

Ramp-Up-Management in Additive Manufacturing – Technology Integration in existing Business Processes

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Abstract

In conventional manufacturing, ramp-up-management describes the planning and organization of the period between finished product development and the achievement of full production capacity for defined products. This classification has to be adapted and restructured by means of product independent and tool-free production in additive manufacturing. Therefore ramp-up-management already starts with decisions on the extent of the use of additive manufacturing, includes the building of technology-know-how as well as the technology integration into processes and infrastructure of the company and ends with the attainment of a sufficient process reliability for the AM-machine. This paper focuses on technology integration in processes and infrastructure, which is part of the German research project OptiAMix. In this project, new systems for process state analysis adapted to additive manufacturing and methods for the optimal integration of additive manufacturing are developed. Furthermore ways of using the synergies of existing infrastructures and new innovative production technologies are determined.

Introduction

Additive manufacturing (AM) is increasingly changing from rapid prototyping to direct manufacturing and is thus becoming a serious technology. The correct use of the technology can decide on competitiveness and the economic survival of a company depending on the industry and business field. The high flexibility in production, the possibilities for the implementation of a large product variety with few adjustments as well as product individualization is perceived by almost all companies as an opportunity for the competitiveness of their own businesses. Nevertheless, small and medium-sized enterprises (SMEs) hesitate to invest in the relatively young technology. But why does the integration of AM fail so often? In a survey conducted by the PricewaterhouseCoopers AG [PwC14] of more than 100 companies, more than 30% mentioned the "uncertainty about the quality of the end products", "lack of expertise in the company" and high investment costs as barriers. Answers, which were mentioned more frequently in the beginning (for example "missing application possibilities" or "low speed") are taking a backseat because of the rapid technology advancement. The survey by PricewaterhouseCoopers shows that hurdles have to be overcome, before the technology can be integrated into most companies. Both the uncertainty about the quality of the end products as well as the lack of expertise show a key problem on the way from AM to industrial application. Employees with many years of expertise in conventional production processes face a completely new technology with completely different manufacturing restrictions. New employees with existing expertise in AM are hard to find, as AM has not yet found the way to non-academic vocational training [Ric15]. There is a lack of existing and on the labor market available know-how with regard to the design process as well as to the handling with new value creation concepts. In particular, SMEs cannot make a sound assessment of whether the

additive implementation of existing products is economically and technically feasible. A further mentioned problem are the high machine costs. Investment costs of more than € 1 million [Woh15] represent a high risk for medium-sized companies. Possibilities to manufacture parts without their own AM system are given by AM service providers. However, external production is not useful for every product. AM service providers are able to handle individual orders or small series. If, however, the production capacity reaches the capacity limits of the service provider, in-house production becomes necessary. To minimize the risks, targeted technology integration is crucial, but the current lack of expertise is countering the integration.

Ramp-Up Management for conventional manufacturing

In case of conventional production processes, the series start-up describes “the period between completed product development and full capacity” [SSS08]. Thus ramp-up management can be defined as the planning and organization of the realization process from the prototype to the serial production of a new product. It is based on the finished product development and includes all decisions to be made on the way to series production. Depending on the type of organization and the final production volume, the phase can include pre-series, zero series and the production ramp-up [SSS08].



Figure 1: Integrated ramp-up management model

The integrated ramp-up management model (Figure 1), which covers the most important areas of ramp-up management, has proven itself in science and practice. It covers the areas of supplier, logistics, production, change and cost management as well as their correlation with suppliers, internal business units and customers. The areas are covered by the ramp-up organization as well as the ramp-up strategy [SSS08].

Ramp-Up Strategy

For companies with a wide product portfolio, a general ramp-up strategy is an elementary part of ramp-up management. The ramp-up strategy defines the overall strategic alignment of the company in the long term for all production ramp-ups and coordinates the different activities involved in the implementation of the individual ramp-ups [SSS08].

