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Approach for Matching Production Technology Capabilities with Strategic Product Requirements

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***Abstract*—In the established product development process the production is mostly not integrated in the long-term strategic product planning due to the missing product concepts. This can lead to immense manufacturing challenges or even the loss of production capability because of the lacking capabilities of the in-house production technologies. As result needed production steps are costly bought, which leads to process inflexibilities and know-how loss. Or product designs need to be adapted for internal production, which leads to long product development processes and long time-to-market. Therefore, the integration of knowledge about the capabilities of the existing production technologies in the long-term strategic product planning is essential. This way the feasibility as well as the consequences of the new product on the production system can be identified early. To do so, the future product requirements and the production capabilities need to be abstracted and balanced to allow a communication on the same detail level. Currently not much literature exists, which describes the knowledge integration of the production capabilities in the long-term strategic product planning. To compensate this deficit, this paper presents an approach for an integrated planning, which outlines the integration processes as well as the abstraction of necessary information.**

Keywords—Production Technology Capability; Product Requirement, Integrated Product Technology Planning

I. INTRODUCTION

Producing companies face an increasing competition pressure. The product life cycles shorten steadily and in contrast the numbers of product variants increase due to individual customer demands which in the end results in decreasing variant quantities [1]. In addition, the competition grows due to the rising number of companies from emerging nations which enter high-tech industries. This intensifies the pressure on companies from high-wage countries to innovate more rapidly [2], [3]. The quick identification of new technologies and their application in new products are essential factors for companies to achieve possible competitive advantages [4], [5]. Therefore the frequency of product and production planning intervals shortens enormously [6]. As consequence an effective and consistent planning is essential to achieve fast time-to-market and cost reduction.

Managing business directors, on the one hand, need to know what the future production is capable in order to set an effective business and product strategy. On the other hand, production managers require the information whether the chosen future orientation of the production system fulfills the strategic product requirements. With a synchronized planning process the feasibility as well as the consequences of a new product on the production system can be identified early. Nowadays the planning domains product, production and technology are insufficiently connected in terms of content, time management and organization [7]. The requirements of product design and the capabilities of available manufacturing technologies should be aligned stronger to gain an optimal economical combination of the capabilities: product design, technology and manufacturing [2]. The often in practice occurring problem of facing immense challenges in manufacturing due to new future products should be eliminated. Besides lacking production capacities the biggest problem is lacking production capability. If the current and future capabilities of the existing in-house technologies are not capable of manufacturing the new product, new and therefore unknown technologies are needed to allow production. At this point costly technology screening and testing is necessary and a delayed time-to-market is possible. Likewise adapting the product concept to meet the production capabilities at this late downstream product planning phase is time consuming and costly as well. Therefore an early upstream information exchange between product concept planning and production planning is needed to gain an economical producible product. Product and production technologies should be developed in interplay from the beginning [8]. In addition, goal of the production should be to provide potential solution options to product development even before a product concept exists. This way production readiness can be obtained faster due to knowledge advance. This advance of production needs to be obtained in deriving the product and technology strategy correctly in order to make conclusions of possible future product requirements.

The business performance depends on the manufacturing performance, cf. [4]. The "business strategy has to be based on the manufacturing and technology capabilities and competencies" [4]. The strategy system as top level of the planning hierarchy needs to align the business, manufacturing and technology strategy. In addition, the strategy system of a company needs to be consistent or to fit in order to achieve competitive advantages [9]. This means that the strategies need to be effective and suitable. Consistency can be achieved when the several company strategies e.g. business, technology and manufacturing strategy mutually fit and when strategy system suitably fits the company´s capabilities [9], [10]. Therefore the manufacturing resources and know-how should be respected in order to align a consistent business and product strategy. This way the attainment of the strategy goals is enabled by the effective and suitable usage of the production system. As delimitation, the special business case of exchanging and purchasing a complete new production system is in the following consideration excluded due to the fact that unique competences in the product-production-system need to be developed over time and cannot be bought directly at the market in order to achieve competitive advantages.

A contribution to achieve consistency is an integrated strategic planning which aligns strategic product development and the production planning. This way feasible production capabilities can be respected in future product concepts. Furthermore the production planning is informed early if new technological know-how is required. But "the measurement of manufacturing performance is complex due to the multi-dimensional nature of manufacturing", cf. [4]. Either information is too detailed and not abstracted enough for strategic thinking or essential information is missing completely. This may result in unrealistic strategy goals or relevant topics are not even discussed due to missing transparency. In practice the correct information exchange depends heavily on individual persons [2]. Therefore an abstraction model is needed to make manufacturing capabilities understandable for the strategic point of view. The goals of the product and the technology strategy need to be abstracted to achieve a comparison with the manufacturing capabilities. Using the first rough product concept developed in the early strategic product planning helps to illustrate the product strategy. In order to achieve consistency in strategic planning the abstracted requirements of the early product concepts need to be fitted with the abstracted production technology capabilities.

