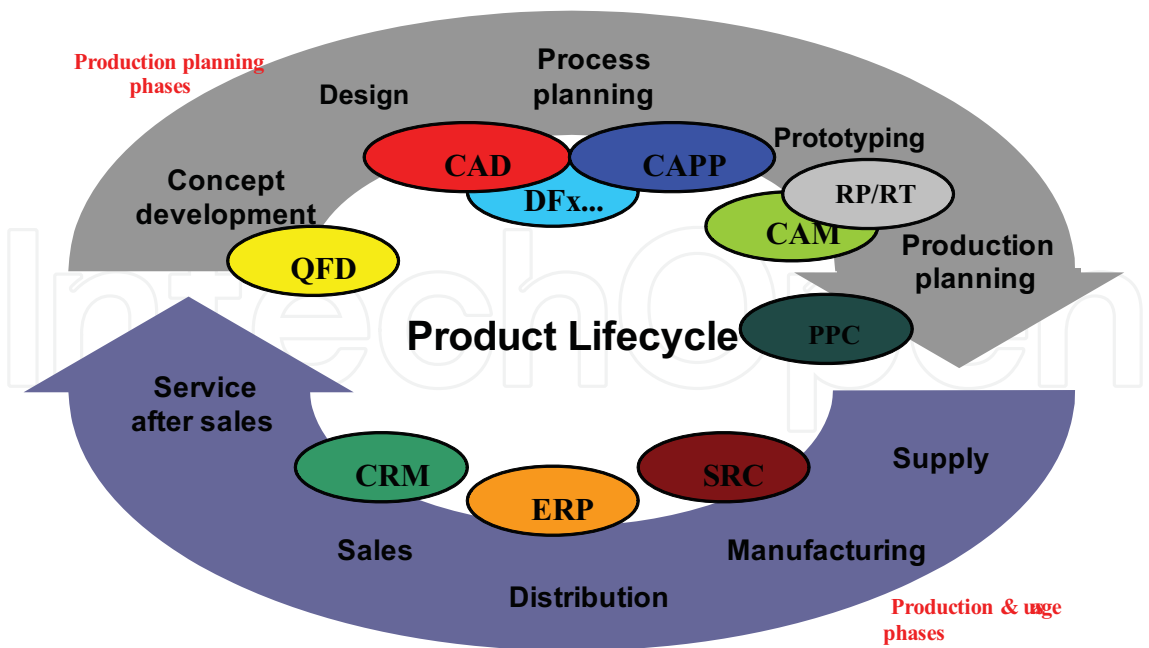


Fig. 2. The use of computer methods and systems in product life cycle

To determine the level of the automation in the area of manufacturing process planning, the selected CAD/CAM systems were analyzed in the view of:

- Assembly process planning,
- Manufacturing stock and process planning,
- Planning of the structures of the manufacturing process plans.

Based on the results of the analysis it was found that the level of automation in the area of manufacturing process planning in CAD/CAM systems is still relatively very low (Duda, 2004). The generation of assembly sequences and the development of the manufacturing process plans for the parts constituting the product is executed in the interactive manner by the manufacturing engineer.

This level is still increasing as the result of the use:

- templates allowing for process planning based on the pattern created earlier,
- modules allowing for the storage of the manufacturing knowledge and its further use during the process planning.

Because of this, CAD/CAM systems evolve toward Intelligent CAD/CAM systems fig. 3.

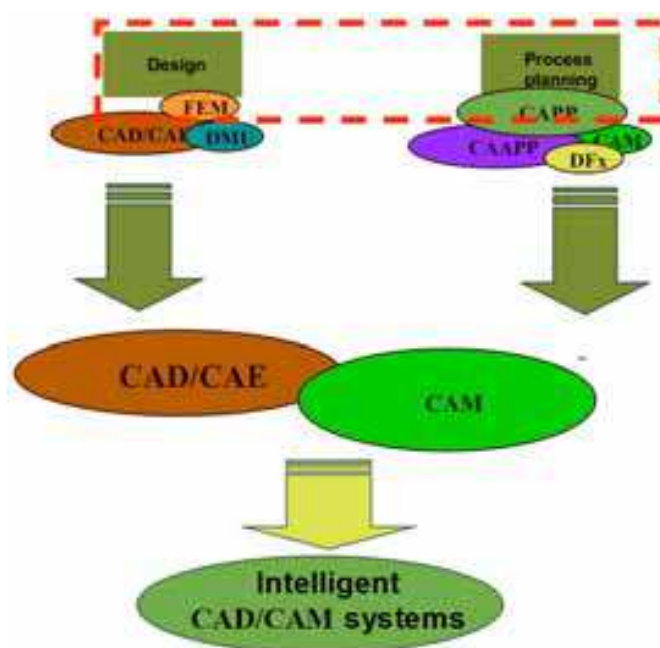


Fig. 3. Development of CAD/CAM systems

CAD/CAM systems use the processor which generates the general temporary data and then converts these data into the format fulfilling the requirements of the particular machine tools. Because of this mode, the execution of the creative decision process executed by manufacturing engineer and the planning based on the available manufacturing resources (machine tools, tools, equipments) is still very difficult.

4. Development of CAPP and CAAPP systems

This confirms the fact that manufacturing process planning is the link connecting the CAD and CAM systems, necessary to achieve the full integration of the production. The results of the executed analysis show the necessity for the intensification of works toward the development of CAPP and CAAPP systems being the key conditions for the further advancement of computer integrated product development. The interests in CAPP systems are caused by the need for the integration of design and manufacturing phases (Inyong

Ham, 1988), (Mari, Gunasekaran, & Grieve, 1995). The manufacturing process planning is the link between these systems of vital influence on the whole integration level of production preparation.

