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Model-based Process Generation For Supporting Agile Shop Floor Management In SMEs

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Abstract

In recent years, the framework conditions on the Chinese market for machine and equipment manufacturing have changed significantly. By now, products are expected to be customized and at the same time offered at low prices with fast delivery times. Thereby, customer-specific production processes are becoming increasingly important in manufacturing. In addition, German small and medium-sized companies are confronted with a progressively turbulent business environment. For example, Chinese customers expect that orders can still be changed after they had been placed. Hence, companies must be able to identify short-term changes and individual requirements at an early stage. In order to withstand the competitive pressure, alternative courses of action must be created by generating new process variants quickly and reliably. To address this challenge, an approach for the automated generation and realization of processes based on an integrated enterprise model for supporting agile shop floor management as part of an agile process management system is being developed in the German-Chinese joint research project "*MAP*" and proposed in this paper. Starting with an introduction into the subject matter, the development gap is demonstrated and an approach as well as an early prototype is presented, followed by an outlook on further development in the research project.

Keywords

Automated process generation; Shop floor management system; Customer-specific production; Agility

1. Industrial demand

Today, many industrial companies are able to control a high number of variants and mass customization on the basis of pre-configured module structures [1]. However, customers also demand individual adaptations to standard product variants [2] [3]. Furthermore, due to an ever-increasing dynamic, product development cycles are becoming shorter. These and further factors have changed the framework in production significantly. Consequently, the complexity of production is steadily increasing [4].

Furthermore, globalization has considerably increased the importance of global trade [5]. For many decades, German companies have been active in the Chinese market. The number of German small and medium-sized companies (SMEs) in the Chinese business environment has also been growing [6]. Nevertheless, when entering a foreign market, especially the dynamic Chinese market, German companies have to adapt to the local environment and understand the local business culture [5]. That means, for example, when requesting for a quotation, Chinese customers expect suppliers to reply with an individual offer including a price and delivery time estimation in only a few days' time [7] [8]. In addition to lengthy negotiations concerning specifications, manufacturers also have to manage short-term changes to orders even though they had already been placed [9] [10] [11]. The mentioned challenges do not only apply to the Chinese market. HUANG, for example, outlines similar challenges for the U.S. market [7]. For a company to establish itself in these dynamic markets, it needs to monitor, identify and adapt to long-term trends as well as short-term changes quickly and in a targeted, well-founded manner. In this paper, following LUCZAK [12], agility is understood as the ability of a company to optimize according to different operating points in order to ensure an easy and quick change between these operating points when the scenarios occur. This ability is becoming increasingly important in process management [13] [14] [15]. To address this, an agile process management system is being developed within the framework of the German-Chinese joint research project "*Machine Learning for Agile Process Management in Machine and Equipment Manufacturing*" (MAP), which is funded by the German Federal Ministry of Education and Research (BMBF) and implemented by the Project Management Agency Karlsruhe (PTKA).

With the budatec GmbH (one of the application partners of the MAP project consortium and hereafter to be named budatec), an agile process management system is being developed for SMEs. It consists of two main interrelated components: On the one hand, a corporate environment monitoring system [16] for identifying influences at an early stage and on the other hand, an agile shop floor management system for fast and systematic reactions. In this paper, an approach and an early prototype is presented for the latter. For this purpose the application case is first described. Followed by the state of the art, where the need for research is identified. Then, in section 4, the automated generation of customer-specific production processes is shown. Based on this, the application is presented. This paper concludes with a summary and an outlook on the next steps.

2. Application case

Budatec is a leading developer and manufacturer of innovative machines and equipment for the semiconductor and solar industry. The main business areas are thermal systems and products related to electronics manufacturing. Based in Germany, the small-sized company's key strength lies in the ability to adapt its standardized products to a customer's individual requirements. Up to 80 percent of the company's products are standardized products with customer-individual adaptations and form the focus of this paper, while fully customized plants make up the remaining 20 percent. Approximately 50 percent of the application partner's machines are already destined for worldwide export. Having gained experience in Asian countries such as Japan and the Philippines, the next objective is to enter the Chinese market.