Ramp-Up Organization

The ramp-up organization includes the planning and organization of the interdisciplinary cooperation at the start of a new production and prevents efficiency losses at the interfaces between the functional areas (supplier, logistics, production management, etc.). This also affects

organizational concepts for ramp-up management as well as their embedding into existing organizational structures [SSS08].

Supplier Management

Suppliers can be an increased risk for the economic success, particularly in the ramp-up phase, since many parts of the product also go through a ramp-up phase, which multiplies the risks. In order not to endanger the own ramp-up processes due to failing suppliers, success-critical suppliers must be identified at an early stage and integrated into the processes of the manufacturer in order to bring the product and process together to the desired level of maturity [SSS08]. The tasks of supplier management are the early integration of selected suppliers for the common ramp-up of the product. In addition to the inter-departmental support of suppliers and the joint development of the products [Wit06], the development of the supplier is particularly important for the reduction of the ramp-up time and costs as well as the improvement of the quality [Wag02].

Logistics Management

A successful ramp-up management requires the implementation of integrative logistics concepts to avoid production problems before the start of production [Wit06]. In particular, the focus is on securing the material flow from the suppliers to the production plant as well as the reduction of internally logistics interruptions between the unloading point and the assembly site [Fit06] [Kir06]. Holistic logistics concepts enable the identification of sources of interference early on by means of a collaborative process, resource and area planning [Stö99]. As a result of this increase in planning quality, which can be generated by the use of integrated information systems, disturbances as well as inefficiencies (e.g. cost-intensive special transports) are reduced. This again has a positive effect on the ramp-up performance [SSS08].

Production Management

In production management, the standardization of production to achieve the reduction of complexity is very important with regard to the ramp-up time. The difficulties associated with a series start-up are essentially influenced by the degree of novelty of the processes and the production resources. In order to make this transparent and manageable, a systematic release management is required for production. If, for example, different product types or equipment variants start in separate packages in a staggered manner, the complexity of the logistics system and the embedded supply chains are successively reduced. The result is a reduction of time- and cost-intensive ramp-up faults [SKF05] [ScFr04] [SSS08].

Change Management

In conventional production processes, even the smallest changes lead to far-reaching follow-up processes and thus to considerable cost increases. In order to solve this problem, during the ramp-up phase, a cross-functional and company-wide planning for the reduction of technical changes must be provided. In this case, the need and the timing of change projects must be discussed and decided. The common set-up of standardized change processes and their implementation in the company provide the basis for short processing and lead times as responsibilities and sequences are defined in advance [Fit06] [SSS08].

Costs Management

The costs of the ramp-up phase must be controlled by means of costs management. The target variables time, quality and costs are the focus for the controlling of ramp-ups [Bla98]. On the cost side, the costs for the ramp-up (tool costs, training etc.) and, on the other hand, the follow-up costs

in the series (error costs, change costs etc.) must be minimized. There is often already a trade-off between ramp-up and follow-up costs within the cost dimension. For example, prevention costs during start-up reduce the costs for test and error elimination in the series. The corresponding target- and future-oriented valuation and control activities are the subject of costs management during start-up [SSS08].

Core characteristics of additive manufacturing - why the approach in start-up management has to change

Contrary to most conventional production processes (subtractive and formative), the desired geometries are created by the addition of volume elements in AM [Geb13]. Thus, a tool-free production is achieved, which in turn enables the manufacture of various components on a single machine, without costly adjustments to the system. However, it is not only possible to manufacture different components on one system. Also, the production of several different components during a single production process or even pre-assembled assemblies are possible with AM [EOS16-ol]. However, the possibility of flexible, tool-free production does not only provide advantages but also challenges. The AM is mostly used in small batches or for individually adapted components. Larger series, whose production would lead to 100% machine capacity utilization, is not economically viable in most cases. As a result, a manufacturer not only has the advantage of flexible production, he also needs a product portfolio that enables him to achieve this flexible production. Only in this way an economic success can be achieved with AM. At the same time, the requirement for a flexible production also ensures that ramp-up management needs to be built up considerably more flexible. The buildup of a production for a single component or product must give way to a ramp-up management for the technology itself and subsequently for different products and a flexible ramp-up concept.

