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# Planning and Control of Automated Assembly Systems

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## ABSTRACT

This contribution describes an assembly planning methodology in a concurrent engineering environment and a supporting computer system featuring continuous data management and standardized data exchange. The assembly planning is related to results available from the product's designer and suitable computer tools provide support for each task. There are 5 major groups of input information that is needed for the various tasks of assembly planning. Data created during planning are stored in an object-oriented database to avoid conversion and can even be re-used directly for start-up or production. Therefore the communication between the computer tools themselves and between the tools and the real automated devices has been standardized according to MMS and implemented as CORBA-objects. An equally important system characteristic is represented by the analyses based on the planning status; they can be applied throughout the planning process. Increasingly detailed and realistic analyses are thus possible during the whole planning process.

## INTRODUCTION

'Digital Mock-up', the use of simulations for joining parts in the virtual world of a computer, is going to be established in the industry. Computer-based assembly planning is becoming more and more important within the field of product development. But assembly planning covers much more than simulation. The main task is to develop an assembly process and the assembly system that is able to generate the product. Besides assembly planning there are of course product design and production planning and some more departments of an enterprise involved in the process of product development. In the following the focus is set on the assembly planning in its relationship to the product design.

## THE CURRENT SITUATION

Many companies today are utilizing Simultaneous Engineering (SE) yet, but they still waste a lot of time within their product development process. Usually a SE-Team meets regulary to discuss the work of one of its members, if it fits all general requirements, but in most cases the real work is still done sequentially: The designer creates the geometries of the parts, the assembly planner gives general hints like 'DFA', but usually he/she starts his/her planning after the geometry has been fixed.

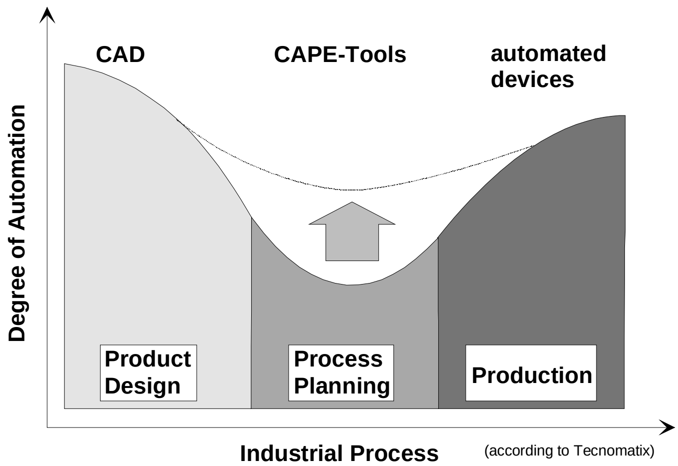


**Figure 1: The Deficit of Computer-Aided-Production-Engineering (CAPE) – Tools (Heimberg and Frey, 1997)**

Some aspects of assembly planning are available in commercial software packages that support the processing of individual task packages (for example layout planning), but there is still a deficit of computer aided tools for process planning (fig. 1) (Heimberg and Frey, 1997).



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Additional, the performance capabilities of the individual tools in their specialized areas are usually limited by the lack of integration. One result of this is the high degree of complexity involved in the repeated conversion of data during transfer from one system to the next. This often results in loss of the time advantage gained from the use of these tools. A further shortcoming lies in the fact that data created in the planning process cannot be re-used for the "realization/op-eration" stage of planning. This is mainly due to the fact that different data formats and structures are used for the planning and control processes. This makes it difficult, for instance, to adopt production sequences or robot programs that were created off-line.

We can thus clearly identify two main problems: one is compatibility of the data, the other is the lack of a direct means of communication between the tools themselves and between them and the assembly system.

## THE GOAL

Continuous assembly planning - beginning with formulation of the objective and progressing all the way to operation of the system - is the declared goal to achieve. ‘Continuos’ in this case on the one hand means that the computer tools should use one common data model that is getting more and more filled with information during the planning and that every involved person can have access to the actual data whenever needed. For example, adding some more information (synthesis) or checking the quality of the process by analyzing the data (for example estimated costs and production times). On the other hand, the continuity should exist not only within the planning. The aim is to make it possible for the data created in the planning process to be used for system to avoid the break between ‘virtual’ planning and reality.