As mentioned above, due to the specifics of the Chinese market, the market entry offers both opportunities and risks [11] [17]. One of the major challenges is the time pressure in the bidding process (*short-term offer*). In order to reply to a customer request with a realistic price and delivery time estimation concerning a standard product with customized adaptation design, various factors must be included in the calculation [7] [8]. Hence, historical data of previous projects need to be collected, stored and utilized to calculate new offers. Furthermore, the company's situation in terms of, for example, liquidity needs to be monitored and simulated for the considered time period, so that decisions such as the purchase or in-house production of components can be made and the optimal offer can be designed for the customer. Another source of competitive pressure lies in the actual price level and the lead time. Therefore, orders with customer-individual adaptations need to be processed as standard orders (*processing as standard orders*), which presupposes that the time for order processing and production planning must be minimized. If the offer reaches the customer quickly enough and the rough estimations correspond to the customer's expectations, the company subsequently needs to go through several negotiation iterations (*lengthy negotiation*). Within these iterations, the specifications are being developed and the details of the offer are being negotiated. Hence, work plans, workflows and master data must be kept up to date with the negotiations. It is evident that the more transparent the production process of the specific product is, the lower are the risks of miscalculation and the better is the bargaining position of the company towards the customer. The same principle applies to changes that the customer requests after the order had already been placed (*subsequent changes*). In this case, the master data must still be adjusted shortly before or even shortly after the start of production. Classic work plan generation approaches reach their limits. Furthermore, the transparent identification and documentation of customer-requested deviations is necessary in order to enable fast and systematic processing of changes in the production process and is less prone to error than, for example, verbal assignment from the project manager to the worker on the shop floor. Finally, the commissioning of the product is often done by local partners at the customer's site (*local commissioner*), which makes the requirements for continuous documentation of the production process and a role-based view of the documentation even more significant.

In contrast to large companies, which make an effective distinction between the functions on the enterprise control level, manufacturing control level and the manufacturing level according to the automation pyramid [18], a small company as budatec needs to integrate certain functions. First and foremost, the company's key strength lies in its flexibility and customer orientation. In order to process customer-specific adaptions quickly, the order must be viewed in an integrated way. Hence, the systems for order management, customer relation management and shop floor management must be integrated as well. Added to this, the product variance of standard products is much lower compared to large companies, which lowers the need for specific information systems. Moreover, the assembly of a vacuum soldering system requires a high level of expertise and manual work, which makes many existing solutions for the automated generation of work plans for production facilities obsolete for budatec. Consequently, there is a need for an alternative shop floor management system.

The requirements derived from the challenges described above are summarized in Figure 1 and comply with the requirements for digital and intelligent shop floor management identified by RAUCH [19]. In order to react quickly and databased to short-term offers, for example, the effort for the generation of a task model for that specific order must be kept to a minimum. Additionally, in order to access existing data from previous orders and their corresponding model as a calculation basis, the maintenance effort must be kept low and the individual work steps must be documented in the first place. A further prerequisite is the access to heterogeneous data sources. The changeability of the generated model plays a major role when dealing with customer-requested changes during negotiations and occasionally also after the order had been placed.

		Challenges				
		Short-term offer	Lengthy negotiation	Processing as standard orders	Subsequent changes	Local commissioner
Requirements	Low effort for the generation of the task model for each customer individual order	x	x	x	x	x
	Low effort for model maintenance	x				
	Changeability of the generated model		x		x	
	Integration of heterogeneous data sources	x	x	x	x	x
	Integrated documentation of individual work steps	x		x	x	x

Figure 1: Requirements for the development of an agile shop floor management system, derived from the challenges of entering the Chinese market as a German SME

3. State of the art

Traditional manufacturing information technology (IT) is characterized by a hierarchical structure along the automation pyramid. This is in contrast to the service-oriented approach (SOA) which is intended to support SMEs. As mentioned in Chapter 2, it should be noted that the common components in the automation pyramid, such as the Manufacturing Execution System (MES), Enterprise Resource Planning System (ERP) and Product Lifecycle Management System (PLM), are not available in most SMEs. By outsourcing the IT infrastructure, SMEs can react more flexibly to changing market situations or customer demands [20]. In order to assist SMEs further, a concept is being developed that describes customer-specific manufacturing processes in an automated way. Considering the requirements shown in Figure 1, previous research related to automatic model generation was reviewed and compared.