In the traditional approach, the design and manufacturing process planning were executed sequentially during the production preparations stage. The goal of the Concurrent Engineering is to convert this sequential approach in the more interactive, parallel process. The CAAPP and CAPP systems should be developed in the view of the convenient style of process planning. A lot of systems were developed based on the sequential model of product development. Such systems receive the detailed specifications of the product as the input data and the manufacturing process plan is usually created in the interactive mode – the manufacturing engineer is responsible for the final effects. Now the tendencies for the development of the systems incorporating the processing possibility of manufacturing systems at the early phase of works, for the customised planning by manufacturing engineer bases on the knowledge, without the limitations on the creative decision process can be noticed. The development of such systems is related to the aspect of the decision taking in the particular environment. The goal of the planning systems is securing the assistance for the engineer during the manufacturing process planning. The products are developed in an interactive manner in the Concurrent Engineering environment: the subsequent versions of products and its manufacturing processes are generated at the early phase of works, when the costs of the modifications are relatively very low. The computer integration of the design and manufacturing is the condition for the effective implementation of CE approach. The manufacturing process planning system should be one of the elements of such solution.

The manufacturing process planning method fulfilling the requirements of the Concurrent Engineering model should feature the possibility for the flexible generation of variants of structures of manufacturing processes and variants of its constituent elements. The semi-generative method was selected for the implementation of CAPP system fulfilling the Concurrent Engineering requirements. The process planning system working in the Concurrent Engineering environment should be one of the main elements of the computer integrated manufacturing system.

The use of modern product development strategies puts some requirements:

- for systems of assembly process planning:
 - ability to assembly processes designing for the generated acceptable assembly sequences,
 - ability to organizational forms of the assembly designing, considering the manufacture system,
- for systems of manufacture process planning:
 - ability to plan processes for the wide range of typical parts,
 - ability to plan processes taking into the account the capabilities of manufacturing systems,
 - ability to generate variants of process plans at different level of details, which is needed to evaluate the costs at various degrees of advancements, from the general concept to the finished version.

The semi-generative method was selected for the implementation of CAPP system fulfilling the Concurrent Engineering requirements. The process planning with the use of these methods requires some expert knowledge from the user. In (Duda, 2003) the process planning knowledge was divided into:

- knowledge about the structures of process plans for typical parts refereed further as 1st type knowledge,
- knowledge defining the process planning strategy imposed by the employed methodology, refereed further as 2nd type knowledge.

The manufacturing knowledge representation is based on the model of manufacturing knowledge in the form of hierarchical decision nets. The following knowledge areas were distinguished:

- the knowledge SK describing the rules for part classification in the view of manufacturing, represented in the form of frames RK and rules {set TK},
- knowledge SF describing the rules for the classification of the semi-finished product for the part types, represented in the form of frames RF and rules {Rule TF},
- knowledge describing the rules and principles for the process planning for the part types, represented in the form of frames RP and rules {Rule TP},
- knowledge SW describing the rules and principles for the semi-finished product design for the semi-finished product types, represented in the form of frames RW and rules {Rule TW}.

The generation of manufacturing process plans is executed based on the following:

- characteristics of parts stored in object oriented database of manufacturing features (Pobożniak, 2000),
- knowledgebase covering the general and detailed rules and principles of manufacturing process planning,
- database of processing capabilities of manufacturing system (Duda, Kwatera, Habel, & Samek, 1999),
- database of catalogue values.

Process planning, due to its complexity is realized in stages, from the general idea to the detailed solutions in an interactive manner. For the process planning mode three planning stages were distinguished (Duda, 2003) fig.4 :

- The selection of the general process structure (Stage I),
- Reverse design of raw material and intermediate states of the workpiece (Stage II),
- Generation of process plan (Stage III).

STAGE I. The selection of the general process structure

In first stage, the generalized structure of the manufacturing process is selected based on the manufacturing and geometrical characteristics of the product. The product is evaluated taking into consideration the values of its attributes, according to the sequence resulting from the knowledge SK describing the rules for part classification in the view of manufacturing. The classification into manufacturing class determines the manufacturing knowledge for the semi-product type selection SF and manufacturing knowledge for shaping the process plan SP.

STAGE II Reverse design of raw material and intermediate states of the workpiece

Second stage is realized in the following steps:

- determination of the type of the semi-finished product,
- planning of the intermediate shapes of the product,
- design of semi-finished product.

