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# An architecture for process planning, analysis and simulation in microsystems technology

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## Abstract

The authors present an integrated process optimization architecture for microsystems technology. This paper will focus on process specification, planning, analysis, and simulation as essential part of this overall architecture. The methods and tools realizing this architecture are described in detail. For validation of the architecture, the LIGA technology is considered.

## Introduction

According to VDI/VDE [1], currently more than 3700 enterprises in Germany have at one's disposal microtechnological processing utilities. The markets will develop dynamically in the near future. So, for instance, the first attempts are undertaken to establish a low volume production in a dedicated laboratory at the Research Centre Karlsruhe. The technological and economic considerations now grow in importance, requiring a more systematical approach to microsystems fabrication. The economic fabrication of microcomponents and systems demands industry-oriented computer-aided tools for process documentation, planning, analysis and simulation.

Existing design and planning aids often yield compromise solutions, hindering to take benefit out of the technological and economic potential. What is often neglected is, that microsystems design cannot be done without regarding the process course and characterization of technologies and materials. A simultaneous planned process can on the one hand transfer the needed technological and economic know-how to SMEs and on the other hand serve as basis for the optimization of production and its costs in producing companies.

## Integrated process optimization architecture

To support the planner in his tedious decision tasks, the authors present an integrated process optimization architecture for microsystems technology. This paper focuses on process planning, analysis, and simulation as essential part of this overall architecture.

The architecture consists of two layers (see Figure 1). The objective of the first layer is to specify the fabrication steps in order to make transparent the complex processes and decision paths. With respect to this task, only holistic enterprise modelling methodologies fulfill the requirements of formal descriptions in several consistent views and hierarchical levels. The second layer of the architecture contains a systematical exploration of manufacturing possibilities for the development of a process plan. A first guess of the principle manufacturing process can be obtained by a process routing module. For evaluation and analysis of the several processing alternatives, yet contained in this plan, a hybrid approach is used which consists of analytical and simulation methods. A temporal analysis investigates the minimum and maximum processing time of the overall process. Other analysis modules can be used in the same fashion for analyzing the process yield and basic process requirements of the product design. Optimization of these criteria alone however, is of no use, because other criteria like process costs, machine utilization or lead times have to be considered. The optimization of these different contradictory objectives is achieved by means of simulation.

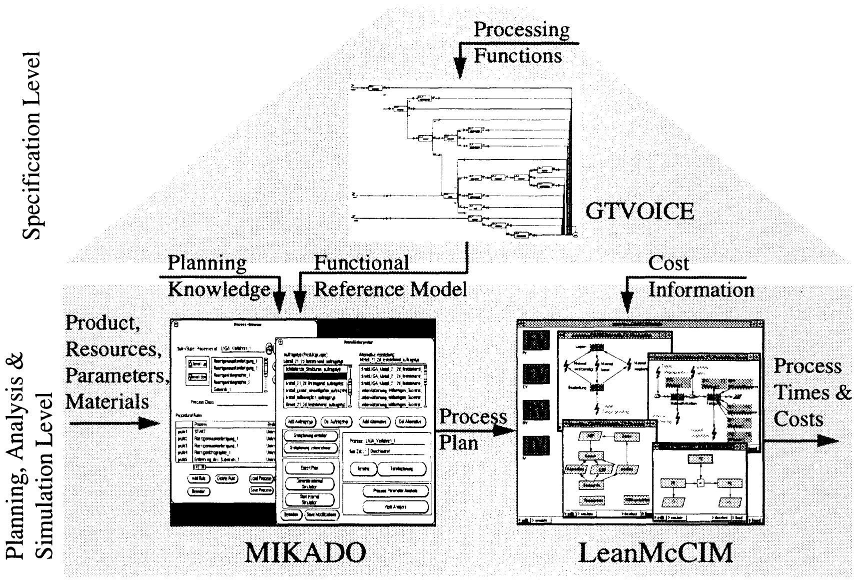


Figure 1: Tool architecture and interfaces.

The architecture is currently implemented in the three tools GTVOICE, MIKADO and LeanMcCIM, integrated to a „workbench" (see Figure 1). GTVOICE is responsible for specification of a functional reference process model as starting point for planning and evaluation. MIKADO deals with analytical and knowledge-based planning and evaluation of process plans. LeanMcCIM is a tool is used for the simulation and economic evaluation of the processes by using benchmark systems.

## The specification level

The planning process starts with an analysis of existing fabrication processes and possibilities. The immense complexity of microsystems production processes can only be mastered by a suitable specification methodology. Existing process representations often miss complexity-reducing principles like view concepts, hierarchical decomposition and graphical notations, making manual modifications a cumbersome task [2].

On the other hand, effective process models are under development in the research area of enterprise and business process modelling methodologies. For this reason, we decided to use the enterprise modelling methodology CIMOSA (CIM Open Systems Architecture) for describing the processes in a structured way in four separate but interrelated viewpoints: the function view, the information view, the resource view and the organization view [3]. Of special interest for our application, thereby is the function view, modelling the process nets (rather than process chains) and their control structures (see Figure 2).

