MODELING AND EVALUATION OF ALTERNATIVE PRODUCTION SCENARIOS IN THE FIELD OF COMPOSITE MANUFACTURING

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ABSTRACT

At the perspective of production process engineering there is special requirements and characteristics for the manufacturing of composites like carbon-fiber-reinforced plastics (CFRP). This paper introduces a special framework for the conceptual production planning of series productions for CFRP-products. The submitted modeling concept has a semi-formal graphical notation, which provides the specification, analysis and evaluation of manufacturing of alternative manufacturing scenarios already in the planning phase. The option of an automatically generated simulation model enables the planning engineer to analyze the system performance of the modeled manufacturing scenario. This detailed analysis enables a further optimization of the scenario without additional expenditure. Apart from the documentation aspects of this modeling concept, the production process engineering will be improved by the management of alternative manufacturing scenarios.

Keywords: conceptual process planning, production process engineering, generic material flow simulation, CFRP, factory planning

1. INTRODUCTION

The highest potential of lightweight construction for aircraft structures or rather all kind of transport technology is provided by carbon-fiber-reinforced plastics (Froböse 2003). Even in relation to aluminum structures a weight reduction of up to 30% is possible, which leads to substantial economic and ecological advantages. Accordingly, the importance of carbon-fiber-reinforced plastics (CFRP) increased clearly in the past two decades for the sectors of aircraft construction, shipbuilding and automotive engineering. The market demands for shorter development times, further cost reductions and increasing manufacturing rates.

The further development of CFRP manufacturing technologies requests a set of new planning methods in order to fulfill the demand for high efficient production processes and systems. For economic reasons the use of carbon fiber composite structures is mainly focused on special applications at the high tech sector like the aerospace industry (Kleineberg, Herbeck and Schöppinger 2003). An important cost driver for the manufacturing process is the minor level of automation. Especially the handling of carbon fiber is difficult because of the low stiffness. Accordingly there exist only a few feasible handling solutions for fully automated production lines (Froböse 2003). An automated manufacturing process includes higher investment costs for machines, robots etc. than a conventional manufacturing solution. In conclusion the investment risk for automated manufacturing solutions is even higher. Therefore it is necessary to plan in a very accurate and proper way.

Also the development of new economical production technologies at the end of the 90's extended the spectrum of alternative manufacturing solutions for carbon-fiber-reinforced plastics substantially. Therefore it is necessary to identify a few good potential manufacturing solutions at early stages in order to concentrate the planning efforts on these. Against this background, a continuous evaluation and comparison of the alternative manufacturing solutions should be possible over the entire planning process. This requires a specific modeling and evaluation framework, which provides an appropriate specification of a manufacturing process and production system.

New product development concepts like simultaneous engineering need more communication and coordination between the interdisciplinary planning engineers. A visual modeling concept can support this kind of communication from the view of process designing significantly. The design of a manufacturing process which involves new materials and technologies requires synthesizing technical knowledge from a variety of sources and experts (Albastro et al. 1995). The early and creative phases of process designing demand for a quick and easy depiction in a semi-formal language to find a direct and common way of communication between all participants. In using a graphical notation for the model, it can be understood by all kind of experts and the production process is documented for future activities. Additionally the formal description is the precondition for a computerized analysis and evaluation. The developed modeling concept supports the very early phases of process designing. Alternative planning scenarios will be described, analyzed and evaluated in a structured and fast way.

2. PRODUCTION PROCESS ENGINEERING

The term of Production Process Engineering (PPE) is used in this paper for defining a special subject of Business Process Engineering (BPE) which is focused on production environment. The objective of process planning is to transform an idea into a saleable product. In dependence on the product and the overall production concept the planning activities differ (Halevi 2003). Presuming a series production of composite parts by building up new production lines there will be a longer phase of conceptual process planning. The high investment volume leads to higher planning efforts. The objective of conceptual process planning is to describe one or more possible manufacturing solutions and to determine the corresponding costs. Normally the manufacturing operations are not very detailed in this phase and only a rough cost estimation can be given. However it allows the engineers to get an idea of the process and its needed resources. A first and rough cost estimation allows the engineers to adapt their decisions regarding to the process costs. The best suitable solutions can be identified and for example progressed in a more detailed process planning. On the other hand the conceptual process planning allows the evaluation of manufacturability and the identification of cost drivers as early as possible in the design process.