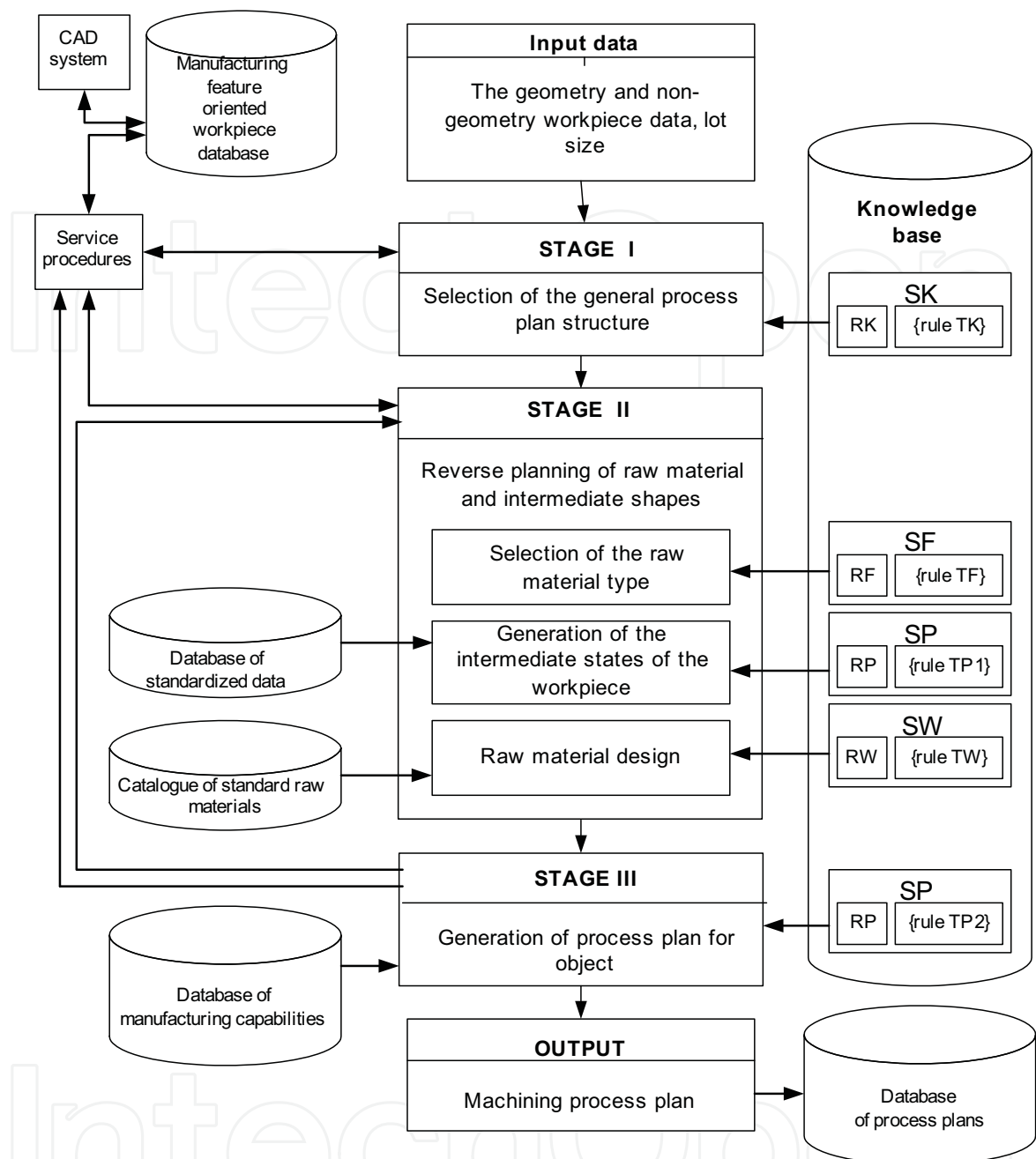


Fig. 4. The block scheme of the algorithm of machining process plan generation

The type of semi-finished product is selected on the basis of the set of rules for classification of the semi-product SF. The necessary parameters are collected from three sources:

- part type; it is the output of first stage,
- geometrical and manufacturing characteristic (material, mass, accuracy requirements, etc.) from feature/object product database,
- dimensions of standard semi-finished products from catalogue.

As the result of the reasoning the semi-finished product type is proposed (rolled, forged, etc.).

Generalized structure of manufacturing process selected during the first stage, is a base for the determination of intermediate states of the workpiece. On the basis of geometrical and

manufacturing characteristics of the product and the manufacturing knowledge the intermediate states and the semi-finished product may be determined by using the reverse (from the product to the semi-finished product) method. This method includes the identification of workpiece surfaces with characteristics matching the planning activities selected according to generalized structure, from end to start nodes on each level of hierarchical net.

The selected type of semi-product and intermediate states determined for the start node form the basis for the planning of semi-product and its process plan with knowledge RW.

STAGE III Generation of process plan

The determination of the intermediate shapes allows to decompose the overall planning goal, the development of process plan, into sub-goals. The planning goal on the III Stage can be defined as follows: Select the means (machine tools fixtures, tools) to realize the sub-goals represented by the intermediate shapes while creating the hierarchical, object oriented structure of process plan for the given workpiece.

The actions are carried out based on the following data:

- characteristics of the raw material and intermediate states of the workpiece being the outcome of the stage II,
- characteristics of the manufacturing system capabilities selected for the process plan implementation.

The algorithm for process plan generation, is realized on the subsequent levels of details covering: generation of operation, set-ups, positions and cuts.

In the first planing step, the list of manufacturing feature transformations in generated process plan PT is determined for each intermediate state.

The subsequent generation levels are realize interactively in the system „process engineer – computer” intended to identify the admissible variants of realization. The selection of the one of the presented solutions by the process engineer at the given level, limits the number of the solutions on the lower levels, allowing for rational structuring of the process plan.

In there is no appropriate solution to be selected at the given level, it is possible to change the solution selected on the higher level in the feedback manner. In this iterative way, the process plan is generated.

Also Computer Aided Assembly Process Planning (CAAPP) systems are being used. The main functions of such systems are (Duda & Karpiuk, 2008):

- definition of assembly units,
- generation of assembly sequences,
- selection of the technical means needed for the realization of the assembly,
- preparation of the technological documentation of the assembly process.

Generation of the assembly sequences has a great influence on the effectiveness of the assembly processes. The works (Łebkowski, 2000) distinguish four basic groups:

- Methods using the three-stage procedure of the sequence generation including: generation of relations between elements of the final product, generation of assembly sequences, selection of the best sequence according to accepted criterion of the optimisation,
- Methods separating the assembly into subgroups and generating the subsequence for every sub-assembly by applying simple rules,
- Methods based on expert systems created for the assembly of specific unique products,

- Methods generating different variants of assembly sequences for products by the modification of the already defined sequences.

The methods of generation of assembly sequences can be divided according to the type of applied procedures. The work (Ciszak & Żurek, 1999) distinguish:

- Algorithmic methods giving optimal sequences assembly according to given criterion,
- Heuristic methods giving solutions in the relatively short time.