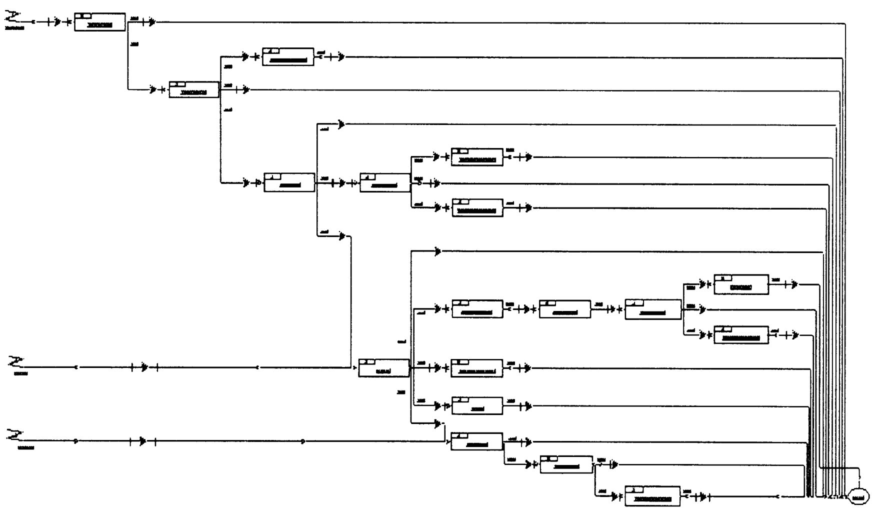

Figure 2: The functional reference model of the LIGA-process.

This means that alternative, concurrent and hierarchical process courses can be represented, as demanded by REFA [4]. The ability to represent alternative sub-processes in one consistent process model, on the one hand allows us to emboss all routes for all possible different order types (e.g. standard metal structures in LIGA). On the other hand, the process model represents manufacturing decisions for a particular order type explicitly by only incompletely specifying process routes with respect to the requirement of determinism (e.g. direct LIGA metal structure or secondary, moulded LIGA metal structure).

For process specification, we could immediately fall back on the CIMOSA enterprise modelling tool GTVOICE, developed by Rillaer & deVries [5]. The tool offers a graphical user interface for process specification and consistency checking functions. To take profit out of these capabilities, we developed a unidirectional file interface to load the logical process model by button-push in MIKADO for further refinement.

It is worth while to mention, that the CIMOSA concept is used as backbone for the development of all methods and tools discussed in later paragraphs. CIMOSAs expressiveness, in big parts posed new requirements for the development of the planning, analysis and simulation functions.

## Process planning and analysis

The task of process planning can be differentiated in the process routing task and the process refinement task. The proposed CIM architecture and planning tool MIKADO supports both phases.

The approach used for process routing is Group Technology [6] (GT). Using GT, the variety of manufacturable products is classified into part families with similar technological processes. A new product is classified as belonging to one of those part families and the respective general process plan is recalled. The big advantage of GT here is, that a very rough imagination of the future product is sufficient to determine the principle process course. Process routing is an interactive process in MIKADO. The user is asked, if the product is of a special type (X-ray mask, optical structure), about the materials class (resist, metal, plastic, ceramics) the principle geometry (2½ D, inclined, stepped, movable), the packaging (fixed on substrate, free, based) and offers - if possible - as solution the correct general process plan for that part. The mapping between a part family and the necessary processing decisions that constrain the process route is defined in the form of production rules.

But still, this general process plan does not specify the process route completely. Besides concurrent activities, it also contains processing alternatives that can be evaluated under several criteria. MIKADO, therefore currently offers three process analysis modules for evaluation of the criteria of technological

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feasibility, processing time and process yield, respectively, at a very early planning stage.

The technological analysis module checks the process plan under evaluation, if it fulfills some basic requirements, posed by the principle product design (e.g. if all processes are capable to produce the desired minimal lateral dimension, structure height and edge profile). The process capabilities are stored within a taxonomical classification of processing functions. Each process contained in the process plan inherits those capabilities as instance of one or more process classes. Furthermore, relationships between process capabilities are automatically maintained to map very specific capabilities (e.g. isotropy of an etching process) to more general attributes (e.g. capability of producing vertical edges).

Temporal and yield analysis share the same working scheme: The process interconnections are analyzed and the criteria is evaluated by particular formulas for each type of process interconnection employing default values given by the user. Because the manufacturing resource is not yet selected, the analysis modules allow to define intervals instead of fixed values.

The temporal analyzer extends the capability of existing network planning methods [7] (CPM and MPM) used in Operations Research for the following reasons to determine the overall processing time, process dates, gap times and time-critical steps.

- representation and analysis of mixed concurrent and alternative processes
- temporal intervals and interval algebra instead of fixed values
- use of multilevel process plans, proposed by Battersby [8]

The results obtained, therefore differ from results obtained by MPM. The following diagram (see Figure 4) explains the semantics behind the results of the temporal analysis.