This paper focuses on an integration of product and production planning in the early strategic development process. Therefore relevant approaches from literature are presented. Based on this, an approach is presented in which the capabilities of the feasible production technologies and the requirements of a strategic product concept are compared to allow a consistency check from which further business actions can be derived.

II. Challenges and deficits of an strategic integrated planning

Strategic thoughts are important for a long term success of a company. A good comprehensibility, transferability as well as transparency of the strategic guidelines are needed to allow a sufficient guidance of the operative domains [2]. However a consistent strategy system is not self-evident due to various company domains which interact. But why is integrating planning not state-of-the-art yet? Separate planning has often organization and knowledge management reasons like clustering of competencies, identifying the optimal specific planning solution or avoiding of compromises. Furthermore, thinking in departments and therefore planning for defined domains is easier and well established [2]. This also results in different "languages" between strategic management and technological shop floor. Therefore the different languages need to be abstracted to communicate on a same level. But what are the necessary strategic product and production parameters which communicate the performance accurately on an abstracted level? New product concepts are fuzzy and no fixed geometry and material features exist that should allow a derivation of a production concept.

In principle new product planning pushed by innovative and creative thinking can be done on "white paper", cf. [2]. This means that no special restrictions like the history of former products need to be respected. For production planning this high degree of freedom does not exist due to existing restrictions like manufacturing plants, production machinery and process know-how. Only with a lot of effort these assets can be changed. Therefore production planning needs to be done on "black paper" due to the restrictions of existing structures, cf. [2]. Today the production of many product variants respecting the existing structures is enormously challenging. The required flexibility in production can mostly not be provided [7]. The strategic product planning on "white paper "and the production planning on "black paper" are therefore on two different levels of information detail. How can the "white paper" and "black paper" information be abstracted to meet on joint level for efficient exchange?

III. Literature review

In literature several product development [1] and planning approaches have been developed, for example, simultaneous engineering [11] cooperative product engineering [12] [13] with main focus on improving product development by optimized exploiting manufacturing potentials. Other methods which integrate the planning domains like the technology calendar [14] or roadmapping [15] [16] mainly focus on suitable and transparent documentation und illustration of the different projects. Achieving a consistent system respecting strategic product requirements and manufacturing capabilities is not the main focus.

In general the operative planning can be seen as mostly mastered [2], [3], [17]. For example, NYHUIS focuses on integrative factory coordination by integrating product, technology and factory planning [7]. The method is based on the general roadmapping idea and deals with the content and time between the three planning domains. Thereby the operative planning level is addressed. For the information exchange NYHUIS proposes feature cards containing input (required) or output (generated) information, e.g. the output from the technology planning is the input for the fabric planning. To support this synchronization process a software solution has been developed [7].

However the characteristic of strategic decisions being blurry makes a comprehensibility, transferability and transparency challenging. The strategic planning is therefore in principle not mastered yet [2], [18], [19]. The product development process according to GAUSEMEIER illustrates an approach to connect the strategic product planning with the production planning, see Figure 1. The process has been mainly derived from the development of mechatronic products.

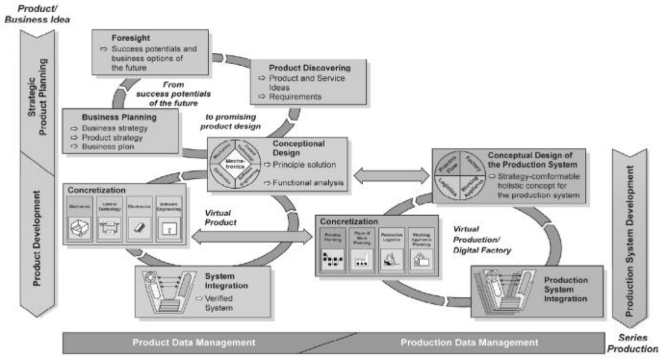

Figure 1: 3-cycle model of the product development process according to GAUSEMEIER [8]

The integrative process considers the steps from the first product idea to final market entry and consists of three main cycles - strategic product planning, product development and process development [13]. The three cycles are connected with each other to form a systematic process from product idea to market entry [8], [20]. Each main cycle is characterized by three sub-steps. The first main cycle, strategic product planning, covers the potential finding for promising product concepts and is characterized by the steps: foresight for potential finding, product discovering for idea identification, business planning for strategy identification and the cycle-spanning conceptional design for principle product solution. The second cycle, product development, creates a virtual product and contains the cycle-spanning product conceptual design, the product concretization and system integration. The third cycle, production system development, describes the virtual production. Starting point is the conceptual design of the production system which continues with the concretization of the production system and results in the production system integration. For the cycle-spanning steps, conceptual design and concretization, a close interplay between product and production development is necessary. This way "the development of the production system starts at an early stage of the product development process, namely if first relevant information for production is available" [8]. The starting point of the production development is therefore the principle product solution and not the defined final product. The development starts at the conceptional design step as soon as relevant product information is available. Thereby a concurrently development of product and production shall be achieved [8]. However in the next step concretization of the production system the four aspects, process planning, place of work planning, production logistics and working appliance planning, are considered which require a final product concept with defined features. Therefore the basis of the production concretization is the specification of the principle product solution. To enable an information exchange between the product and the production concretization step a specification technique consisting cross-sectional workshops is introduced [8].

