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Integrated Product and Process Development: Modular Production Architectures Based on Process Requirements.

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Abstract

Due to cost pressure, shortened development cycles as well as increasing variety and technical product complexity companies face more complex parallel development processes. Especially during ramp-up this leads to huge difficulties regarding the management and coordination of the departments involved across company and supply chain. To overcome these difficulties and to cut down timelines for development Modular Production Architectures (MPA) have shown evidence to be a useful management-tool during ramp-up. The implementation of this three step methodology is the main subject of this paper.

At first a range of product types and general processes are determined for which the MPA should be relevant. In addition, the relevant processes with potential requirements to product design need to be identified. As a second step, the ideal production process is identified by investigating process alternatives for the MPAs' range company-wide. All current production processes and equivalent alternatives are evaluated through expert interviews and assessed by their capabilities and standardization potentials. Thirdly, for each best-practice sub-process boundary conditions of process parameters are identified and transferred into product design requirements.

By implementing this approach companies are enabled to ramp-up new products in less time with lower costs due to an effective management-support of the MPA-process.

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*Keyword:*Lean Ramp-up; Standardization; Modularization; Modular Product Architecture;

1. Introduction

1.1. Motivation

Today's industry is challenged by several trends. Product variety and technical product complexity increase due to changing customer needs. These trends result in what is known as "the dilemma of scale and scope" [e.g. 1]. On top of that, there is another trend that challenges industry: Product life cycles shorten while more product types of growing technical complexity come to market [2]. Along with this, the available time-frames for ramp-up phases need to be reduced. [3] Consequently, due to many products, which come to market at different times, manufacturing industry faces a situation of permanent ramp-ups. Ramp-up describes the phase between finished product development and serial production. [4] Some of the main effects of permanent ramp-ups are parallel product and process development along the supply-chain (simultaneous engineering), iterative loops and rising difficulties due to design changes close to start of production. [5] These problems need to be addressed to cut down ramp-up costs and efforts.

As research published by HENDRICKS AND SINGHAL indicates there can be negative effects of delays during product introduction on profitability. Thus, potential risks which affect the scheduled start of production should be reduced. [6] Due to the mentioned trends development and ramp-up processes get more complex what in turn leads to more and more complex coordination among internal and external partners. [7]

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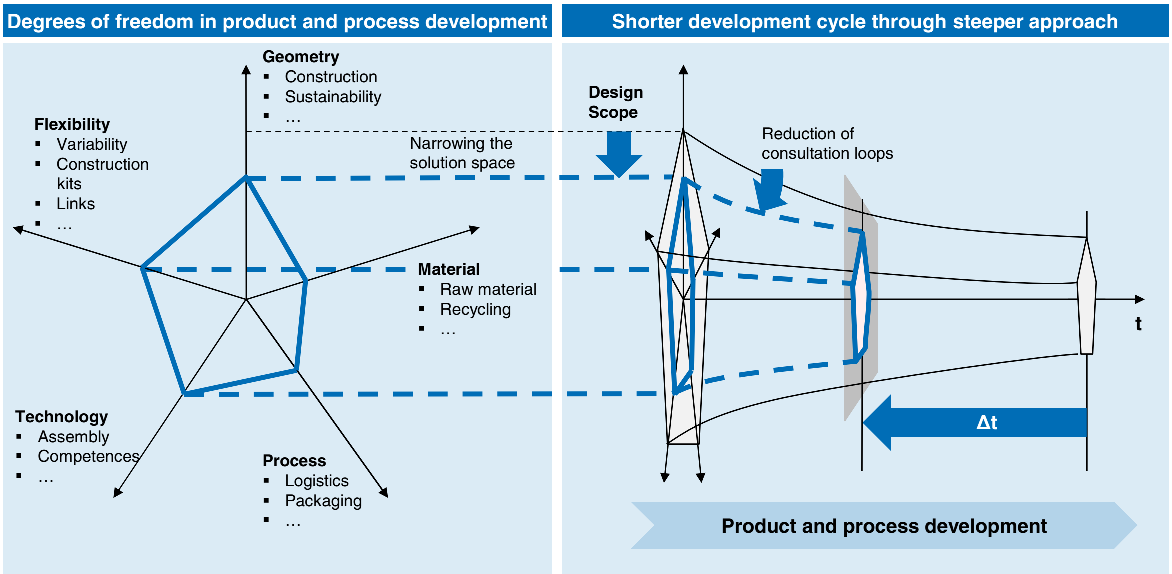

