RAPID DESIGN OF MODEL-BASED PROCESS CHAINS – A GRAPH BASED APPROACH

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Process chains in manufacturing and order processing increasingly depend on the successful usage of information systems. However, available approaches typically lack the opportunity to evaluate the expecting process chain and modeling quality or rely on a system driven in-depth analysis. The presented easy-to-use graphical approach overcomes existing drawbacks and integrates the domains of manufacturing and order processing at the same time.

1. INTRODUCTION

The proper design of manufacturing and corresponding order processes represents one of the major core competencies of discrete parts manufacturers. In addition, the enterprise must consider appropriate information systems to support the design and implementation of the processes. Due to increasing process and process chain complexity, the usage of information systems is almost inevitable. Hence, model-based process chains are a synonym for information system supported process chains stress the corresponding foundation in particular, i.e. process models.

The individual user, however, faces an increasing variety of alternative information systems. It becomes more and more difficult to choose the adequate information system and to evaluate its usability (Monostori, 2003; Wagenknecht, 2005). Due to the information system driven perspective of the software suppliers, information systems are very often brought into the market without deeper concepts of suitable manufacturing and order processes. Generic information systems standards (Chen, 2004; Mertins, 2005; Schekkerman, 2004) often lack individual industrial applicability due to the high level of abstraction.

The process modeling must cover the needs of a successful process design, the integration of information systems and relevant design interactions. The design process is usually divided into the domains of factory planning and order processing using different information systems leading to a broad variety of process models, notations and database locations. Order processing is typically observed as the end of a consecutive design chain with no feedback loops. As a result, it must cope with fixed design decisions without taking account of relevant interdependencies. Moreover, the aspect of continuous process improvement must be considered.

In most cases, available process design concepts (e.g. Kuhn, 1995; SCOR, 2005; Schönsleben, 2004; Sepet, 1998, VDI, 2000) either focus on strategic aspects in process design or rely on a highly detailed in-depth process modeling. Additionally, only very few approaches (Haats, 2000; Kuhn, 1999) transfer the findings of process modeling (Booch, 1992; Chen, 2004; Dangelmaier, 2001) to the domain of manufacturing as well as order processing and consider relevant design interactions.

2. DESIGN CONCEPT

The following paper intends to fill the described gap as it presents a basic concept for the rapid design of model-based process chains. Due to the conceptual nature and the usage of information systems for the design and implementation of both manufacturing as well as order processing, process design is interpreted under the perspective of process modeling. The graph-based approach particularly takes the needs of a fast and efficient design of process alternatives during the early design stages into account. Accordingly, for the sake of simplicity, the concept follows an inductive design principle (Schäfer, 2003) deriving general findings out of individual and empirical data from selective industrial use cases.

The consideration of design as modeling poses the opportunity to derive a more detailed view of the design process. Following the findings for a successful modeling methodology (Booch, 1992; Dangelmaier, 2001), the design concept comprises four elements: design constructs and rules, a design notation and a design methodology. The proposed design concept can be seen as an umbrella for the variety of existing design concepts (e.g. factory planning, production planning and control) particularly taking modeling aspects in process design into account. This explicit consideration of the modeling aspects allows supporting and depicting the original process designs. Moreover, the aspect of choosing a proper process notation, which covers both static as well as dynamic process aspects, is addressed.

3. STATIC ASPECTS IN PROCESS MODELING

The adequate modeling of static aspects allows visualizing relevant process elements, relations and functions in process chains. In order to continuously support the process design activities, process modeling is supported for both manufacturing as well as order processing.

3.1 Process notation

Based on an appropriate symbolism, the process notation depicts all relevant process modeling information. The proposed easy-to-use process notation is hereby understood as a support notion that is not intended to replace original commercial and standard notations (e.g. Bernus, 2006; Chen, 2004), which are mostly more detailed. Having the role of a mediator and communicator, the process notation is rather intended to render the different worlds of process modeling comparable.

The proposed process notation allows depicting and interconnecting process modeling both in factory planning as well as order processing. Factory planning and order processing are typically separated, however highly interrelated. The primary models of factory planning are usually stored in tools of the digital factory (e.g. Technomatix). Models of order processing are stored mostly in ERP-systems (e.g. bill of materials, process plan, inspection plan). Both worlds are only rarely integrated (e.g. SyteAPS/AIM). A shared notation allows expressing and communicating knowledge of different domains in a common and agreed language.