Ramp-Up Management for additive manufacturing

In conventional production, ramp-up management is formed by the core areas of supplier, logistics, production, change and costs management. These are aimed at the goal of bringing a product to series production and thus to realize the business objectives in the market. However, this approach can no longer be pursued consistently in AM since a single AM machine is used for the production of various components and products and should therefore be integrated very flexibly into the company. In the OptiAMix research project, the integrated ramp-up management model was therefore extended to an integrated AM ramp-up management model. Looking at the five core areas of conventional ramp-up management, one can differentiate between technology-related and product-specific goals. Logistics, production and change management depend strongly on the product and can only be taken into account after the integration of the technology into company. Supplier and cost management, on the other hand, include both product and technology related tasks. A reorganization of ramp-up management is therefore useful for AM and additional technology-related tasks must be considered, as shown in the following figure.

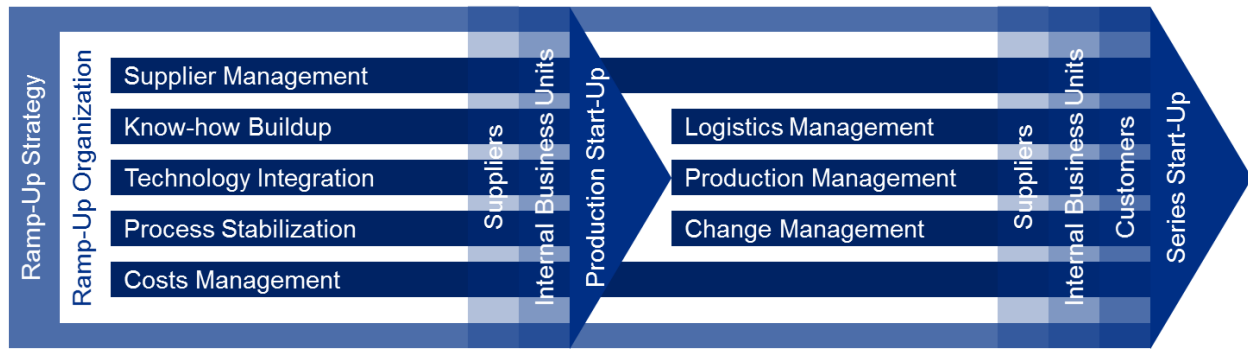


Figure 2: Integrated ramp-up management model for additive manufacturing

Figure 2 shows the rearrangement of the ramp-up management for AM in two successive sections. The target of these two sections is the production start-up as well as the final series start-up. The areas of logistics, production and change are integrated into the series start-up phase, while supplier and costs management remain as core elements throughout the entire ramp-up. In addition, ramp-up management extends to the start of production by the new AM-specific areas of know-how buildup, technology integration and process stabilization. There are also changes to the involved stakeholders - there is no customer contact in the first phase until production start, since no product has yet been defined.

As the AM ramp-up management up to the start of production is focused in the OptiAMix project, the modified and new core elements will be discussed again in the following. The requirements for supplier management are significantly reduced up to the start of production and also as a whole in AM. Subcontracts are mostly restricted to raw materials and spare parts for the AM machines. In addition, on industrially used AM machines, usually only one or at best very few materials are used in order to avoid protracted changeover times of the machines in which the production is stopped. On the other hand, particularly in the beginning of the use of a new technology, which, like AM, is still relatively young, there is an increased demand for spare parts, which must now be given special attention in supplier management in order to comply with the set schedule. Costs management remains very similar to that of the conventional ramp-up, the targets are still time, quality and costs. New tasks are mainly due to the more time-intensive new areas of know-how buildup, technology integration and process stabilization, which must also be taken into account in the controlling department. In the core area of process stabilization, test plans are to be developed, which should lead to the optimum set-up of the own AM machine with the lowest possible sample and build-job number. The test bodies and methods are the same as those of the conventional production (for example, tension rods), but must be transferred to the parameter setting of the systems.