All existing approaches use models, which describe the actual work process and the required resources, as a basis. These models must be able to be generated or adapted quickly and easily for new customer requests. To achieve this, the goal is to be able to compare resource capabilities automatically [21]. In order to be able to describe the capabilities in a standardized way, CUIPER uses the VDI 2680 [22] and JÄRVENPÄÄ taxonomy in comparison [21]. BACKHAUS describes a task model in his work which is used to ensure derivation and modelling of capabilities and their mapping to resource instructions and communication interfaces [23]. This approach ensures a good adaptation of the generated models. Other approaches for adjusting the model are described among others by HUCKABY and HUCKABY AND CHRISTENSEN [24] [25]. LAU goes one step further and uses an automatic comparison of capabilities to achieve a faster adaptation and generation of the models [26]. All approaches integrate a large amount of different information and documents. LAU and JÄRVENPÄÄ go the furthest in this respect, using this information for automatic capability matching [26] [21]. In order to realize a rescheduling or a documentation of the individual work steps, it must be possible to write information back into the model. LAU uses this circumstance to achieve an even utilization of machines [27].

Requirements	Existing approaches: CUPIER 2000	LAU 2010	HUCKABY AND CHRISTENSEN 2014	BACKHAUS 2016	JÄRVENPÄÄ ET AL. 2016	MÜLLER 2016
Low effort for the generation of the task model for each customer individual order	◔	◔	◔	◔	◑	◔
Low effort for model maintenance	◔	◔	◔	◑	◑	◑
Changeability of the generated model	◑	◕	◑	◑	◑	◑
Integration of heterogeneous data sources	◔	◑	◔	◔	◑	◔
Integrated documentation of inividual work steps	○	◑	○	○	○	○

● Level of Support > 80% ◕ Level of Support < 80% ◑ Level of Support < 50% ◔ Level of Support < 25% ○ Not Supported

Figure 2: Comparison of existing approaches with the derived requirements

As can be seen in Figure 2, all of the approaches named above require a medium to high level of effort to create a task model. In addition, most of the steps are still manual. In CUIPER, for example, the graphically modeled description models are manually supplemented with the descriptions of the required assembly processes and the allocation of the corresponding resources [22]. Adjusting the model is possible with all of the approaches presented, but is mainly done manually as well. Changes can be implemented, however, bringing in external data sources is considered only rudimentarily by most approaches. Thus, HUCKABY ET

AL. and HUCKABY & CHRISTENSEN [24] [25] use the basic, general, atomic action considering the technical constraints and parameters. The feeding of process information back into the model is addressed by only a few approaches. The approach presented in this paper will build on the findings of the discussed scientific work. Its originality lies in the capability of taking into account order-specific product information and thereby enabling the automated generation of production processes for customer-specific adaptions to standard product variants.

4. The automated generation of customer-specific production processes

In contrast to the existing approaches for the production of product variants described above, the model-based process generation concept presented in this chapter must enable production plans to be enriched with order-specific product information – especially about the customer-individual design adaptations. In this way, order-specific production processes can be implemented. This additional information can be stored in plans and design drawings described in the following paragraphs.