2.1. Conceptual Process Planning Activities

The process planning is part of the product development process and determines how raw material is transformed into its desired form. Such planning activities can be aided by the use of concepts like e.g. digital factory or CAPP (computer aided process planning). In general these concepts are orientated to later phases of process design, which will address especially technical aspects. In distinction the conceptual process planning focuses more on the economic issues by selecting e.g. the best suitable production techniques (Patrick, Dantan and Siadat 2007). The conceptual process planning can be described by a sequence of activities, which have to be accomplished (Figure 1). The shown order can change, but should stick to the four defined phases:

- Creation of Process Chain
- Resource Assignment
- Creation of Procuction Structure
- Dimensioning of Production System

The first phase "Creation of Process Chain" is characterized by determining the production techniques, process chains and quality assurance methods in addiction to the product specification. Thereby for each activity a time module has to be created, which defines the process time in dependence to the product specification and for e.g. machine performance. By using process chain templates the modeling effort can be reduced for process sequences of typical CFRP-production techniques. The first step by designing a process chain is to create a sequence of manufacturing or assembly steps without assigning any resources. The idea for this procedure is the goal of getting new and innovative solutions by thinking without technical, economical or organizational restrictions caused of the resources (Zenner 2006).

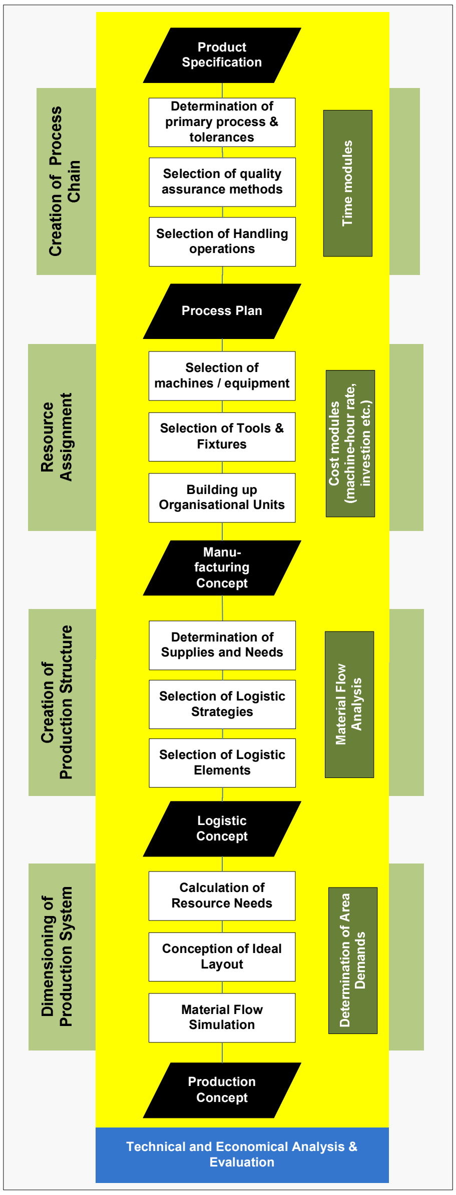

Figure 1: Conceptual Process Planning Activities

The second phase "Resource Assignment" is addressed to the selection of process compatible resources. This includes the machines and devices as well as the tool and fixtures. Especially the CFRP manufacturing needs an accurate design of handling operations, which normally includes the conception and construction of appropriate tooling, fixtures and handling devices. The assigning of worker is realized by creating organizational units which also include machines and equipment. By using or creating cost modules for each organizational unit, the allocation of direct and indirect costs is realized. The manufacturing concept contains a rough estimation for process time as well as for investment and operating costs.

The third phase “Creation of Production Structure” is characterized by designing the logistic concept. Therefore the manufacturing concept is projected onto the production structure. Thereby material flow connections between e.g. machines or organizational units emerge. According to the classic logistic functions of transshipment, storage and transport this production structure is extended with logistic elements. Based on material flow analyses, compatible logistic strategies are selected. With the use of logistic elements like e.g. buffers, storages and transport systems the logistic concept is modeled. This kind of modeling is only qualitative and describes only material flow connections. Additional data about the information flow can be noted but will not explicit be considered in the modeling concept.