5. Development of DFx systems

Market action should be directed to decrease the costs of the product manufacturing, improve the manufacturing processes and the production organization while maintaining the required quality and meeting the assumed technical requirements.

On the stage of the analysis of the design, DFx methodology is used fig 5.

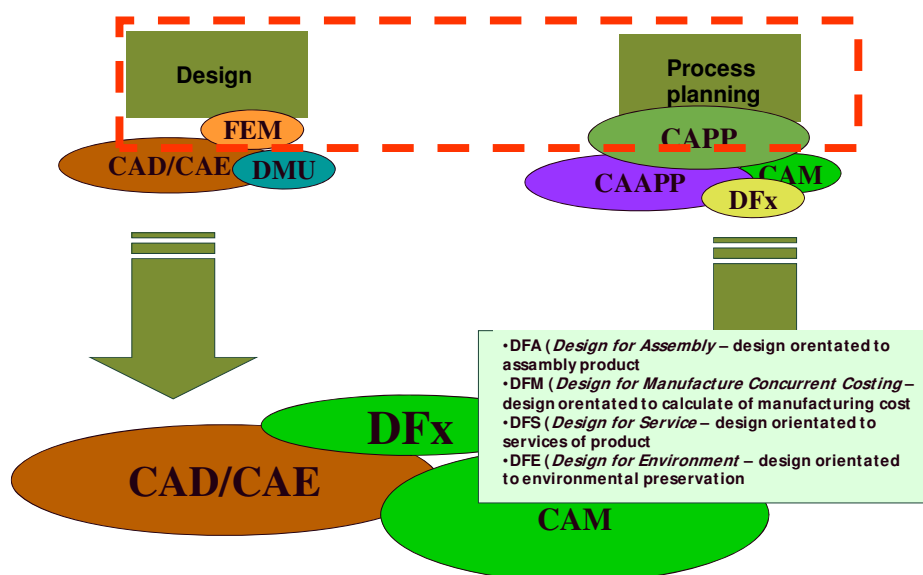


Fig. 5. Development of DFx systems

DFx techniques analyse the existing designs to propose the changes lowering the product cost. The most popular systems on the market is now Boothroyd and Dewhurst's DFMA (Design for Manufacture and Assembly) which contains the following modules:

- DFA (Design for Assembly),
- DFM (Design for Manufacture Concurrent Costing),
- DFS (Design for Service),
- DFE (Design for Environment).

DFMA methodology was developed by Prof. Boothroyd and Dewhurst. This methodology helps to reduce the costs of manufacturing and to ensure the correctness of the assembly by analysis outputting the conclusions concerning the product design.

6. Integrated process and systems development in PLM environment

The key condition for the effective concurrent engineering and cross enterprise engineering is the computer integrated environment of design and manufacturing – the common platform for computer aided systems for the product development. Effectiveness of the CE

and CEE strategies results from the better management of information in production process. The efficiency of activities depends on the provision of right information, to right places, for right peoples in the right time. PDM (Product Data Management) systems play the coordination role in the synchronization of the flow of information (Eigner, 2004). PDM systems manage the data about the product services, product structure, its documentations and processes with the ability of processing data in the electronic form.

PDM systems allow for modelling, storage and transformation of all data related to the product. Development of the integrated systems evolves toward the PLM (Product Lifecycle Management) solutions (Kahlert, 2004). PLM strategy increases the integration and automation of realized functions PLM environment includes the following applications for the product development:

- PPM (Product and Portfolio Management),
- CAx (Product Design),
- MPM (Manufacturing Process Management),
- PDM (Product Data Management).

Features of modern development strategies indicate the need for product development phase integration. Integration and parallel execution of activities were received through the separation of the conceptual design stages, allowing for the creation of the variant design solutions. Variants are then evaluated in the view of the requirements of the next development phase. The selected variant fulfilling the established criteria is next further developed in the detail design stage Fig 6.

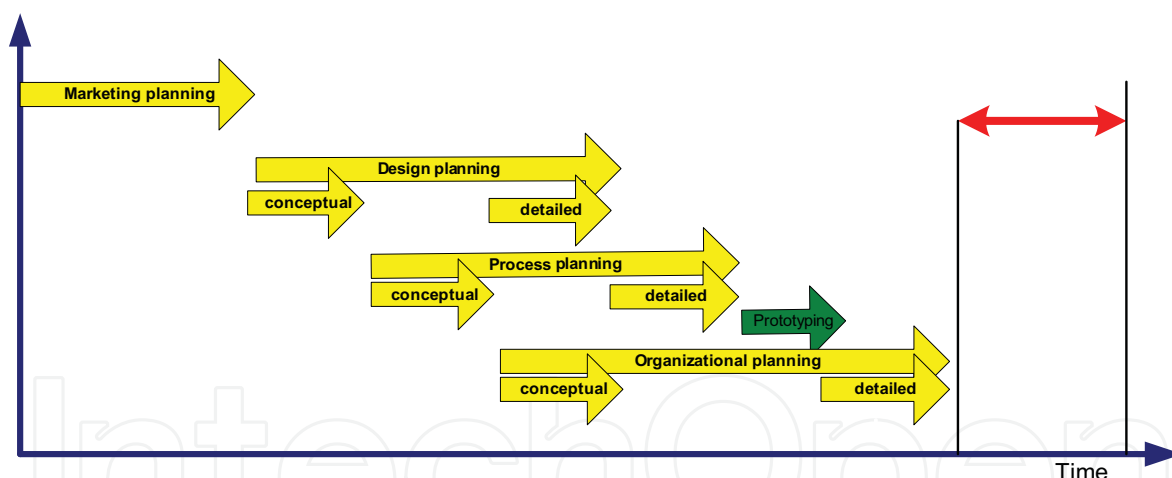


Fig. 6. The separation of the conceptual and detailed design stages

Integration in the area of design and technological product development indicates the extraction of the following phases (Fig. 7):

- conceptual process planning (PHASE III A),
- detailed process planning (PHASE III B).