The model-based approach builds on existing solutions. The Unified Service Description Language (**USDL**) [28] and the dynamic model generation, which is based on the modules of the Modular Shop floor IT [29], are worth mentioning. In the course of Industry 4.0, the linking of machines and IT as well as the amount of generated data is increasing strongly. Services are the foundation for the linking. Based on inter-connectable process modules created with the Integrated Enterprise Modelling Method (IEM) [30], a first **dynamic generated process model** was developed to describe and control a production process. This enables a flexible reconfiguration for customized products and variants as well as a faster setup of new production processes [31]. The enterprise modelling tool MO²GO [32] was used to create the described modules, which includes an information model and the actual process description [32]. The modules were developed according to the service concept.

As shown in Figure 3, the model-based approach consists of the following components, which are further explained below:

- **Business process model**, which contains the business and productions processes for the standard product variants of a company
- **Process modules**, which describe work sequences for the production of standard product variants that consist of individual work steps
- **Plans and constructing drawings**, which support the worker in production processes
- **Order management**, which contains the information of customer orders
- **Model generation system**, which generates a specific process model for an individual customer order based on the customer's requirements (standard product variant with customer-individual adaptions)
- **Specific process model for the customer order**, which contains descriptions of all work steps and the associated documents to support the worker in the production process for the individual order

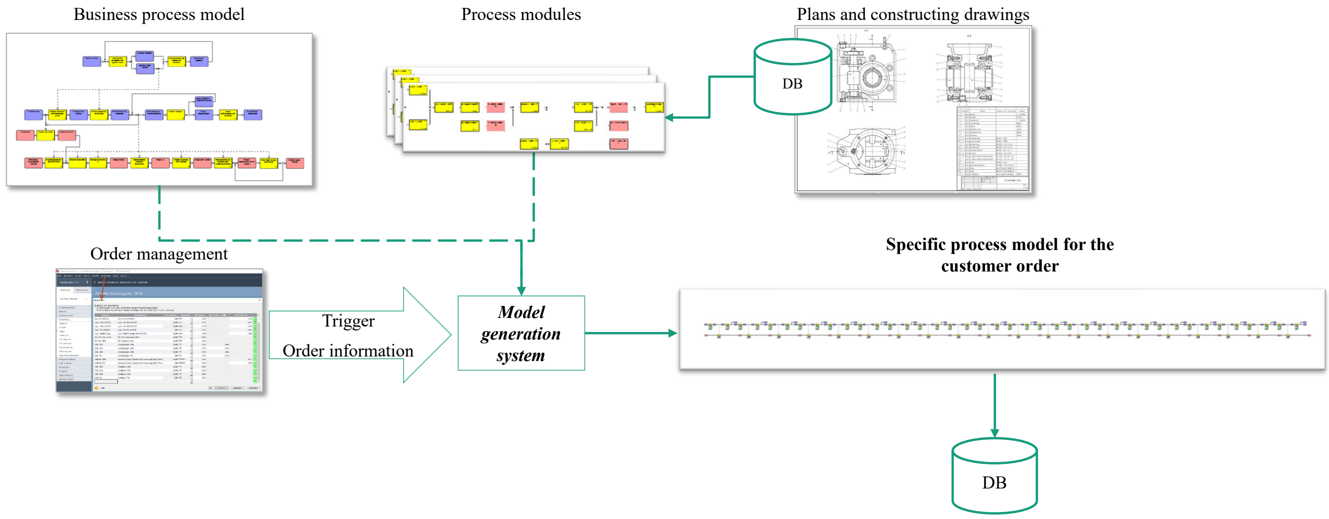


Figure 3 Concept of the model-based approach

Business process model

The business process model describes the entire value chain of the company. These workflows include purchasing, warehouse management, human resources and the actual production. It should be noted that the individual areas can differ in their level of detail. All processes that remain the same over a long time period and do not exhibit a high degree of variance can be detailed very precisely. In order to be able to follow a modular approach in automatic generation, the level of detail of the production must be selected accordingly. This means that only individual work sequences and not every single work step of the production are modelled within the generic business process model. In Figure 4, the upper halves of the process modules (illustrated as large puzzle pieces) describe the generic procedure for building a soldering oven. The detailed work sequences are represented by the small puzzle pieces in the lower half of the figure and will be referred to as "*process modules*" in the following.