## THE PROPOSED SOLUTION

For this reason, within the framework of Collaborative Research Centre ‘SFB 336’, methodologies and tools are being developed at the Institute for Machine Tools and Industrial Management (*iwb*), which on the one hand aim to make early use of assembly planning possible in parallel with product design (concurrent engineering). On the other hand, attempts are being made to improve the planning process itself (in terms of planning time and quality); this is accomplished with mutually attuned computer tools. With this in mind a data model has been developed that makes it possible both to manage the data during the entire planning process and to create a process model for the assembly system (fig. 2); this model can, for instance, serve as a control for the start-up phase of the planned system. This processing and control model can be validated in advance during the planning process, using a 3D-simulation system.

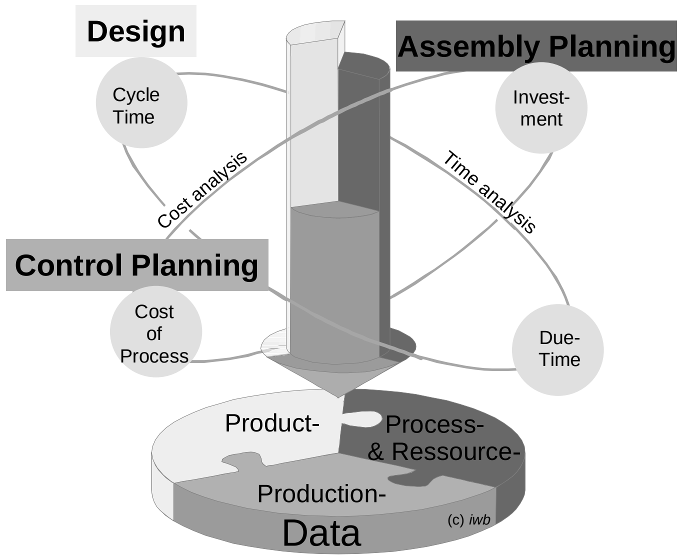


**Figure 2: Continuous Planning with Synthesis and Analysis Based on a Common Data Model**

### The Five-Layer-Methodology of Assembly Planning

The *iwb* methodology of assembly planning is based on the principle that the assembly planning should start as soon as possible. Therefore the results of the product design have been analyzed and the corresponding tasks of the assembly planner have been matched to them. We have identified five important kinds of data the assembly planner needs to do his/her work. Besides the *general information* about the product that is given by the project management the following design information is important for the assembly planner: *product structure*, first *geometry of a single part*, first *subassembly* and *complete design of the product*. For these five blocks we have created five ‘layers’. Each layer contains the tasks of the assembly planning that can already be started with the specific information. For example, the tasks of the second layer can start as soon as the product structure is available. These layers are non-consecutive phases, they are just characterized by the needed input

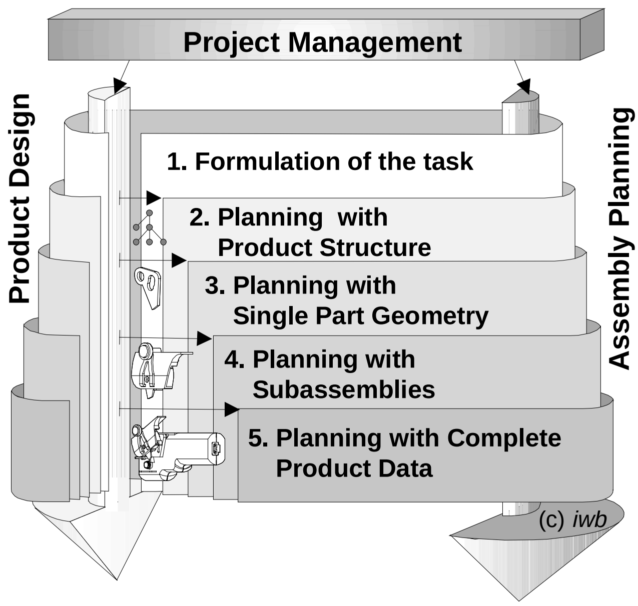


**Figure 3: The Five-Layer-Methodology of Assembly Planning**



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and can all last till the very end of the planning (fig. 3).