Fig. 1: Time-to-market benefits due to standardization

To deal with these challenges in a highly dynamic and interdependent ramp-up environment a well-worn path is standardization by modular product architectures. Examples can be found in the automotive sector as well as in the field of consumer electronics e.g.

This paper presents a process-driven methodology capable of handling complex relations between product and process development. Our methodology aims to enable producing companies to implement lean ramp-up processes. Lean ramp-up describes the transformation of the lean principles from production to the ramp-up. The adoption of those principles allows companies to create more value with less effort at an elementary stage of the product development process. [8]

This approach deals with the question how well-known expertise in production technologies can influence product design at an early stage. The solution we find bases on the idea of process standardization and management of process requirements and restrictions. As shown in fig. 1 a relatively small reduction of the boundaries of design scope at an early stage of product development allows a significant reduction of the time to market. For example, it might be useful to restrict product dimensions to reuse machining equipment–positive effects include reduction of costs for new equipment and more important a steeper ramp-up learning curve. Therefore it is important to identify, quantify and determine all relevant restrictions of the product and process characteristics. This leads to the possibility of process standardization of the product development processes which is the basis of the methodology described in the following paper.

1.2. Structure

As it will be shown in section 2, some research has been carried out in the field of integrated product- and process development. Although, among other unsolved questions there is no answer given why there is still a gap between theoretical concepts and practical application. Section 3 presents a methodology to overcome difficulties arising from the trends described above towards a process driven ramp-up. Additionally our methodology is detailed using an example from the WZLs' industry experience.

2. Literature background

For more than a decade standardization of product components has been one of the major tools to reduce product complexity. [9] Some of the prominent examples include product construction kits and product architecture standards. [10] Although there is a wide practical appliance of these concepts, consistent definitions can hardly be found. The general basis of standardization concepts is founded upon modular systems. There are some general definitions including ARNOSCHT who suggests a definition for a modular system: "Modular systems are based on modules which can either be assemblies or components. Defining standardized links enables a modular system to create various combinations and to create product variants. "[11]

Following ARNOSCHT modular product architecture is only one potential form of a modular system. But it is by far the most popular one as the number of available literature may suggest. While definitions given by most authors may vary to some extent, a common core includes the aspect that modularization can be described as the decomposition of a product into modules along defined links. [11,12,13,14,15,16]

As shown in various contributions standardization in form of modular structures, systems or architectures is one possible approach towards a higher level of efficiency and a more profitable economic base with lower costs per output. [17,18,19] A standardization approach in general requires detailed information of the processes and thus the process of collecting the relevant data itself reduces complexity because of risen transparency. [16,20,21]

Problems regarding process standardization arise from the limited flexibility towards change and innovation. [22] On the one hand, as long as modular product architectures have been implemented, the need for flexibility of the production system is generally lower than in an environment without modular products. On the other hand some flexibility should be maintained to enable the production system to integrate product and process innovations. [23]

Several works indicate that standardization of products in terms of modular architectures and assembly systems should precede the standardization of processes. The standardization of process then can be subdivided into standardization of the actual operation and standardization of the sequence. [24,25]

SCHUH identifies certain levels of standardization. A high level of standardization implicates a corresponding level of process variance reduction and is consequently one key driver towards reduction of complexity. [22] Along with complexity within companies goes time and cost pressure because of the high level of relations and interdependences that have to be taken into account during development processes of product and production processes. Following GRÜNEWALD one way to overcome these challenges and to enable an efficient R&D process is to adapt qualified solutions from a certain set of competences and standards. [26]