The fourth phase “Dimensioning of Production System” is the ordinary field of factory planning. The objective is to determine the resource needs and to create a draft layout. The determination of resource needs can be done first by static calculation and then more detailed and accurate by dynamic material flow simulation. Because of stochastic deviations the use of a dynamic simulation model can help to make a good dimensioning of especially buffers, tools and fixtures. The identification of temporarily “bottle necks” can help to adjust and fine-tune the production structure in order to reach a better system performance. The result of this phase is a production concept which contains the numbers and capacities of all manufacturing and logistic objects as well as the alignment in a draft-layout. Because of having many handling operations with tools and fixtures, it is useful to layout the production concept in order to get accurate area demands. Normally the additional area demand for handling operations is difficult to estimate without a layout.

After defining the production concept, a technical and economical analysis and evaluation will be done. Normally a set of different planning scenarios will be tested and compared. Because of having strong technical restrictions, the automatic generation of alternative planning scenarios for e.g. different product designs is more or less impossible. Especially the estimated process times would change in dependence on the product design specification. Therefore an extensive optimization of alternative planning scenarios with specific operations research models is not done.

2.2. Management of alternative Planning Scenarios

In general a lot of suitable solutions will exist for a planning problem. The planner’s objective is to find the best solution in an acceptable planning time. Depending on the planning problem, various possible solutions differ in the achievement of planning objectives like e.g. cost, quality, flexibility, time. Especially the design of large-scale production systems can multiply little differences to big amounts. Therefore a planning engineer should be assisted methodically by the management of alternative planning scenarios in order to find the best solution. Normally, generating of ideas and approaches is much easier than reducing and finding the best appropriate alternatives. Every alternative planning scenario which is further determined increases the planning expense (Bley and Zenner 2005). Therefore, an early abort of adverse planning scenarios is needed. For the special field of process designing the following level-concept of a Planning Pyramid for alternative Process Designs is proposed (Figure 2).

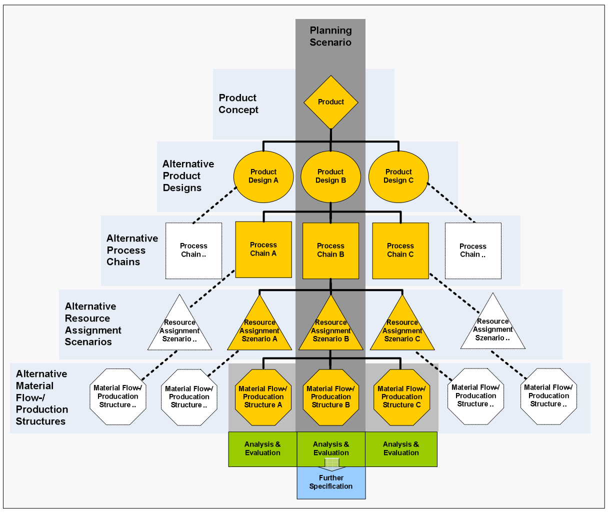

Figure 2: Planning Pyramid

Every manufacturing process is designed for a defined type of product. Therefore the topmost level of the planning pyramid is used by the product concept. The second level contains alternative product designs. Normally these two levels are assigned to a product design or construction team. The following levels describe the actual field of process designing. The level of alternative process chains defines different sequences of process steps for manufacturing and assembly. Usually the alternative process chains differ in manufacturing technology and method. At the next level every process step is assigned to necessary process resources like e.g. machines, tools and workers. In order to reduce the possible assignments it is useful to define resource assignment scenarios which determine one special configuration of assigned resources. At the last level alternative material flow and production structures are defined which determine e.g. layout, transport and storage solutions.

The different levels of the planning pyramid represent various elements of planning. A planning scenario contains exactly one element of each level. Each of these planning elements can be specified more detailed on its own. The first evaluation of a planning level would base on rough guess and get more precisely during the planning process. The evaluation and decision about the best suitable alternatives would lead to further planning activities and specifications.