Simultaneously with planning, time and cost analyses (Cuiper et al., 1996) can be performed at any time. For example, predictions are made regarding the anticipated due-times; based on these, it is then possible to determine the costs per unit. In this way, planning alternatives can also be assessed from an economic perspective as well, both absolutely (related to the objectives) and relatively (related to one another). Incorrect planning can thus be avoided. During this process, the predictions (for example, due-time, cycle time and cost of process, investment) become increasingly accurate since the data become more and more refined during the course of the planning. As far as due-times are concerned, this means that at first initial guide values (for example, from tables) are used for the calculations; these are then calculated with the times determined in the simulation, and finally with the times that actually prove necessary for each assembly process.

## The CA-Tool For Assembly Planning

To implement this approach, various computer tools in a type of "modular system" are made available for assembly planning. They include the Pro/ENGINEER commercial CAD system, which was adjusted with the aid of its accompanying programming environment; the Computer System For Assembly Automation CosMonAut (from the German: **Co**mputer-**s**ystem zur **Mon**tage-**Aut**omatisierung) (Cuiper et al., 1996) and the USIS 3-D simulation system, both developed at the *iwb* (Woenckhaus and Kugelmann, 1994). An individual combination of these components can be put together to match the task at hand and serve as an efficient aid in assembly planning. The produced planning data is kept in the object-oriented database ONTOS DB/Explorer. The main advantage of this is high-speed access to individual objects even for complex data structures. Within the framework of SFB 336, an integrated product and process model that meets the requirement for continuity was developed according to Rumbaugh's object-oriented method (Ambrosy et al., 1996). The assembly process is described by means of an object-oriented Petri-Net syntax. Thus, during sequence planning a structure is already generated that can later serve as the basic framework for system control.

For the exchange of CAD models and simulation data, inter-process communication has been realized between the

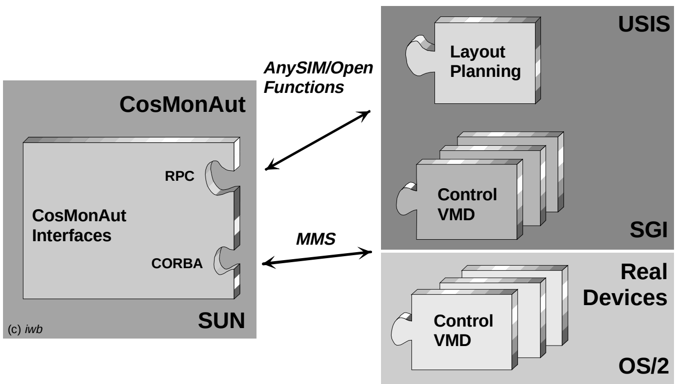


**Figure 4: The Communication Between the Components of the Assembly Planning Toolkit**

CosMonAut planning system and the USIS simulation (Cuiper et al., 1996). This is based on the *Remote Procedure Calls* (RPC) technique. Here, a program acts as a server that offers its services to other programs, the clients. The advantage of this type of communication is that it is not limited to one operating system; instead it works on any heterogeneous computer network if the individual systems support the corresponding protocols. This makes it possible to utilize platform-specific strengths (such as database or graphics applications).

For the communication of the planning system with the SFB experimental system at *iwb*, a *virtual manufacturing device* (VMD) based on the MMS standard (Esprit, 1995) has been implemented for each robot (Reinhart et al., 1997). A VMD is a program that can communicate in the computer network using a standardized vocabulary. The requests are converted in the VMD into the machine-specific control commands and are passed on to the machine control system, where they are finally interpreted and executed. In the case at hand, communication between the planning system and the VMD is based on the CORBA-standard (*Common Object Request Broker Architecture*) (fig. 4).