Another approach to tackle standardization within companies presented by several authors are process construction kits. A process construction kit describes the modularization of a production process into modules. [27,28,29] These modules represent sub-processes with individual process chains. Each of these modules is defined by precise input and output information as well as classification criteria. [28] These information allow an exact definition of the links between the modules which enables companies to configure the modules to suit their needs. Therefore the modules are often set up in a process library that is a knowledge-management tool and a database of process know-how. [27,29]

Although all approaches presented show some impact to reduce the difficulties arising from permanent ramp-up situations, there is still a deficit that has to be challenged. This deficit is located within the range of product and process standardization. More accurately, a combination of these two approaches has not yet been presented. The presented MPA approach contributes to close this gap in literature with a concept that allows adjusting the design of products with process know-how at an early stage.

3. Modular Production Architectures

The applied and introduced methodology is based on requirements derived from restrictions of the production process. We present a three step approach to gain knowledge about process restrictions, derive a Modular Production Architecture (MPA) from these information and implement this approach across company departments. This methodology aims to shorten timelines for technology and process planning and to cut down the need for consultation loops between R&D and planning departments by using process standardization. Thus, the methodology enables an effective and efficient process ramp-up meeting time, cost and quality targets. In addition cooperation between the involved departments is increased and improved as the methodology creates process transparency and awareness.

Step 1: Determining product and process types

Firstly, a range of product types and general processes are determined for which the MPA should be relevant. Generally, the wider a range of products and processes taken into account is, the bigger the impact of a MPA approach will be. Vice versa an approach too narrow can lead to little impact as already little changes to the product concept would make the existing MPA irrelevant and generate no significant benefit of the standardization. For example an automotive supplier could aim to set up a MPA for drive train shafts. During this first phase the company needs to define the range of the MPA. It could be limited to hollow designs and a certain specified range in diameter.

Furthermore, the relevant process steps of the MPA should be defined. Sticking to the example, for a hollow shaft a MPA could be restricted by the processes between distributions of semi-finished products to the finishing processes of the shaft surface, which could be covered by an individual MPA. These restrictions enable companies to set up MPAs each valid for certain scopes of standardization. A turning process, e.g., might need a more specific restriction because of diameter limitations of the existing lathes, whereas a surface finishing process might be more flexible towards shaft diameters. Separate consideration in separate MPA assures that each MPA covers as many product types as possible.

Furthermore the relevant processes with potential requirements to product design need to be identified. These relevant processes go beyond the range of the MPA and cover all processes the component is exposed to during product lifetime. This means that beyond assembly processes also service aspects e.g. are taken into consideration. It is important to note that – although processes and components may vary across a wide range – a number of general links between product and processes can be identified. These general links are equivalent to general requirement categories towards the component to be addressed. We suggest the following categories, which can be used as potential classes of requirements to start off with. But anyhow they should be adapted individually to company and component requirements:

- Affiliation: Examples include requirements such as defined areas for handling equipment and definition of minimal handling forces of the machinery.
- Alignment: Requirements of this category are derived from information about the alignment forces and alignment processes.
- Fixation/ Links: In this category all links between machinery equipment and work piece are defined.
- Service/ Rework: Service-requirements cover accessibility and dismantling issues.
- Logistics/ Handling/ Packaging: Logistic aspects include requirements to the packaging concept. For example certain standard sizes for containers and boxes could be part of this category if relevant.
- Ergonomics: Requirements of this category include accessibility of screws and maximum clip forces.
- Production concept: This category contains product restrictions derived from conceptual aspects, such as process sequence.