2.3. Cost Evaluation and Analysis

In order to calculate proper part costs an analytical approach of cost evaluation is selected. Such an analytical approach is the most accurate method for cost evaluation (Patrick 2007). In distinction to other approaches like e.g. analogical and parametric ones which orientate to aggregated parameter models, this approach defines cost modules for each organizational unit. Such a cost module defines variable and fixed costs for the organization units. In dependence on the workload the hourly rates can be calculated. For imitating more product types using the same production line, the workload and the process costs can be adjusted. Especially the fixed costs have to be allocated to the different product types. In dependence on the level of detail an organizational unit can consist of only one machine or a production cell with a lot of machines and workers. The basic cost types of an organizational unit are:

- labor costs
- resource costs
- supply costs
- area costs

By differentiating logistic and process costs, the factory and layout planning can be assisted (Figure 3). Especially the logistic costs are depending of the selected material flow and layout solutions. Therefore the factory planner can compare different factory solutions and e.g. improve the factory layout. The logistic costs consist of transshipment, transport and storage costs. The process costs are the indicator for the quality of the manufacturing concept. For making better analysis, the process costs can be further divided into manufacturing, assembly and inspection costs.

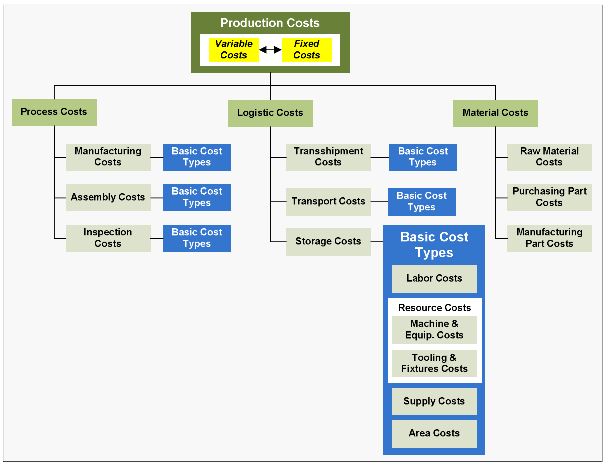

Figure 3: Ontology of Cost Modules

In order to calculate the production costs also the material costs have to be recognized. The material costs consist of raw material costs, purchasing part costs and manufacturing part costs. The production costs per part can be easily calculated by multiplying the hourly rates with the estimated process times. Because of having dynamic process times for the logistic elements, these costs cannot be calculated without identifying the actual using rates of different product types. In the case of having only a one-product production all costs can be converted directly into costs per part and different planning scenarios can be compared very easily.

3. COMPOSITION OF MATERIAL FLOW OBJECTS

For the development of the modeling concept it was necessary to identify the main logistic characteristics of CFRP manufacturing. One of these characteristics is the use of tools like e.g. molds for shaping the working pieces. In differentiation to other manufacturing technologies the molds follow the material flow and serve as carriers. Furthermore, auxiliary material like e.g. vacuum bags enter the manufacturing process, follow and leave the material flow after a while. Another important aspect of CFRP manufacturing is the ability of combining different parts in a manufacturing sequence. This is normally a characteristic for assembly processes. In conclusion it is necessary to define stages of production for each part in order to get a transparent depiction of auxiliary materials and tools in the material flow. This characteristic will be named in this paper as the composition of material flow objects.