# APPLICATION

In the following, the application of five layers of the assembly planning methodology (fig. 3) during a product development project is described.

## First Layer: Planning with General Information

The assembly planning can already start as soon as the project has had its kick-off. Usually, the kind of product and the approximate scale of its volume and weight are known as well at this time as the expected production rates per year. For example, the existing manufacturing facilities can be analyzed for their capability regarding the new product.

## Second Layer: Product Structure

The first important data from the designer that can be used by the assembly planner is the proposed product structure. It is usually created before the geometry, which means that the assembly planners can enter the planning process at a very early stage of the development. The planning tool CosMonAut is designed so that an initial assembly-sequence recommendation is generated from the product structure (fig. 5). The planners can then make use of their own experience and creativity to add to this suggestion; they also have the option of ignoring this variation and redesigning the process structure according to assembly-relevant aspects. The process is visualized using the symbols of the Association of German Engineers' guideline for handling operations VDI 2860 (VDI, 1990). All the processes are stored in the database so that they can be reused for further plannings. Today, about 80% of the assembly process for a new model of a car is the same; in this case the skeleton of the assembly process can be built easily through copy and paste from the predecessor, saving lots of time.



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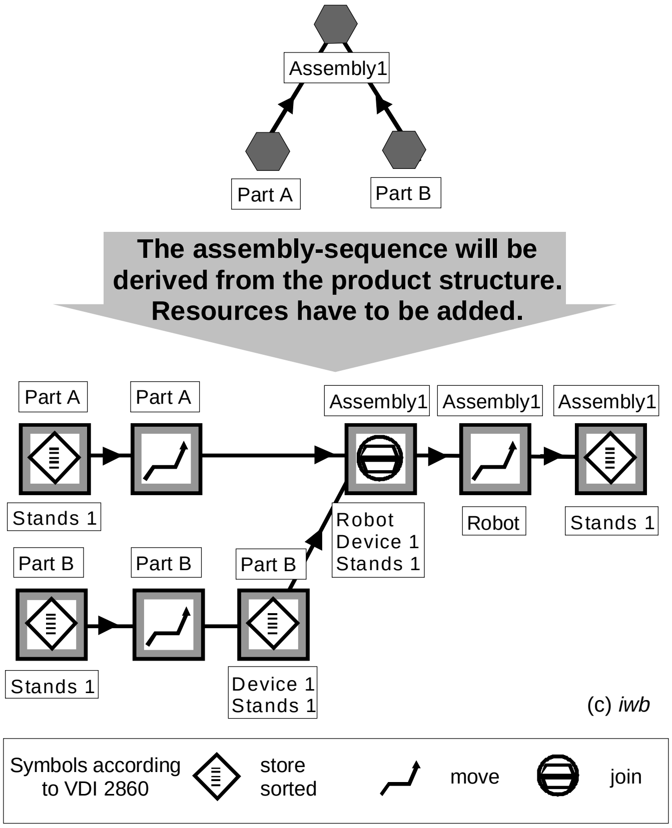


**Figure 5: The Assembly Sequence Is Derived from the Product Structure**

**Third Layer: Single Part Geometry**

Getting the first geometry of a part of the new product from the designer, the devices for storing the parts can be selected. Using the 3D-CAD-models of the new part and the existing devices, the planner can easily check if the company's equipment can still be used for the new production. If not, he can start the design of a new device very early or he can give feedback to the designer to change the part's geometry. At the *iwb*, parametric models are used to improve the adaption of standardized types of devices to individual devices (Reinhart and Loferer, 1996).

Additional to that, at this time the assembly process can be extended by adding more specific tasks for the handling of the single part (for example, orientation or fixation of the part). But the work on the description of the assembly process is a task of the second layer. So there is a step 'down' to the second layer in the project's progress for modifying the previous results. Within the whole planning, there may be lots of situations like that, where a task of a 'minor' layer has to be repeated with more detailed or even changed information. This is why all the layers last till the end of the whole planning.