Building expertise within the company

Particularly in the coming years, the know-how buildup will be a major component of ramp-up in AM. There is still no fully-defined vocational training program for mechanics in AM. Only at the end of this year the German Chamber of Industry and Commerce (IHK) will start with the apprenticeship for a certified industrial engineer with the subject of AM. But even this provides no complete three-year vocational training as usual in Germany [SKZ17-ol]. As a result, companies can only make use of trained experts from the universities when recruiting new employees. However, these can be over-qualified for tasks such as machine control and thus be too expensive. SMEs need an exact concept to save unnecessary costs during ramp-up in particular.

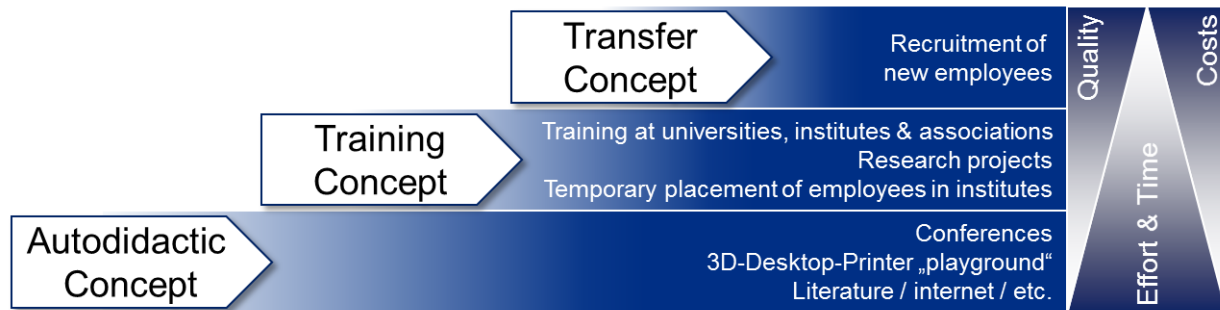


Figure 3: Three levels of know-how transfer into the companies

Figure 3 shows the three concepts and levels of know-how buildup identified OptiAMix and currently available to companies. As with any training subject, the simplest and cheapest way to learn about the technology is the autodidactic way. The World Wide Web, technical literature and conferences provide sources of information for this purpose. Regarding AM it is also possible to build up know-how by the use of “try and error”. With many devices cheaper than \$ 3,500 and materials cheaper than \$ 30, the technology allows a relatively cheap way for a quick buildup of experience with short-term learning and development success, and gives employees fast access to technology in general. The advantage of an autodidactic learning of the technology are the very low costs, however the company is dependent on the intrinsic motivation of the employees, the learning effect is very lengthy and due to the lack of control a sufficient and internally comparable know-how level cannot be guaranteed. This is different in the know-how buildup by the use of training programs for employees. In this concept the know-how buildup can again be achieved in three different ways. The easiest and fastest way of expertise buildup is to train employees in programs and workshops at universities, at institutes or at associations [DMRC17-ol]. However, since these are usually carried out as day-by-day or one-week events, they only can be used either to create a basic knowledge for a larger group or to acquire special knowledge for already trained employees. In order to train individual employees in the technology as a whole, companies should rather rely on research projects or the temporary placement of their own employees at research institutes. Research projects enable a foreign-funded examination of the technology as well as the exchange with experts from universities and institutes. However, the proposal process as well as the mostly applied research period of several years are relatively lengthy and uncertain. The temporary placement of employees in research institutes, on the other hand, can be significantly better planned and limited in time. This has the advantage that employees will gain a general knowledge about the technology as well as a very specific knowledge, as they will already use the technology in everyday work. Also a networking of the company and the research institute can arise. One disadvantage is that the number of research institutes is limited and not every research institute is willing to share know-how with companies. In order to increase the know-how level within the company and in a very short time, the recruitment of university graduates from the field of AM is necessary. However, the time savings may lead to a low acceptance of their own employees as well as high costs, especially as long as the additive production is not firmly anchored in vocational training courses, and the number of trained specialists is very low.