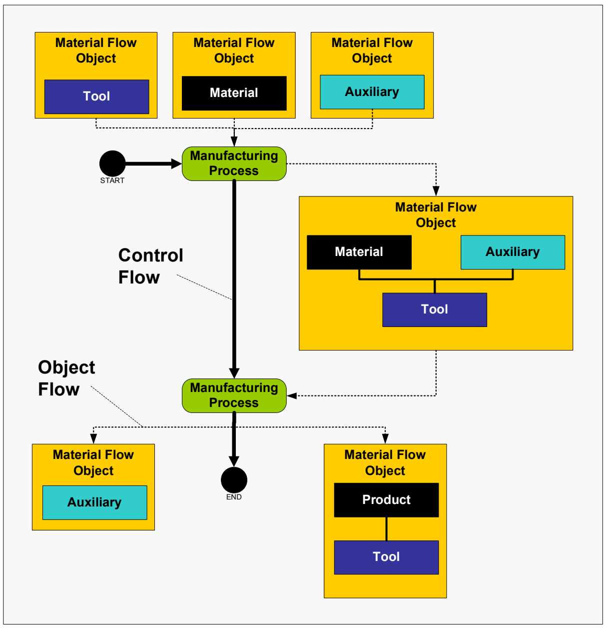

Figure 4: Modeling the Object and Control Flow

By defining the requirements for the modeling of CFRP manufacturing processes it was noticed that the common enterprise modeling techniques like e.g. CIMOSA, IEM, UML allow the modeling of material flows, but not in such a detailed way like needed (Bernus 2005). Also the most popular software solutions for digital factory like e.g. DELMIA, UGS are not able to fulfill the special requirements for CFRP manufacturing. Therefore a graphical modeling concept was developed which orientates to the common enterprise modeling techniques, but is extended to the ability of combining different material flow objects to new instances of material flow objects.

Every passive resource like e.g. tools, materials which enter a process step is defined as a material flow object (Figure 4). Several material flow objects can be combined to only one material flow object. The composition of material flow objects orientates to the physical part connection. In addition to the object flow a control flow is used for the planning of the process sequence. This control option is very basic but acceptable for defining process chains of series productions. The predecessor and successor of process steps are defined in this way.

4. GRAPHICAL MODELING CONCEPT WITH PROCESS AND STRUCTURE VIEW

The high complexity of production processes engineering requires a view concept for modeling. The view concept serves as an expedient to reduce the complexity of model designing (Scheer 1994). Therefore two basic views are provided, which differ in process and system view (Figure 5). The vision is to enable every engineer to read and understand the model with less introducing.

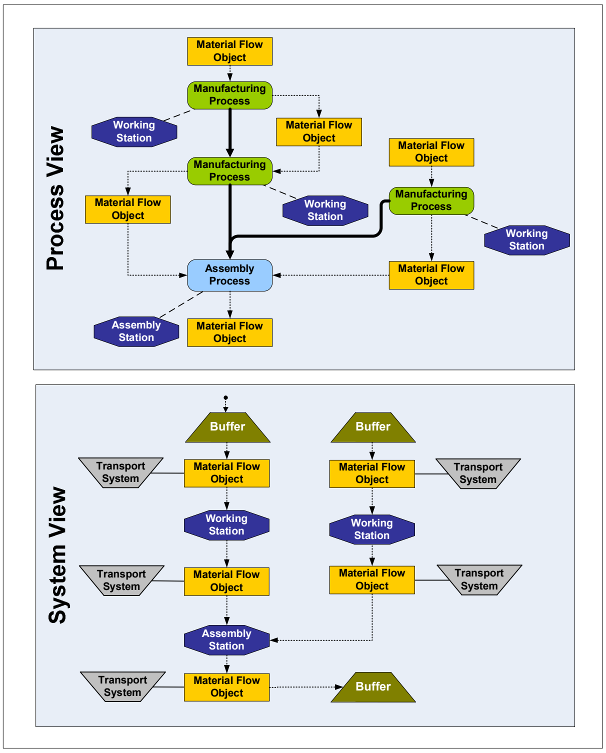

Figure 5: Process and Structure View

The process view is focused to the process structure. First the process sequence is modeled by connecting the process steps with each other. Then the material flow is added. By assigning the resource elements to the process steps, the manufacturing concept will be created. Every process step has to be assigned to a processor. The processors are the basic elements of the system view. They are connected by material flows. In general the processor is an organizational unit. The system view can be generated from the process view. The system view describes the structure of the production system and is mainly addressed to the logistic implementation of transport and storage systems. By adding logistic elements to the system view, the both views will get inconsistent. The process view contains no logistic processes in order to focus on manufacturing aspects. In spite of the both views are linked by the processors and material flow objects. Therefore any change in the process view will lead to changes in the system view. Various processes of different product variants can be integrated in into same system view. Every physical transport between two processors should be assigned to a transport system.

5. GENERIC MATERIAL FLOW SIMULATION MODELS FOR DIMENSIONING

Material flow simulation models help to understand the behavior and structure of logistic systems. They are the preferred planning tool for analyzing and designing such systems. But there is a problem with simulation models. The development of such a model needs a lot of time and is highly complex. Finally, a real or a planned system is described by the simulation model. Nevertheless, it is not enough to develop an accurate simulation model. The model must be understood, updated, reused and inhered by others. Normally, the simulation results are written down in separate documents but the simulation model on its own is not documented. Most of the knowledge about the model is directly linked to the simulation engineers and can be lost. Therefore it will be necessary to document the simulation model itself (Oscarsson and Moris 2002).