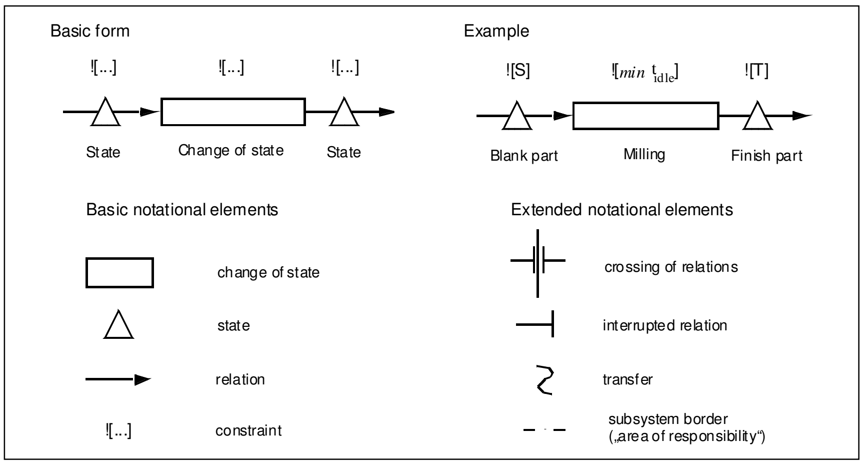

Figure 1 – Graphical process notation

Enhancing existing approaches (Dangelmaier, 1993; Felser, 1996), the proposed graphical process notation uses elementary nodes and arcs (see Figure 1). The systematical representation of manufacturing and order processing, corresponding system elements, their states and relations as well as relevant constraints (e.g. model consistency, stock, idle time, due date) addresses both sufficient modeling performance as well as simplicity. As a mediator notation for the domains of factory planning und order processing, the notation allows anticipating expectable modeling and corresponding process quality. Some of the very basic graphical design elements can be already found in commercial information systems (e.g. Technomatix) or can be easily depicted using standard visualization software (e.g. MS Powerpoint).

3.2 Design Constructs and rules

Design constructs represent the basic building elements of the synthetic modeling approach. The designed process chains must represent a large and increasing variety of process and process chain alternatives. The concept of modularity represents a promising approach for covering this variety (Aurich, 2003; Lindemann, 1999). The flexible combination of process modules to a process chain depends on the clear definition of process interfaces. Correspondingly, a process module is characterized by a transformation (change in state) of system elements, assigned to a system (input) and their corresponding states, into system elements with defined states provided by the system (output), within a defined set of deviations (Wagenknecht, 2005). The change in state includes temporal changes.

The provided definition is valid for both manufacturing as well as order processing. In case of factory planning, additional specifications based on the underlying material flow structures (line, collector, split, distribution) can be used. Thus, the possible variety of manufacturing processes can be reduced to a distinct set of process modules covering the whole process chain starting with delivery reception and ending with dispatching (see chapter 4.1).

The success of using process modules in process design strongly depends on the provision of appropriate rule sets, which describe valid directional and undirected (constraint) relations between these constructs. Therefore, summarizing a range of existing approaches, the provided set of design rules covers the aspect of process configuration, process segmentation and process linkage. Process configuration applies the fundamental principles of object orientation as appropriate objects can be specified subject to structures, relations, functions and attributes. Process segmentation covers the aspects of process composition and process aggregation. Process composition establishes a superior process called super process containing one or more sub processes. Decomposition leads to a subordination below the focused process. Process aggregation refers to a subsumption, whereby the different processes can still be identified. The result can be referred to as a "process chain".

Process linkage describes appropriate rules of how to combine process modules. While the implementation of a process chain is considered as a sequence of mutual related state conditions, the linkage of process modules can be related to this linkage condition. A defined order between process modules is given in case the output of one process module corresponds with the input of another process module.

3.3 Design Methodology

Design course

The design course describes the design in a general and idealized manner. Due to interrelated design decisions, process modeling is considered as a two-step design activity comprising the initial design of the manufacturing processes and the subsequent design of the model-based order processing processes.

Following the systems engineering approach, process chain design is defined as the elaboration of the problem or initial situation respectively, the design objective and design solution. All the major design steps are linked via hierarchical control loops. The chosen design strategy follows the "planning" principle as defined within the domain of artificial intelligence (AI) (Puppe, 1993). That is, the objective of process chain design consists of finding a closed graph, which transforms the input (e.g. incoming goods) into the required output (e.g. outgoing goods) as identified in the initial situation. To do so, common heuristics for system design (Maier, 2002; Suh, 1990) such as decomposition, search, allocation and specification are applied for process design and are strongly interrelated. As relevant process states are already defined during the process decomposition, the following search and allocation of appropriate process modules already leads to a given process structure.