The basic goal of the conceptual phase is the determination of the variants of manufacturing processes on the base of the design product features selected during the design planning stage. The multivariant nature of the process planning is due to the possibility to use different manufacturing methods and raw materials for the elements constituting the product. The multivariant nature of the assembly processes is due to the possibility to use several assembly sequences with the application of methods and manufacturing means and

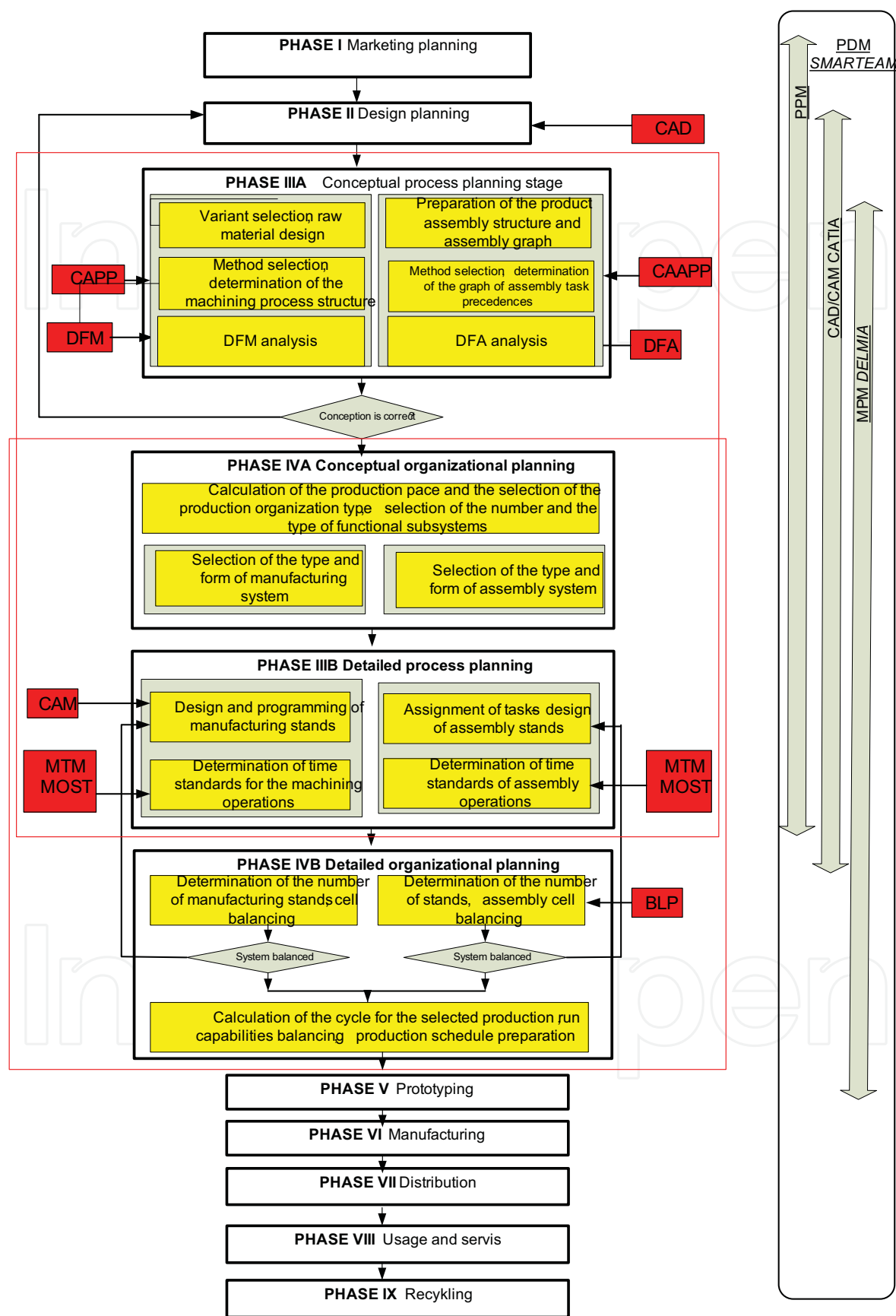


Fig. 7. Parallel execution of product development phases

different automation levels. On the base of the defined variants of manufacturing/assembly processes, the manufacturability analysis DFM and assembleability analysis DFA are carried out. The results of the subsequent iterations are used to simplify the product design (by minimization of the number of parts and the integration of parts), thus decreasing the time and costs of the assembly and to estimate the times and costs for different manufacturing methods of constituent product elements. It should be noted that the DFA and DFM analysis should be applied together to check whether the simplification of the product structure and elimination of some parts does not lead to the higher manufacturing costs. The result of the analysis is the selection of the product design variant and the variant of the manufacturing and assembly plans for constituent product elements with the level of details allowing for the necessary organizational calculations.

Integration in the area of technological and organization product development indicates the extraction of the following phases:

- conceptual organizational planning (PHASE IV A),
- detailed organizational planning (PHASE IV B).

The information from the previously executed product development stages describing the production task (production program of products and their design features, variants of manufacturing plans) are used as the base for the organizational planning. The main goal of the conceptual production organizational planning stage is the development of the production system concept. The planning activities cover:

- for the assumed planning data: required volume of production, allowable duration of production, calculated production pace,
- selection of the production organizational variant by choosing the type and organizational form of the production,
- selection of the number and types of functional subsystems for transport, storage and quality checking.

The result of the above actions is the concept of the production system offering the possibility to execute the detailed manufacturing planning (PHASE IIIB) within the scope of developing the concept of the manufacturing stands, selection and design of the manufacturing assembly stands. The design activities on the detailed process planning stage cover the activities resulting in the preparation of the instruction sheets for the manufacturing/assembly.