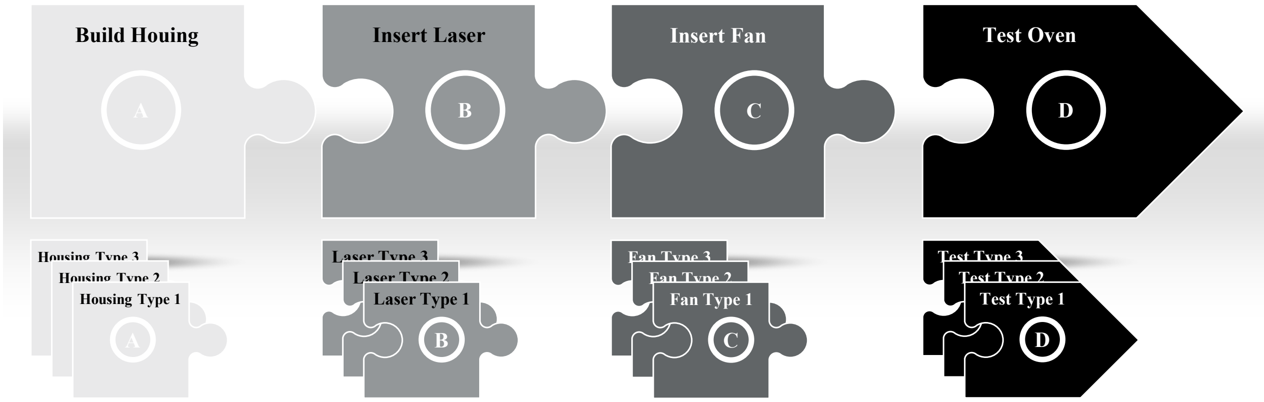


Figure 4: Concept for a generic model using the example of the production of a soldering oven

Process modules, plans and construction drawings

The exact description of the work sequences takes place in the individual process modules, illustrated as small puzzle pieces in Figure 4. Here, the necessary individual work steps are described with all aspects required for this specific task. Therefore, supporting information in the form of work instructions, plans or documentations are needed. Based on the specific customer configurations, the required documents must be adapted accordingly. If, for example, completely new production technologies are to be used for a work step, the documents must be manually checked and possibly adapted. The documents can be stored in a wide variety of locations and IT systems. Furthermore, supporting tools and necessary employees can be modelled in the modules.

Order management

The order management system handles the management of existing, past and new incoming orders. Such a system is present in most SMEs and requires a user interface. Once a new order is added to the order management system, the order information must be transferred to the downstream *model generation system*. The data to be transferred is, for example, the project number, the customer's name and the delivery date as well as the customer-individual requirements for the design adaption of the product.

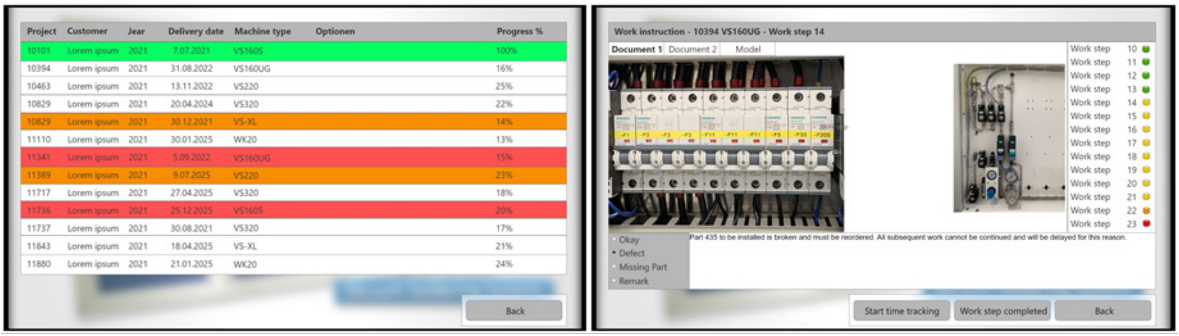
Model generation system for an order-specific production model