**Fourth Layer: Subassembly Geometry**

Once the designers give them the provisional results in the form of geometric information for the individual subassemblies, their spatial assembly planning work can begin. To accomplish this, the 3D-simulation system is called up with the parts that are to be assembled. Within that simulation a digital mock-up based on the CAD-data can be done. If problems (for example, collision of parts) occur, either the assembling sequence has to be changed by the planner or feed-back to the designer has to be given in order to improve the parts' geometries. Otherwise, the equipment for that operation can be determined. After the planning of all joinings is complete, assembly process times are determined in USIS and fed back to the planning system, thus forming the basis for initial due-time analyses. The tasks of that layer have to be done at least for all the critical joining-operations. In the database mentionened above, the sequence of a process and the related devices with their 3D-coordinates are stored. By using these predefined processes and equipment from the computer's knowledgebase the planning itself is accelerated. Also, the possibility of re-using parts of the existing assembly system can be validated very early.

**Fifth Layer: Whole Product Geometry**

Once the whole product geometry is available, the system planning can begin. In this context, it refers to the selection of operating equipment required for the process steps and the design of the production-system layout. The off-line programming of robot movements is also considered as part of this step. Usually, at this time the assembly planning is to start.

All the operating equipment assigned to the process is loaded from the database into the 3D-simulation system by the CosMonAut planning system. There, the spatial arrangement of the operating equipment and product components can be derived, based on the layout structure (for example, the device *is on* the load stand *is on* the floor) as determined in the planning system. After this, the corresponding robot programs can be created for the automated assembly processes. The individual programs are associated with the assembly processes so that the planners can find them again very easily. In a way similar to spatial assembly planning, the times for the assembly processes are returned to the planning system from the simulation system. The times are now significantly more accurate, since they are calculated from the program that will later be used for processing. Based on this, a cost calculation that includes hourly operating rates can be made in CosMonAut, and thus a check made as to whether the time and cost planning goals can be met.

**Control Planning**

The assembly sequence is set up according to a Petri-Net, and consists of modeled states and transitions. During the planning steps mentioned above, representation is reduced to the symbols for handling operations; it is not until the elementary control planning stage that all components of the network are shown. Here, each operating equipment state that is part of the Petri-Net corresponds to an action (for example, "transport of lower part") and every transition corresponds to a "finished" message (for example, "lower part is correctly in the device"). Since the assembly-process model is oriented to the flow of material, the basic control sequence is predetermined. This control is divided into partial steps, which are each represented by a state in the Petri-Net. The corresponding elements of the



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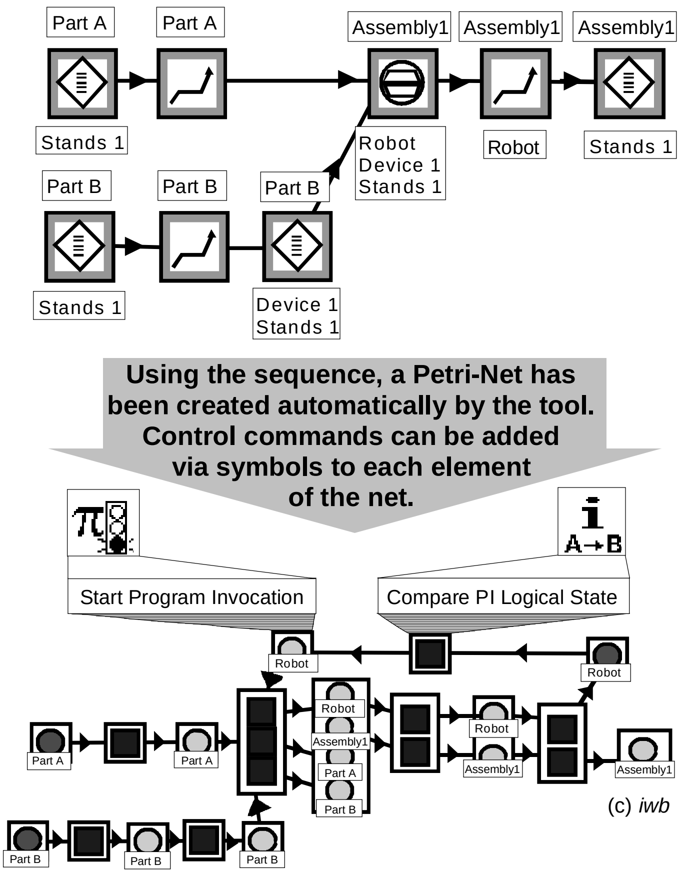