For this reason a standardized documentation would help to explain the model in order to describe the underlying processes, controls and logics. Especially the visual depiction of process sequences in a detailed way, how it is needed for the field of process designing, cannot be done in a simulation model directly. All relevant aspects for generating process and system structures can be modeled with using the process and structure view. Therefore, modeling is more transparent and can be better communicated to other participants. In differentiation especially to the business process modeling techniques, this concept focuses on material flow modeling and less on information flow modeling. Therefore only some basic control flows like e.g. process sequences are graphical modeled and the more complex control and decision procedures have to be programmed separately in the simulation software.

In distinction from efforts of creating a common simulation language like e.g. SRML (Simulation Reference Markup Language) the submitted approach orientates to the modeling of production structures and processes by using a graphical notation. For doing material flow simulation such a graphical model has to be converted into a simulation language/model.

The advantage of such a material flow oriented graphical model with only simple information flows is, that it could be easily compiled into different simulation tools/languages. Normally the integration of planning and control operations is more challenging, but the creation of the basic production structure is also very time consuming. The preferred discrete simulation tool for the implementation of this framework is DELMIA Quest. The inner material flow simulation structure of DELMIA Quest corresponds in an ideal way to the developed graphical modeling concept (Figure 6). By assigning process steps to the corresponding processors like e.g. workstations, the material flow simulation structure can be compiled very easily and fast.

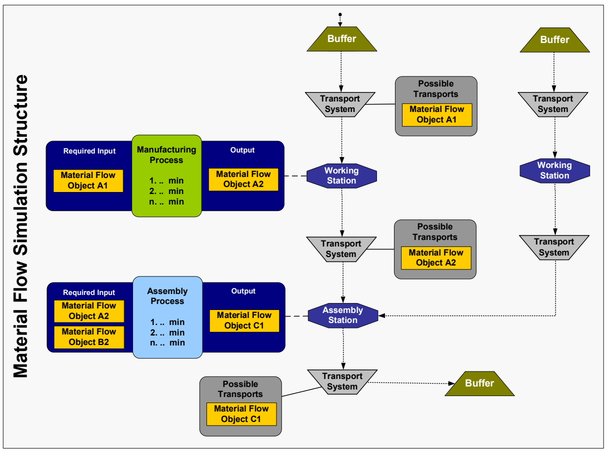

Figure 6: Material Flow Simulation Structure

Additionally to the graphical notation an object oriented database software solution has to be developed. Not all production process and system information can be added to a diagram. Also the different planning scenarios have to be managed. A first prototypical implementation is done by using yEd Graph Editor, MS Access and DELMIA Quest. The diagram is modeled in the yEd Graph Editor and transferred to MS Access via XML. The simulation model is created in MS Acecess by using the scripting language of DELMIA Quest. The project's implementation has shown, that especially the management of alternative planning scenarios by using resource and process libraries is extremely challenging.

6. CONCLUSIONS AND FUTURE WORK

Especially in aerospace industry the CFRP product development process is characterized by complex planning problems. The possibility of integral part manufacturing enables many alternative product and process designs. In order to find the most promising design and manufacturing solutions, various alternative planning scenarios have to be defined, specified, analyzed, evaluated and compared to each other. The management of so many scenarios is very difficult, because each scenario has several iteration loops. In result a lot of changes have to be accomplished and analyzed in the planning model. Therefore a framework for the management and evaluation of alternative planning scenarios is developed and presented by this paper.

Additionally, this paper provides an approach of a object oriented modeling concept with a semi-formal notation, which is focused on production processes and material flows. Such a model supports the analysis and evaluation of alternative production scenarios by the option of material flow simulation. A basic material flow simulation model can be generated for external discrete simulation tools. Regarding to future works the full implementation of the concept in a prototypical application is planned. Additionally, the view concept should be enhanced for the subjects of quality management. Especially the importance of quality management in aerospace industry leads to the need of an integrated designing approach for creating compatible manufacturing and inspection processes.

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