The design course can be expressed in the same graphical notation as the design objects (e.g. processes) and is applicable for both manufacturing as well as order processing. They are linked via hierarchical control loops (see Figure 2) to fully consider relevant interdependencies between the typically separated design domains.

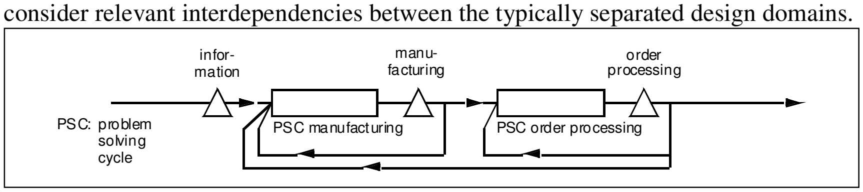

Figure 2 – Design course as a hierarchical control loop

For example, if a proper design of an information system supported order processing is not possible, modifications of the manufacturing processes must be considered.

Process consistency

Process design is successful in case the process models can be directly implemented, i.e. without corrective actions. That is, in the case of using information systems (e.g. digital factory, advanced planning & scheduling), model based activities should not call for a subsequent human trouble shooting in order to provide feasible solutions. Accordingly, the required fit (Tomiyama, 1998) of the chosen process module and the provided states of change with the required state of changes within the process represents a basic design condition. Using the introduced design rules, process design starts with the design of required processes and sub-processes representing necessary states in change. Subsequently, an adequately fitting process module is selected. The need for a ”consistency of choice” is valid both for manufacturing as well as order processing.

“Model consistency” secures an appropriate fit between model-based order processing and manufacturing process. Due to the usage of manufacturing process models, the success of order processing is tightly bound to the accuracy of the provided models in the information system. The consistency condition implies that the processing results are actually feasible. The appropriateness of model-based order processing is analyzed based on the explication of the applied manufacturing model using the same notation as applied in the design and modeling of the manufacturing processes (see Figure 3).

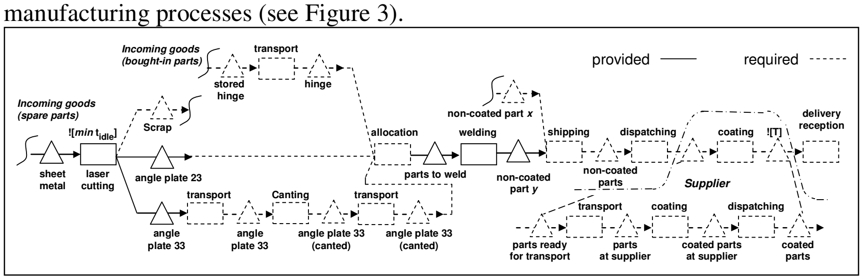

Figure 3 – Model consistency of medium to short-term planning (abridged)

Process consistency is a major aspect of the process notation. Thus, the successful or missing modeling support by the used information systems can be clearly depicted. The differences between the provided and required states and changes in state are denoted with a solid ("——— ") and dotted ("- - - -") line respectively.

In case of order processing, modeling is only appropriate in case the provided model perspective fits the manufacturing processes. Deviations between the provided and required modeling perspective are a direct result of using information systems with limited applicability. Fortunately, based on the provided graphical notation, the need for additional concepts, e.g. the integration of additional human planners, can be derived directly from the missing gaps in the sketch of the required manufacturing process chain.

3.4 Use case

To illustrate the applicability of the proposed design concept, a design example from a medium sized automotive and construction industry supplier is given. The introduced new order processing system both extends as well as substitutes the current information systems. However, due to the complexity of IT-structure and functions, it has been difficult to clearly elaborate and evaluate the order processing quality to be expected, necessary modifications of the order processing system and the required integration of organization, material structure and information systems.

In this situation, the proposed process design concept appeared to be a helpful approach. For example, following the initial mapping of the existing manufacturing processes, a closer view upon medium to short term planning revealed that the new information system strongly supports the planning of machining processes considering the required resources and planning objectives (see Figure 3). However, transport, storage and inspection as well as external coating processes remained unsupported or are processed by legacy systems. That is, to achieve proper order processing results, the new information system must be highly integrated into the information structure while the shop floor worker must support the adherence to delivery dates. Moreover, excess part storage must be abandoned leading to a modified material flow while external coating needs a clearly fixed lead-time.

Additionally, to meet the individual process design task, the process modeling of provided and missing information system support has been extended for different color codes to represent the different information systems.