The *model generation system* is triggered by the incoming order data and compiles the specific product model accordingly. For this purpose, the generic model from Figure 4 is taken and compared with the customer-specific product configuration and documents. Depending on the configuration, the general work sequences are now replaced with the specific work steps, and the specific production model for the customer order is generated. According to the customer order, the specific process model for the customer order can be composed of, for example, the housing type 1 with individual adjustments for increased stability (due to the increased risk of earthquakes in the customer's region), the laser type 2 and no fan. The process model created in this way is based on existing product variants but personalized by the customer-specific adjustments. The modelled individual work step descriptions contain all the necessary information to manufacture the product. In addition, the worker on the shop floor is able to save his work progress, any problems that arises or suggestions for improvement in the model for future considerations.

The requirements summarized in Figure 2 are expected to be fulfilled by the presented approach, which is currently under development. By the modular structure of the model, the effort to generate a customized model as well as the model maintenance and adaptation of existing model parts can be reduced to a minimum. This allows for quick creations of customer offers as well as for fast and coordinated reactions to short-term changes. Furthermore, new technologies can be easily mapped in the model and it is not necessary to adapt each individual model, but only the corresponding model parts. Hence, a high changeability of the model is ensured, which is especially valuable for the implementation of subsequent changes. Likewise, various data sources can be connected to support the worker with the necessary information, for example construction drawings. The model also offers the possibility to store work step related information. This makes it possible to document each individual work step. These two factors contribute to the agile implementation and tracking of short- and long-term changes to customer orders.

5. Application

The demonstrator currently consists of an early prototype in the form of a mock-up, which was initially validated with budatec. The model, whose automated creation is presented above, serves as the data basis. Figure 5a shows a general overview of all customer projects. With this, the responsible employees can quickly read the most relevant information related to an order, such as the project number, delivery date and the product to be manufactured as well as the work progress. For a better overview, completed projects are highlighted in green, whereas orange and red markings represent problematic projects.



a. b.

Figure 5 Mock-up of the early prototype based on a customer-specific process model

After having selected a specific project, the view shown in Figure 5b is displayed to the user. In the upper part of the screen, the order number and the product to be manufactured for this order are displayed. Detailed work instruction and design drawings can be displayed below via different tabs. On the right, the work progress and the following work steps are illustrated. In the lower area, the worker can evaluate the current work step and store additional information. In order to determine the exact duration of a work step, the worker must define the start and the end of production as well as any interruptions. The entered information is returned to the specific production model for the customer order. Afterwards, this information can be evaluated and used as a planning basis for creating new customer offers quickly and reliably in the future.

6. Summary and outlook

To establish itself in a turbulent business environment, an SME must be able to create alternative courses of actions quickly and in a target manner. However, short-term changes before and after order entry lead to significant difficulties in shop floor management. This paper derives the requirements for an agile shop floor management system from the challenges of an SME in the Chinese market and presents an approach for model-based process generation to reach these requirements. On the basis of the presented mock-up, the relevant information to be displayed on the user interface needs to be identified in the next MAP project phase as well as the corresponding data sources. Subsequently, the data needs to be imported into the process model and the user interface itself must be designed in a way that it serves as a role-based assistance system for the project manager, warehouse manager, worker and commissioner. Further considerations of the application partner include the usage of augmented reality (AR) glasses for a better and seamless display of information. Lastly, the system is planned to be validated based on a demonstrator at the application partner's site. In order to react quickly, short- and long-term changes (including for example travel restrictions, trade barriers and port shutdowns) must be identified at an early stage. For this purpose, further research will be needed in the framework of the MAP project in order to develop a methodology for classifying and evaluating influence factors as a basis for a corporate environment monitoring system.

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Biography

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