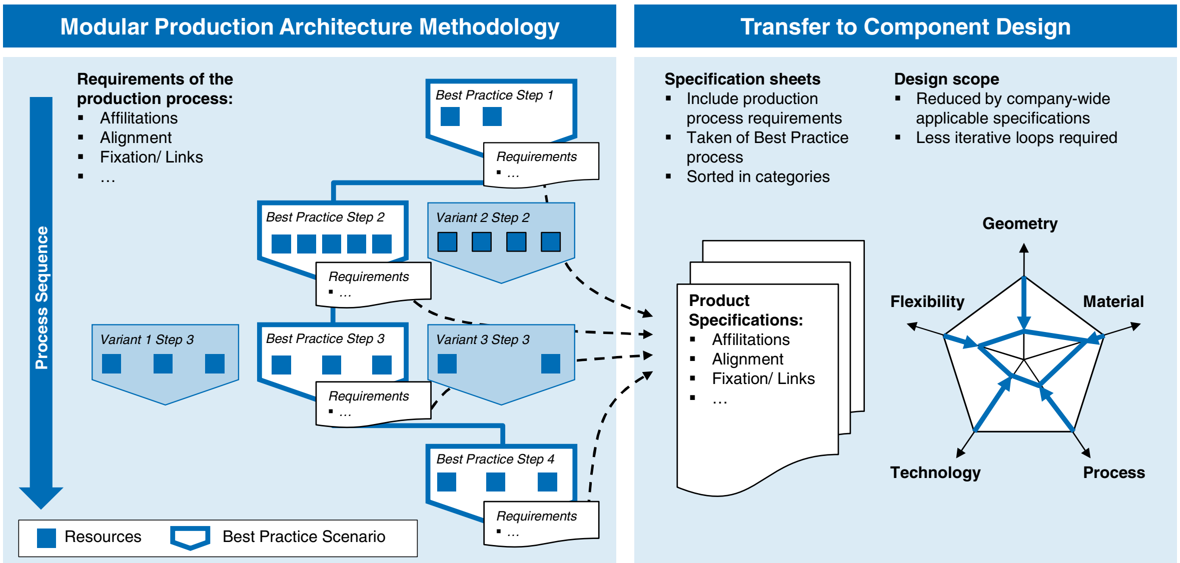

Fig. 2: MPA transfers Best Practice to Component Design in order to reduce Time-to-Market

- Tools and Machinery: This category contains all aspects derived from the available machinery, maximum product dimensions e.g.
- Process Data: In most cases these data represent restrictions the product has to withstand during the process, such as minimal machining forces or temperature curves.
- Quality & Safety: This category contains quality aspects like tolerances and safety restrictions such as high voltage limitations.

Because products and processes vary between companies these categories should be adapted carefully. More important than the specific categories of requirements themselves is the bottom principle. The categories represent linkages between process and product. They help to implement the MPA concept because all different sorts of aspects of these categories are reflected and can be transferred to product design.

Step 2: Identifying best-practice

Secondly, the ideal production process is identified by investigating process alternatives for the MPA process range company-wide. All current production processes and equivalent alternatives identified are evaluated as shown in the left part of fig. 2. This means that all equivalent alternatives have to be compared during expert interviews. Following this, the alternatives have to be assessed by their capabilities and standardization potentials. During this step each process alternative of the production system is investigated questioning whether the specific sub-process is able to part of the best-practice process. This approach requires detailed knowledge and good experience about the processes in use and is therefore mainly applicable where incremental product innovations meet broad process experiences. On the other hand, especially with disruptive innovations this knowledge often does not exist or is being built up concurrently. In this case valuable information can be gained via benchmarking across competitors. A wide range of different product designs and process alternatives usually indicates an ongoing change, whereas small variety can assure confidence into the standardization purpose. Consequently, those processes with little variety regarding process design can be included into the ideal concept of the MPA – given that it is part of the production system.

Step 3: Setting product design boundary parameters

Thirdly, for each best-practice sub-process boundary conditions of process parameters are identified and transferred into product design requirements (right part of fig. 2). These product design requirements are then woven into the product component's specification sheets. When this methodology is implemented at an early stage during product and process design, the design scope of the integrated product and process development environment shown as well in fig. 2 is then reduced beneficially. This in turn leads to the positive effect on the coordination process along the supply chain especially during ramp-up as shown in fig. 1.