4. DYNAMIC ASPECTS IN PROCESS MODELING

So far, the proposed process design concept supports the static modeling of process structures and functions. In the following, it is shown that the concept can be extended to cover dynamic aspects in process modeling for manufacturing, i.e. process parameters.

4.1 Process states

In general, the number of relevant *n* parameters of a process can be represented in the form of *n*-dimensional state space (Westkämper, 1994). The graphical representation of the state space can however be difficult if many specific properties and their corresponding parameters must be taken into account.

Considering a manufacturing process from the point of view of the material flow, the properties of time, quantity and location are sufficient to clearly define the state of a part. However, as the detailed definition of the location leads to a three-dimensional parameter, a 5-dimensional state space with limited possibilities for graphical representation would be the result. Fortunately, the aspect of distance is usually sufficient to characterize the individual state of a process. The aspect of location can therefore be reduced to the aspect of distance. Correspondingly, the concept of a three-dimensional state space of manufacturing processes representing the relevant states of time, quantity and distance is proposed (Figure 4).

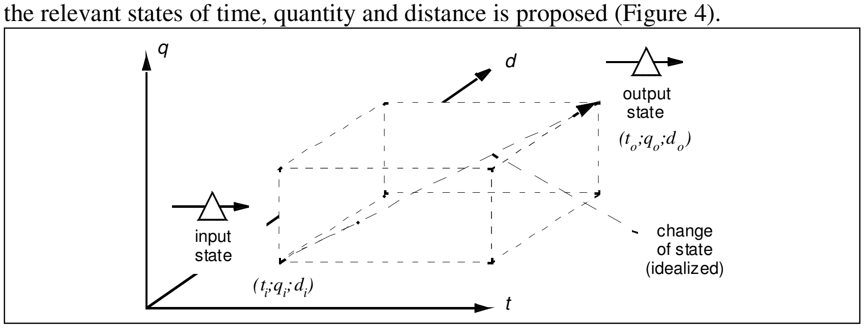

Figure 4 – State space of a manufacturing process

The proposed static nation of a process can be transferred into the three dimensional state space. Every node representing the specific state of a process can be located within the state space based on the specific values of the parameters of time, quantity and distance. The change in state of a process corresponds to the state space between subsequent process states. The idealized linear change in state of a process with each one input and output state is given in Figure 4.

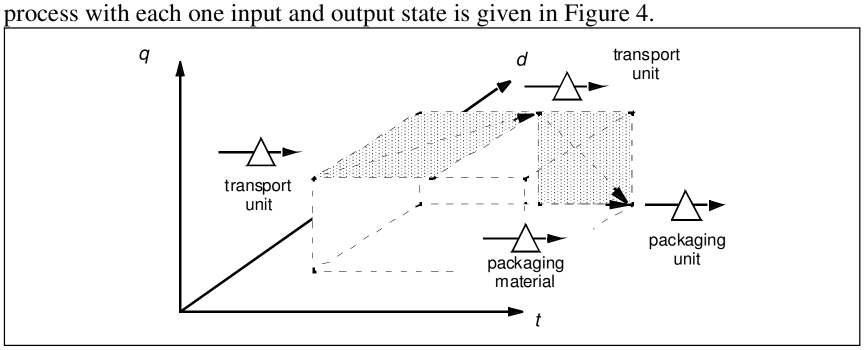

Figure 5 – Process modules in the state space diagram

The concept of a state space cannot only be used to represent processes but process chains as well. Figure 5 depicts a simple example of a process chain, which consists of two manufacturing processes. The individual processes are depicted using the process modules “transport” and “packaging”. The overall change in state for the part corresponds to a change in distance (transport) and a decrease of quantity due to the aggregation of several transport units to one packaging unit (packaging).

The given process chain is characterized by the introduction of an intermediate state for the processing of the input state into the output state. The process module packaging requires introduction of an additional state representing the packaging material. Additionally, Figure 5 depicts that the necessary linkage characteristics, i.e. the identity of output and input states of subsequent processes, is given.

The following Table 1 depicts the distinct set of process modules, their material flow structures as well as relevant aggregations (for the parameter quantity).

Table 1 – Process modules in manufacturing

Type	Process module	Co	De	Ag	Di
Line element (1;1)	primary shaping				
	metal forming				
	rearranging of particles				
	transport				
	shipping			x	
	dispatching			x	
	storage			x	x
	delivery reception		x		x
	allocation				x
Collector element (a;1)	joining				
	surface coating				
	placing of particles				
	packaging				
	picking				
Split element (1;2)	inspection		x		
Distribution element (1;b)	cutting		x		
	extracting of particles		x		

Co – Composition De - Decomposit. Ag – Aggregation Di - Disaggregat.