In order to make the right decision, which know-how buildup concept or which concept combination best suits one’s own company, close coordination with cost management is necessary. The approaches each have strongly correlated strengths and weaknesses in the target variables time, quality and costs. Thus, the weighting and focus should already be defined by the cost management

and a clear recommendation on how to build up know-how should be provided by the controlling department.

Technology integration into existing business processes

In the research project OptiAMix, an approach was developed to elaborate an optimal company-specific product development process (PDP) integration. In the case of the general approach model, the different starting situations of the participating research partners resulted in a separation of the approach after partial completed AM-integration and no integration of the technology at all into the company. The partial integration can be, for example, the previous production through AM service providers.

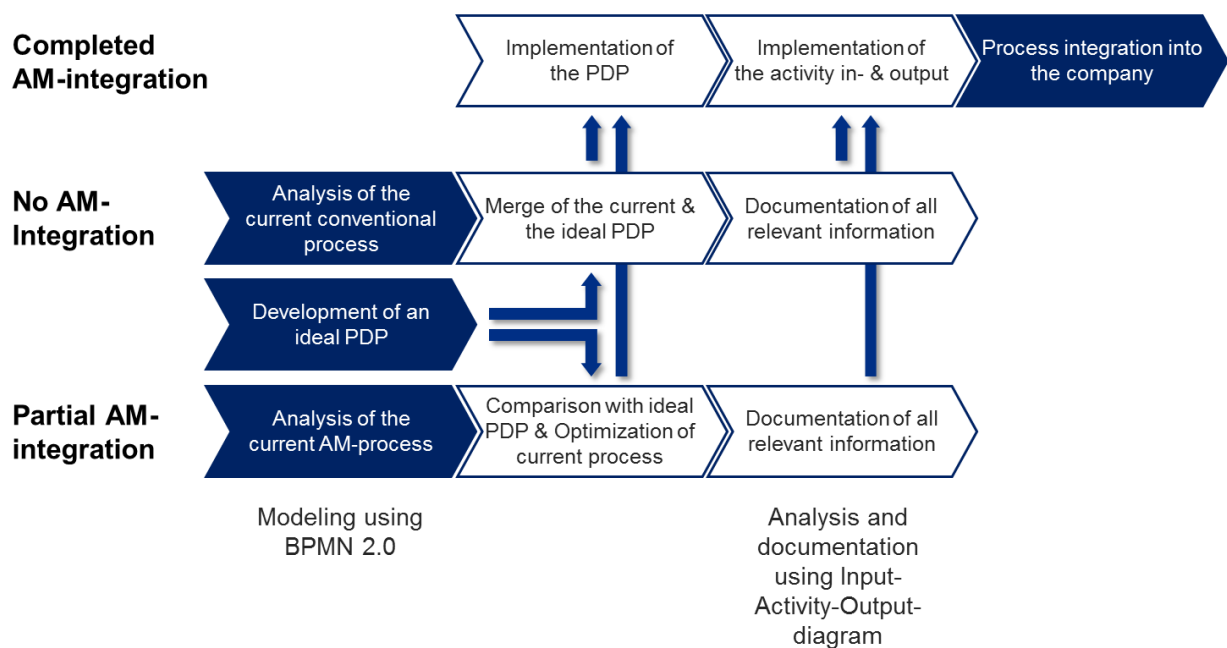


Figure 4: Procedure model for technology integration

Analysis of the current product development process

Figure 4 shows the approach to technology integration in four steps. First of all, the current PDPs have to be analyzed in the company. For this purpose, the company should address the two use cases of the general PDP as well as a real PDP with the example of a single product. The general PDP helps in the development of a clear process sequence while the real PDP helps in the determination of possible problems as well as of frequently occurring deviations from the ideal procedure. Depending on the initial situation, the analysis can also be carried out with reference to conventional manufacturing but also with respect to already performed AM components. In a second step the real and the ideal PDP have to be compared and merged or optimized. Since the actual integration of the new technology into the existing processes in the company is carried out in this step, the main attention within the procedure model should be given to this step. Existing processes, which are compatible with the processes of the AM product development, should be strengthened with regard to good acceptance by the employees and all further steps should be adapted by partial process parallelism or if possible by optimizing the existing processes. The result of this step is a new PDP optimized for AM. The installation of the new PDP is followed by the