To maintain a high level of commitment all requirements have to be respected by all relevant departments and stakeholders. For example design requirements such as alignment forces have to be considered during dimensioning of the component by the design department. Consequently, if the component is purchased, the restriction has to be considered by engineering and purchasing departments. By pursuing this methodology, the design scope is restricted advantageously. Integration of the development and purchasing department ensures that the restrictions do not have negative effects in terms of limiting the degrees of freedom for upcoming product generations.

A solid embedding of the MPA concept on a high hierarchical level ensures that each MPA savours a sturdy commitment. However there might be situations in which a deviation from the MPA might be necessary. Therefore it is helpful to allow deviation from the MPA by a standard procedure. One possibility is to assess the alternative concept in a business-case. If the alternative concept is economically more promising it should be pursued. Otherwise the ability to transfer innovations from draft to production would be limited. During a regular follow-up of the MPA it has to be examined which of the new processes and developments have to be integrated into existing MPAs. Alternatively, new MPAs have to be developed.

Feedback from industrial experts indicates that the methodology presented is a useful tool that brings up process simplification during product and process development and ramp-up. These indications need to be verified and validated to evaluate the benefits of the presented methodology more deeply. Additionally, certain aspects should be focused during further research: On the one hand strategic implications of standardization approaches have to be clarified. At the moment it is evident that there is no general strategy as automotive companies e.g. tend to very different strategies. Volkswagen for example is integrating e-mobility components into their existing MQB-architecture. In contrast to this approach BMW is setting up an entire new e-car range with an individually designed architecture. On the other hand, the inhibition of innovation by modular production architectures has to be addressed. Also, the raise of concerns towards standardization approaches especially in an environment of disruptive innovations such as e-mobility has to be addressed.

4. Conclusion

The methodology presented in this paper contributes to overcome the growing difficulties companies face due to increasing variety, technical product complexity as well as coordination and communication effort during product development and ramp-up processes. We have identified a lack of literature regarding the coordination of process and product standardization since no methodology can be found which links process requirements to product design. The MPA approach overcomes this deficit and enables companies to reduce ramp-up time and ramp-up cost likewise. In addition we noticed and still notice a high demand for standardization and optimization of the production process. As shown above our standardization approach does not emphasize the fixation of certain process parameters but rather sets defined restrictions for these parameters. Furthermore benefits can be conceived of the know-how transfer provided by the methodology in form of significant savings which can be achieved. Especially in larger companies specification sheets with a more detailed level of process data and requirements is key to a better and more cooperative working environment.

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References

[1] Kampker, A., Schuh, G., Burggräf, P., Nowacki, C., Swist, M., 2012. Cost innovations by integrative product and production development. CIRP Annals - Manufacturing Technology 61, 431–4.

[2] van Iwaarden, J., van der Wiele, Ton, 2012. The effects of increasing product variety and shortening product life cycles on the use of quality management systems. International Journal of Quality & Reliability Management 29 (5), 470–500.

[3] Herrmann, C., Wenda, A., Bruns, H., Weinhonig, K., 2009. Ramp-up Failure Rate: Einführung einer Qualitätskennzahl für den Produktanlauf. Zeitschrift für wirtschaftlichen Fabrikbetrieb ZWF 104 (6), 454–8.

[4] Schmitt, S., Schmitt, R., 2013. Lifecycle Oriented Ramp-Up - Conception of a Quality-Oriented Process Model, in: Nee, A. Y. C, Song, B., Ong, S.-K. (Eds.), Re-engineering manufacturing for sustainability. Proceedings of the 20th CIRP International Conference on Life Cycle Engineering, Singapore 17-19 April, 2013. Springer, Singapore, New York, pp. 441–5.

[5] Scholz-Reiter, B., König, F., 2010. Entwicklung der Kernkompetenz Anlaufmanagement . Mit der Adaption von "lean" Prinzipien den "Fast Ramp-up" erreichen. Productivity Management 15 (4), 42–5.

[6] Hendricks, K.B., Singhal, V.R., 2008. The Effect of Product Introduction Delays on Operating Performance. Management Science 54 (5), 878–92.