4.2 Tolerance specification

In practice, each manufacturing process within a process chain is not only characterized by different setting parameters but state deviations as well (denoted as Δ). Out of the perspective of the material flow, such deviations can affect all the three dimensions of time t, quantity q and distance d and can reach both positive ($+\Delta$) as well as negative ($-\Delta$) values. Reasons are the planned collating (aggregation) respectively decollating (disaggregation) of process elements as well as inevitable disturbances of a manufacturing process. As a direct result, manufacturing processes must be considered as rather inhomogeneous. Positive and negative deviations lead to a specific range of tolerances with upper and lower limits.

The individual modeling of each parameters deviation can be combined to a three-dimensional state space as well. To do so, every given state of a process element within a manufacturing process, while considering relevant deviations, can be depicted by a three-dimensional state space (see Figure 6).

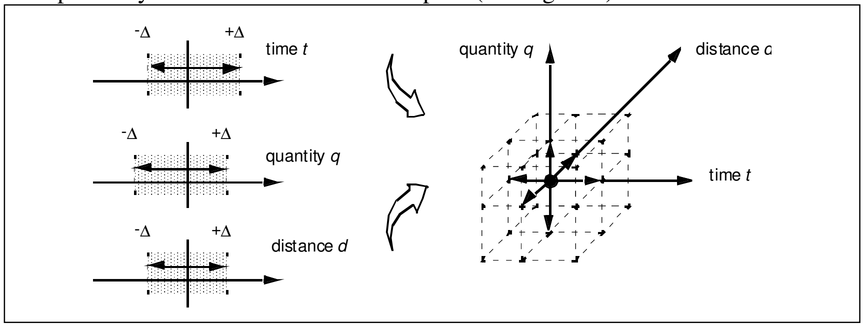

Figure 6 – Combination of tolerances of a manufacturing process state

The consideration of relevant deviations extends the state modeling of system elements of a manufacturing process. The individual deviations of the values of the different nodes must be integrated into the concept of a state space (see Figure 7).

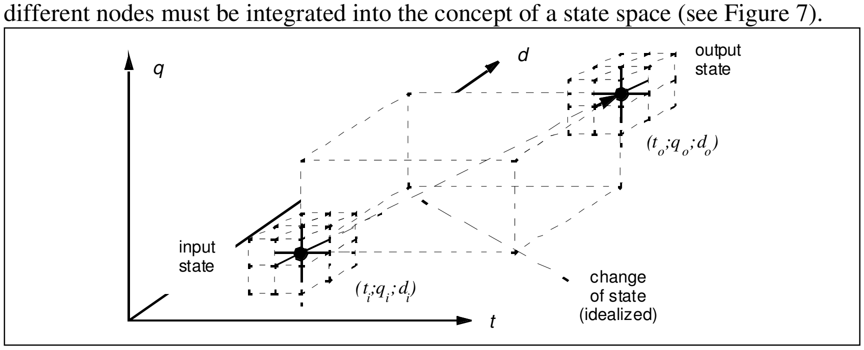

Figure 7 – State space of a process module with tolerances

A model-based order processing must both properly depict as well as manage possible deviations in manufacturing. The specific range of tolerances must cover the specific characteristics of a manufacturing process (e.g. lot size, scraped parts, variable machining times, delivery locations). The final tolerance requirements are usually defined directly and indirectly by the customer specifications. Initial tolerance specifications are the responsibility of the supplier. Tolerance specifications of the intermediate manufacturing processes are the direct result of values and interrelations of operation, resource and part characteristics, i.e. the manufacturing technology itself. As a result, the dimensions of the individual processes must be gradually brought up to the required specification.

In order to maintain the linkage condition of subsequent processes, the output tolerance of a process must correspond to the input tolerance of the subsequent process. Following the concept of a tolerance channel (Westkämper, 1994) to visualize single parameter tolerances, manufacturing in terms of time, quantity and distance can be described as a tolerance tube through which the manufacture is to be successfully led.

7. SUMMARY AND OUTLOOK

The proposed concept strongly supports the graph based design of process chains in manufacturing and order processing taking particular care of the information system characteristics, deficits and limitations. Results of industrial use cases prove the usability and applicability. Major benefits include both the individual design of processes in manufacturing and model-based order processing as well as the simplicity to rapidly synthesize and analyze alternative process solutions. Future work is required to development a modeling support for the dynamic process aspects as the modeling of static process aspects can be easily done via visualization tools (e.g. MS Visio) or customized in Digital factory or ERP-software.

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