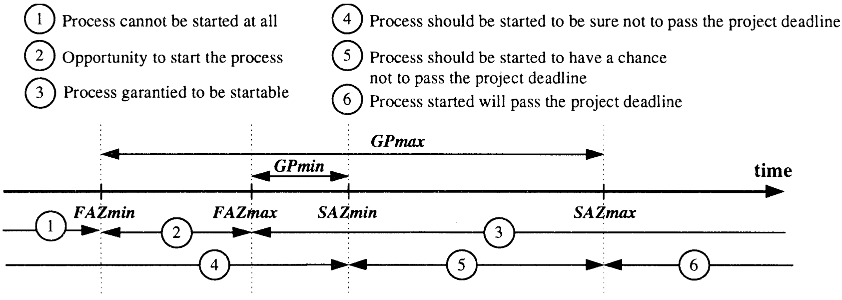


Figure 3: Results of temporal analysis and their semantics.

Without going into details of the yield analysis module, the further planning process in MIKADO will be explained. Having constrained the process route to alternatives acceptable from the aspects of time and yield, in the second planning phase, the details of each manufacturing operation are defined. These detailed information provided by the process are the manufacturing resource, the process parameters and the working materials to use. The authors believe, that this step can only be done in an interactive manner. But the system should offer catalogues of pre-defined elements and give warnings on an invalid process configuration or propose solutions on request. About the realization of resource, parameter and material catalogues is reported elsewhere [9]. Current work considers the use of a reference solution environment in this planning phase, to define constraints and goals as requirements on the process configuration. Each requirement will reference a particular process class for which it is valid and a resource, process parameter or working material class, for which it is relevant (e.g. an x-ray exposure process needs a synchrotron radiation source). Furthermore, requirements can be posed on characteristics of the solution (e.g. characteristic wavelength of synchrotron radiation source < 2 Å). To support the planner, inconsistent process configurations will be detected and solutions provided on request.

## Process and cost simulation

Dynamic process and cost simulation is an integral part of the proposed architecture. The objectives are the evaluation of alternative process plans considering the aspect of production planning (e.g. according to times, costs or quality criteria) and pre-calculation of product costs as critical information in product design and process planning.

Questions according to theses topics are:

- What costs will occur during the life cycle of the product?
- What will be the due times per product and production process?
- What machines can be identified as bottle necks?
- How can the capacities of the several machine be co-ordinated to reduce the due times?
- Is it worth to invest in new machines or even a new technology?

The costs of a microsystem product according to process planning are influenced by its material, the manufacturing process (for example LIGA, silicon or micromilling technology), the assembly process (handling, packaging, interconnection technique), and the resources used. How ever the share of material costs is quite insignificant in comparison to the value added during the production process. The most cost-intensive item are the expensive and high-technology machines. Especially in the LIGA technology there exist so many interdependencies and alternatives among the several process steps which make a simulation model necessary.

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For simulation and dynamic evaluation we use the tool LeanMcCIM [10]. The tool allows the modelling of CIMOSA business processes, resources, orders and products in three different views. As a new aspect of enterprise modelling the economic view [10] was integrated.

The economic view models aggregate the relevant aspects of business processes for analysis and optimization in form of benchmarks. It allows the evaluation of business processes, products and resources but also entire business process chains. The constructs of the view allow the creation of benchmark systems and the multi dimensional assignment of defined benchmarks to objects to be evaluated. The generation of benchmark systems is treated as an implicit part of business process modelling and is done in parallel to the modelling of business processes. A developed graphical benchmark system description language allows a very good overview of the created benchmark systems.

For this application the tool contains only one generic business process and a set of resources required to produce the specified products. Several benchmark systems were developed containing all relevant performance, cost and time benchmarks. The specific business processes and resources are selected via the completely specified process plan from MIKADO. According to this an interface between LeanMcCIM and MIKADO was developed which allows an unidirectional file transfer.

## Validation on the LIGA-technology

A general enterprise model was built that represents all processes and resources to fabricate microsystems products by the LIGA process. Up-to now, a complete hierarchical functional reference model of the LIGA-process, containing over 100 separate steps is built-up, extended by an Process and an Equipment Catalogue, storing over 200 classified process and equipment types and their capability characteristics. About 18 part families were identified for LIGA components and characterized by 4 attributes.

Our experience in applying GT to the LIGA process showed, that for the reason of free choice of lateral geometry offered by the process, it was very easy to identify a general process route for a part family of very different products.

## Conclusions and future work

The paper presented an integrated process optimization approach for microsystems technology and the tools realizing the modelling, planning, analysis, and simulation functions. Both, technological and economic aspects are integrated in one common framework.

Future work concerns methods to adequately support the process refinement task as mentioned before. Furthermore, the extension of the successive planning approach to a dynamic top-down approach is planned: When the decisions taken by the planner are recorded together with their effects, they can be used for finding solutions the next time.

The validation of the proposed concepts will go further on the low volume production of LIGA components at our Research Center.

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