The planning of the process plan operation covers:

- selection and design of the manufacturing machines, equipment and tooling,
- selection of the structure of the process plan, generation of set-ups, machining cycles and technological parameters,
- preparation of the control programs for the operations executed on the programmable devices,
- selection of the time-standard elements (Duda, 2010).

The planning of the assembly plan operation covers:

- selection and design of the manufacturing machines, equipment and tooling,
- selection of the structure of assembly operation, and the assembly activities,
- preparation of the control programs for the assembly devices, robots and manipulators,
- estimation of the assembly operation times.

The results are the base for the selection of the organizational variant of the manufacturing stands and the base for the detailed organizational planning stage (PHASE IVB) covering:

- calculation of the production pace, selection of the production type (serial, parallel or serial-parallel),
- synchronization of the isolated functional subsystems of manufacturing cells by calculating the number of stands and line balancing,
- preparation of the production schedule, balancing of the throughput for the designed manufacturing systems.

The presented process of integrated product development is executed iteratively. The subsequent versions of product, process and manufacturing systems are created using digital techniques which allows for the complete analysis of the generated solutions.

7. Modelling of the product development in production preparation phases with the use of the BPMN methodology

The aims of the Concurrent Engineering are achieved through the parallel realization, integration and standardization of development phases of the whole product lifecycle. Parallel execution of the design and process planning phases leads to the reduction of production preparation time. In the area of information integration, the application of PDM system and the development of the workflow diagrams are used. The successive development phases occurring in the product lifecycle can be decomposed into the constituent elements. The BPMN notation is use for the modelling of development processes occurring in the design and process planning phases in order to implement the workflow diagrams fig 8.

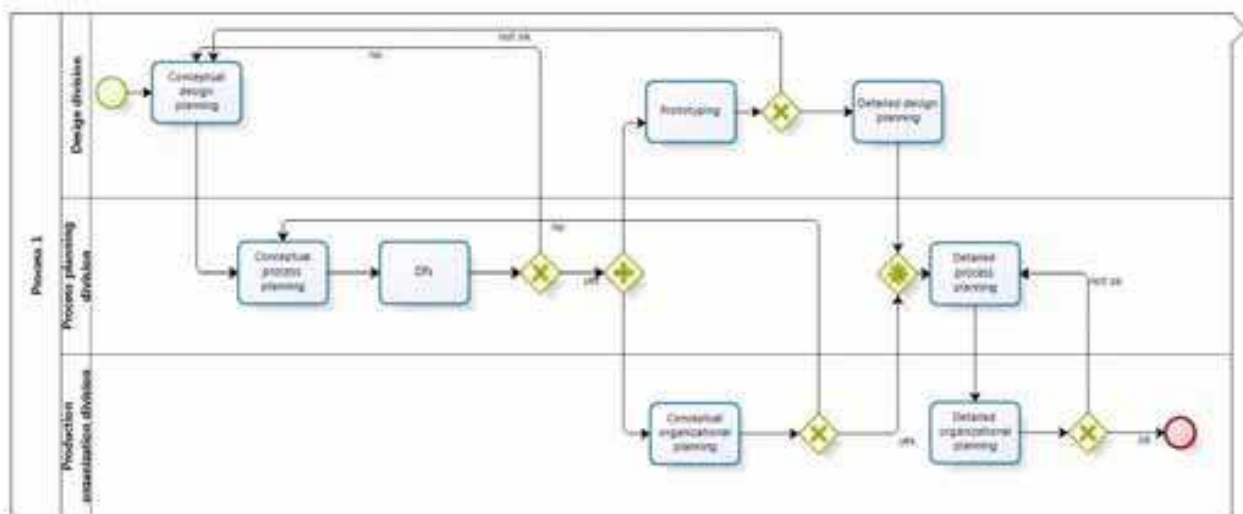


Fig. 8. Model BPMN of product development in production development phases

8. Verification concept in PLM environment

The verification was done with PLM solutions offered by Dassault Systemes. These solutions include the following systems (Fig. 9,10):

- CAD/CAM CATIA for product, manufacturing process and resource design,
- PDM SMARTEAM and ENOVIA for the development process management,
- MPM DELMIA for process and manufacturing system design.