[7] Schuh, G., Kampker, A., Gartzen, T., Wesch-Potente, C., 2010. Management of Instability by Staged Assembly Ramp-Up. 3rd CIRP Conference on Assembly Technologies and Systems,, 1–6.

[8] Dombrowski, U., Hanke, T., 2011. Lean Ramp-up: Handlungs- und Gestaltungsfelder: Von Anfang an die richtigen Dinge richtig tun. Zeitung für wirtschaftlichen Fabrikbetrieb 106 (5), 332–6.

[9] Eversheim, W., Schuh, G., 2005. Integrierte Produkt- und Prozessgestaltung, 1. Aufl ed. Springer, Berlin.

[10] Buiga, A., 2012. Investigating the Role of MQB Platform in Volkswagen Group's Strategy and Automobile Industry. International Journal of Academic Research in Business and Social Sciences 9 (2), 391–9.

[11] Arnoscht, J., 2013. Beherrschung von Komplexität bei der Gestaltung von Baukastensystemen. Apprimus Wissenschaftsverlag.

[12] Göpfert, J., 1998. Modulare Produktentwicklung, in: Franke, N., Braun, C.-F. (Eds.), Innovationsforschung und Technologiemanagement. Springer Berlin Heidelberg, pp. 139-51.

[13] Ericsson, A., Erixon, G., 1999. Controlling design variants: modular product platforms. Sme.

[14] Fixson, S.K., 2005. Product architecture assessment: a tool to link product, process, and supply chain design decisions. Journal of Operations Management 23, 345–69.

[15] Fixson, S.K., Park, J.-K., 2008. The power of integrality: Linkages between product architecture, innovation, and industry structure. Research Policy 37, 1296–316.

[16] Ulrich, K., 1995. The role of product architecture in the manufacturing firm. Research Policy 25, 419–40.

[17] Yu, J.S., Gonzalez-Zugasti. J. P., Otto, K.N., 1999. Product Architecture Definition Based Upon Customer Demands. Journal of Mechanical Design 121, 329–35.

[18] Schilling, M.A., 2000. Toward a General Modular Systems Theory and Its Application to Interfirm Product Modularity. The Academy of Management Review 25 (2), 312–34.

[19] Kohlhase, N., Birkhofer, H., 1996. Development of Modular Structures: The Prerequisite for Successful Modular Products. Journal of Engineering Design 7 (3), 279–91.

[20] Tassey, G., 2000. Standardization in technology-based markets. Research Policy 29, 587–602.

[21] Schuh, G., Potente, T., Kupke, D., Ivanescu, S., 2012. Standardization and Adaption Requirements in Production System Transplants. World Academy of Science, Engineering and Technology 70 (10), 846–52.

[22] Schuh, G., 2005. Produktkomplexität managen: Strategien-Methoden-Tools. Hanser Verlag.

[23] Scholz, R., 1995. Geschäftsprozessoptimierung. 2. Auflage, Bergisch Gladbach/Köln.

[24] Klotzbach, C., 2006. Gestaltungsmodell für den industriellen Werkzeugbau. Shaker.

[25] Schuh, G., Kuhlmann, K., Pitsch, M., Komorek, N., 2013. Digitalization as a Key Enabler for Efficient Value Creation Networks in the Tool and Die Making Industry. Proceedings of PICMET '13: Technology Management for Emerging Technologies, 1976–984.

[26] Grünewald, T., 1997. Von der Produkt-zur Prozessbetrachtung: flexible Standardisierung komplexer Auftragsabwicklungsprozesse. VDI-Verlag.

[27] Grunwald, S., 2002. Methode zur Anwendung der flexiblen integrierten Produktentwicklung und Montageplanung. Utz, Wiss., München, V.
[28] Bichlmaier, C., 2000. Methoden zur flexiblen Gestaltung von integrierten Entwicklungsprozessen. Herbert Utz Verlag.
[29] Rupprecht, C., Fünffinger, M., Knublauch, H., Rose, T., 2000. Capture and Dissemination of Experience about the Construction of Engineering Processes. CAiSE 2000, LNCS 1789, 294–308