clarification of all process inputs and outputs as well as their documentation. Based on this, flowcharts and checklists can be developed for a standardized implementation of the PDP. In the project, the modeling language BPMN 2.0 was chosen for the analysis and documentation of the PDP, since, on the one hand, the modeling language has established itself as a state of the art in the last few years, and on the other hand the formal process grammar prevents serious differences between the respective processors in the analysis of the processes [GöLi13]. In addition, an extension of the BPMN for the classification of information paths was introduced in the project. These connections between the individual processes were marked in color to ensure a distinction between material transport (e.g. the path of the component from the machine to the post processing), quantitative information (e.g. measurement for post processing) and qualitative information (e.g. positioning recommendation for several components on a construction platform). This allows companies to access checklists (quantitative information) or work plans (qualitative information) already in the ramp-up phase until the process is completely integrated and internalized by the employees. The result of this analysis at the partners is a partially highly complex process map, like shown in a reduced size in the following figure.

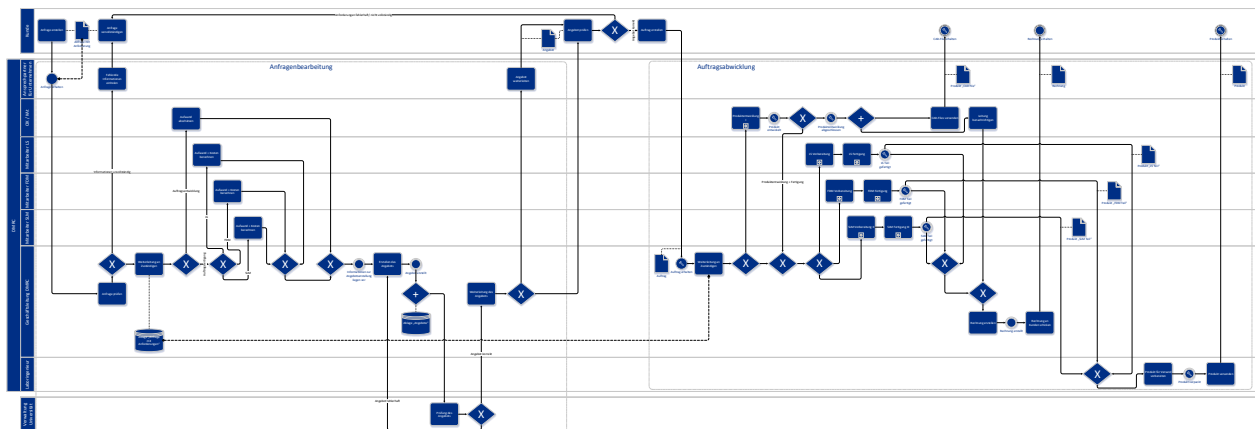


Figure 5: Real AM-PDP

Already during the analysis of the current processes at the research partners, the processing staff recognized problems as well as inefficient procedures, which as an additional success also led to a critical discussion and therefore to a further know-how development.

Development of an ideal AM product development process

At the same time as the analysis of the current PDPs at the project partners the development of an ideal AM PDP was carried out at the DMRC. This process, also developed by means of BPMN 2.0, is based in particular on literature analyzes and the long-standing experience of the institute's staff, who have been able to bring various perspectives in the development through various disciplines of the different chairs of the university. For this purpose, commonly known and well-established process models from various disciplines, such as the VDI 2221 [VDI2221] from the conventional product design, the V-model according to Barry Boehm [Boe81] for software engineering or the DIN 66001 [DIN66001] for program flow charts.