**Figure 6: The Petri-Net Is Used for the Control of the Assembly System**

network for the initialization of the operating equipment and similar actions then have to be added.

For the most part, programming of the required operation at the individual process steps was already accomplished off-line in USIS during system planning; this has to be done now for the steps that have just been added as supplements. Furthermore, the control sequence must be completed so that the robots execute the correct operation program at the correct time. For this purpose, in CosMonAut, there is an option of assigning control methods for operating equipment to the states of the Petri-Net according to the MMS standard. This ensures the basic functionality of a controller (establishment of a connection, loading / starting / aborting programs, ending a connection etc.). As the single steps for the process in the previous planning phases, the control commands can also be shown as symbols, which were designed at the *iwb*, in the tool's window on the screen (fig. 6). So the expanded assembly sequence model can be re-used as a control model.

Once the individual control commands have been incorporated into the process model, execution of the overall program can be triggered from CosMonAut. In addition to manual step-enabling actuated by pressing a button (single-step mode), automatic step-enabling after a specific cycle time is possible. In each step of the control sequence, the robot programs that were created off-line are loaded and executed using the VMD's and the corresponding MMS commands. The current work is to feed back the real times from the machines to CosMonAut. After this has finished, time analysis is also possible here (for example, to determine how long a robot needs to execute a specific assembly process). In this way, the assembly process times, which were first estimated and then simulated, can be checked to determine their quality. The actual research work is to optimize the support for the control planning and on implementing that optimized control sequence program on a low cost hardware.

## SUMMARY

At *iwb*, a methodology and a toolkit for assembly planning with continuous data management and standardized data exchange have been created. The planning tasks have been arranged in planning layers depending on the necessary input data to optimize the development process. Suitable computer tools provide support for each step in the planning of an assembly system. Complex measures for the conversion or repetition of planning data are eliminated. Data created in the planning (such as the assembly-process as a control model or robot programs) can be re-used directly for start-up or production (fig. 7). An equally important system characteristic is represented by the analyses based on program status; they can be applied throughout the planning stage. Increasingly detailed and realistic analyses are thus possible during planning, beginning with the rough guide values for assembly times and culminating with actual times. The methods and tools described here are verified using the SFB assembly system at *iwb*, but can be used equally well for the manufacture of parts or other time-discrete processes.

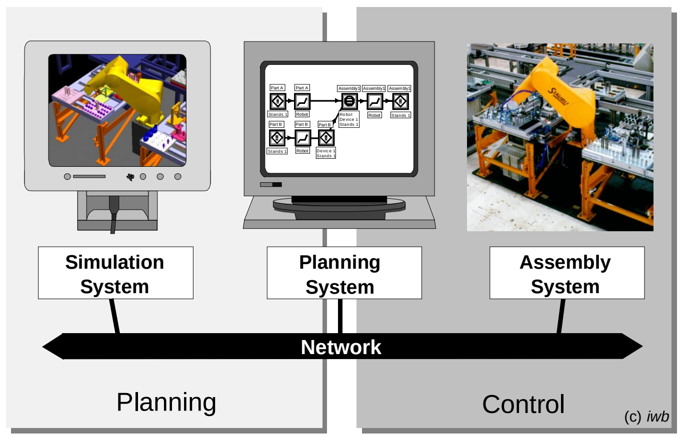


**Figure 7: Continuity from Planning to Control**

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