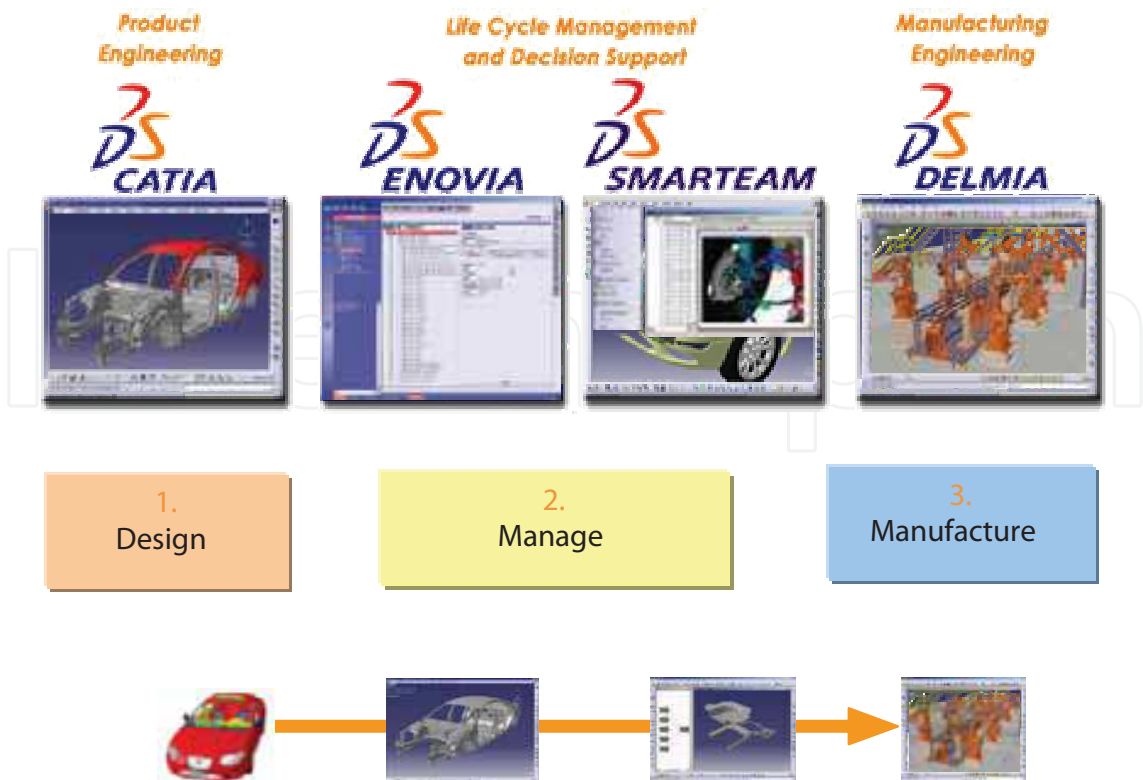


Fig. 9. Areas covered by PLM Delmia solution

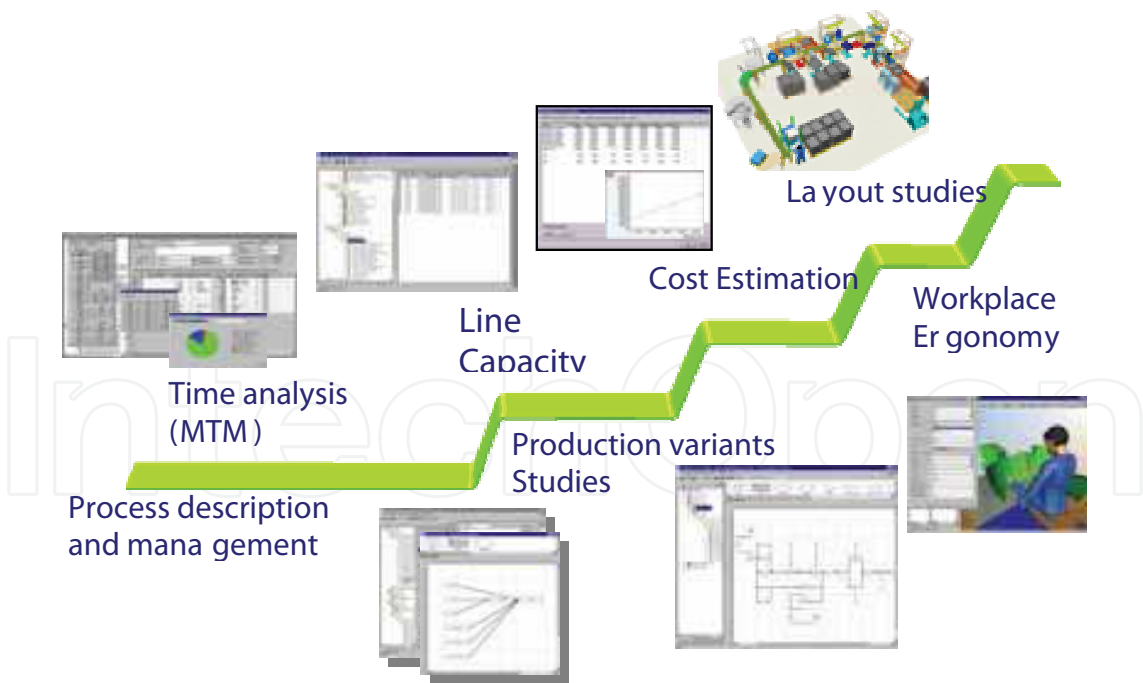


Fig. 10. Process Engineer functions

The projects of gear reducer and car water pump were used to verify the presented concept and CATIA/DELMIA software deployed at Institute of Production Engineering. The tests included the following:

- creation of the digital product model,

- creation of the assembly documentation,
- creation of the manufacturing concept including the definition of process and assembly system library, and the preparation of the digital models of assembly system,
- creation of the process simulation and the ergonomic analysis of work stands.

8.1 Conceptual process planning phase

The assembly process is created on the basis of the digital product model prepared with CATIA system. The process planning activities includes:

- the development of the product assembly structure – separation of the assembly units (assemblies, subassemblies and parts),
- development of the assembly process plan including the basic parts for separated assembly units, methods and hierarchical order of assembly of these units to receive the design features of the product,
- mounting of subassemblies, assemblies and parts prepared with Part Design module in Assembly Design module based on the developed assembly plan.

The results of the above actions are necessary to make the assembleability analysis of the product and for iterative improvement of the design form in view of the assembly requirements. The product design resulting from the subsequent iterations and its assembly plan form the base for defining the graph of the assembly activities, representing the admissible variants of the execution of product assembly.

8.2 Conceptual production organization planning phase

The conceptual manufacturing organization phase is used to select the appropriate form of the production organization, production pace, and the initial calculation of the number and type of functional subsystems. On this phase, also the type and organizational form of assembly system is selected.

8.3 Detailed process planning phase

The selected type, organizational form of the assembly and the graphical product assembly plan verified with DMU Kinematics module of CATIA are the basis for the assembly process planning. The assembly process planning includes the selection of the operations and activities, selection of the assembly equipment, conceptual design of the assembly stations as well as the decisions on the concept and the selection or design of the transport system components. Based on the above process, the digital model of the assembly system and work places is created. The data required for the making the detailed production organization calculation and for the calculation of the duration of assembly activities are gathered from the components of the digital model of the system. The duration times of the assembly activities were determined using the MTM and MOST methods.