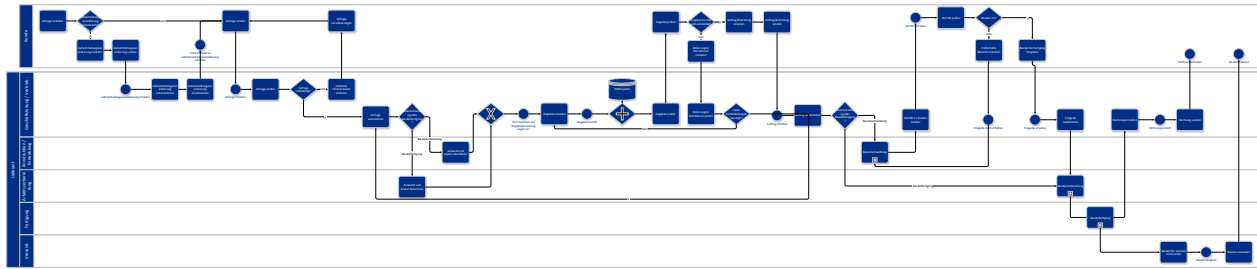


Figure 6: Ideal AM-PDP

The result of the development is the process shown in Figure 6. Already through the overview of real (Figure 5) and ideal (Figure 6) process a clear difference can be seen. The number of process steps, stakeholders and branches are clearly reduced and more structured in the ideal process. However, the comparison of target values and actual values in the real process, which is very important in the PDP, is also strongly reduced, since an error-free procedure is assumed in the ideal process, which cannot be implemented in reality.

Merge of the processes & Definition and documentation of the activity information

By analyzing the current processes and the elaboration of an ideal AM-PDP, companies must carry out the combination or matching of the two overall processes depending on the initial situation. First, a reduction should be made to superordinate processes (e.g., topology optimization as a parent process). The individual activities of the reduced processes have then to be compared with those of the ideal AM-PDP in the case of partial integration (for example, production via a service provider) and the current process must be optimized. A compromise between the best possible level of integration and the acceptance of the employees is to be made. The closer the new process is to the existing procedures, the easier it is for the employees to handle the new technology, but this also includes the danger of failures in the new process. If AM is not integrated at all, the integration of the AM-PDP is carried out without previous adjustment, however the existing processes must be strongly considered again to reach a high level of acceptance. With the merging and optimization of the processes, all individual activities of the overall process are then analyzed. In an input-activity-output diagram, the required input as well as outgoing output are defined for each activity. In the OptiAMix project, a division into material, quantitative and qualitative input and output, based on the color separation of the information paths, will be carried out. Ultimately, input and output in the ramp-up phase are then used to create checklists and work plans, which can be matched and optimized with the real process as the development took place after completion of the product development. Thus, an important self-learning effect of the PDP already takes place up to the ramp-up phase.

Conclusion & Outlook

The integrated ramp-up management model, adapted to AM, shows a considerable increase of effort in the start-up of a production for the years up to the complete establishment of the technology. The buildup of know-how will be an obstacle to the integration of the technology, especially for SMEs, until non-academic vocational training courses are firmly embedded in the everyday work. Furthermore, the ramp-up management for AM requires a controlled technology integration in order to maintain the advantages of the flexibility of the technology while at the same time increasing the acceptance in the company. The project OptiAMix has already gained important insights into these challenges. Approach models for the development of know-how as well as for

the integration of technology have been fully developed and are ready for use. However, the developed methods and procedural models are to be evaluated in the coming years within the project as well as in the general application in detail. Adaptations to the approach model for additive start-up management as well as know-how design and technology integration are possible. In connection to a full evaluation, a general approach to the integration of new technologies will be provided to the business world, and in particular to SMEs.

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