8.4 Detailed production organization planning phase

The selected structure of the assembly process and the determined duration times of assembly activities covered by the operations are the base for the synchronization within the isolated assembly subsystem. For analysed production organization forms, for example production lines, these steps include the calculation of the number of stands and line balancing.

The activities for the selected organization forms (assembly stations) include ergonomic analysis. The outcome of the detailed production organization phase is the digital model of the manufacturing system linking all the components of the assembly system with assembly

process plan stored in library and process schedule (Fig. 11). The further test on simulation model are used to analyze and improve the system being developed.

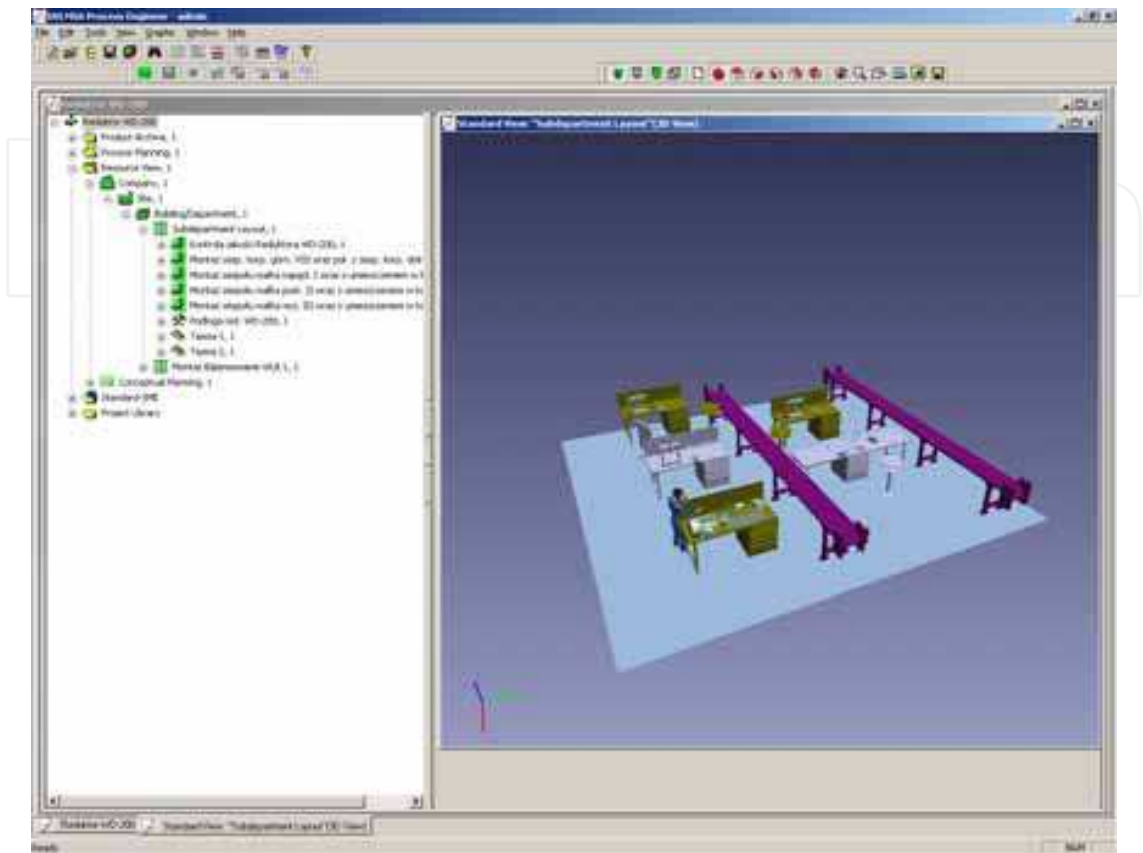


Fig. 11. Assembly station design

9. Conclusion

Design and process planning integration is achieved through:

- Creation of the interdisciplinary teams consisting of: designers, manufacturing engineers and other specialists.
- Use of DFMA (Design for Manufacturing and Assembly) systems.
- Better cooperation with suppliers and clients.
- Integration of data and functions.

The model of the development process is the key element for the creation of the workflow diagrams. These diagrams form the basis for the effective functioning of the PDM systems working according to the selected development strategy. Further works shall be directed toward the preparation of the notation for the modelling of workflow diagrams and the generation of the source code for the module managing the workflow in PDM system. This will accelerate the implementation of PDM (Product Data Management) systems which evaluate toward the PLM solutions (Product Lifecycle Management).

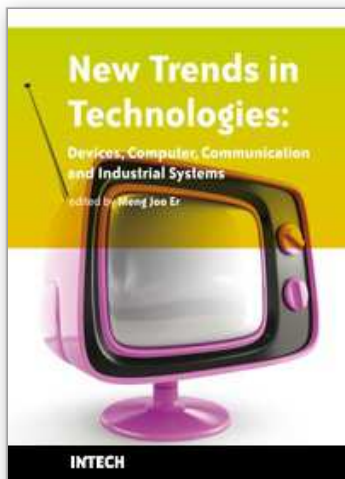
Integration of the design and process planning phases leads to:

- Reduction of information losses.
- Cooperation of different divisions to achieve the clearly defined common goals.
- Reduction of the competition between the company divisions.

Implementation of PLM solutions with the ERP, SCM, CRM systems and easily available means of communication like internet and intranet allow to use CE and CEE for the product development in distributed environment. New methods of product development (CE and CEE) fulfil the requirements imposed by the market and globalisation.

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