The approach of GAUSEMEIER illustrates very well how the process for an integrated product and production development can be performed. However, main focus is in optimizing the future product and not a consistency fit in planning. Furthermore it is not described how the information of the production system is abstracted to allow integration in the strategic development process. The information about the production system only flows in the conceptional product design but not in business planning step. Therefore the production capabilities are not sufficiently respected in the new product und business strategy planning. A consistent strategy can therefore not be guaranteed.

SCHUH et al. present in [2] another approach for an integrated product, production and technology development process which bases on a developed product concept with geometrical features. As information exchange tool a function cost model is introduced which influences the product and the production planning domain. The function cost model assigns each product function element to an economic value added and also contrasts each element with its realization costs. To do so correlation between the functional elements and their economic value added needs to be described by a continuous function using a parameterized value model. For this the available manufacturing technologies need to be evaluated regarding a possible realization of specific functional elements and resulting costs using a parameterized cost model. These function models are the basis for a combined view of product and production technologies with which relevant research foci can be identified. However, the described approach needs very detailed information and data which leads to high complexity. Furthermore a transparency in costs is in the main focus and not a consistency between strategy and production.

To compare the consistency of the strategic product requirements and production capabilities a generic technology model with abstracted performance parameters is necessary. Besides, being in the early product development step detailed product features do not exist. A generic model is therefore sufficient as well as best suitable. Generic technology models like form OPITZ [21], KNOCHE [22] or SCHÖNING [23] are a suitable description basis for production technologies but lack giving universal performance parameters which allow a comparison of technologies as well as the integration of product requirements. SCHUH, GRAW and SCHÖN therefore present a new generic technology model which contents specific performance parameters [24]. The goal of this technology model is to find new industrial sectors in which a machine manufacture can additionally exploit its production technologies. The machine capabilities are abstracted to the generic technology performance parameters: geometric complexity, dimension, tolerance, surface quality, material flexibility, production volume. Likewise for each industrial sector the clustered product requirements are abstracted to performance parameters to allow a comparison with the machine capabilities. This way the machine manufacturer can identify whether additional technical adjustments would be necessary to allow production. After respecting the different market characteristics as well as the company characteristics the best exploitation solution can be identified, see Figure 2.

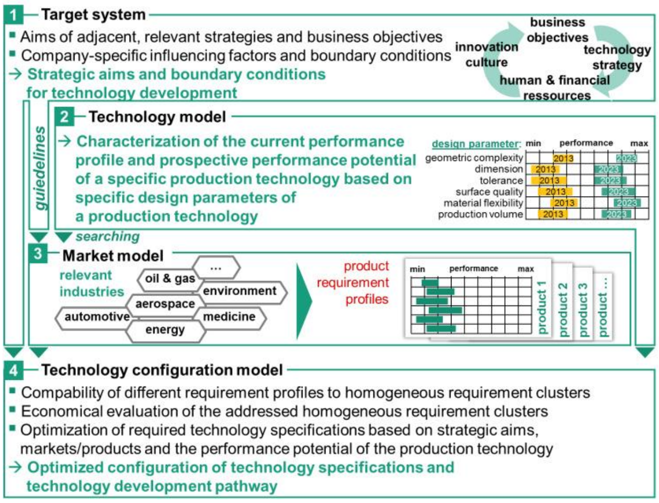

Figure 2: Exploitation Method according to SCHUH, GRAW and SCHÖN [24]

The generic technology model illustrates a very suitable way to compare abstracted product requirements and production capabilities. Therefore the generic technology model can be adapted to illustrate the current and future capabilities of the production systems. Furthermore, the requirements of the strategic product concept can be integrated to clarify the production feasibility. However, the generic technology model currently only allows the abstraction of single machines and not of an entire production system. Clustering the capabilities of different manufacturing technologies similar to the product clusters is not suitable due to the interactions of manufacturing technologies in process chain. Further research is therefore necessary to respect these technological interactions.

The process of planning can be seen as established. In literature several product development processes exist which illustrate how the synchronization and integration of the product and production planning processes can be done to improve the future product. However, consistency of the product and technology strategy with the production capability is not in the main focus. Furthermore no method especially explains the quality of information needed to the fit the requirements of the product strategy with the capabilities of the production system. A conjoint description "language" is missing to allow a fit of these two different domains. A method is required which translates the production capabilities and the strategic product requirements on a same technological level.

IV. Approach for Matching Production Technology Capabilities with Strategic Product Requirements

In the following an approach is proposed which illustrates how a consistency check can be performed, see Figure 3. Thus, information about the capabilities of the production system can be respected in the product strategy alignment. The basis of the method is an adapted generic technology model which shall work as "translation" tool between production and product. In the technology model the quantitative technology information are abstracted and classified using the six technology performance parameters: geometric complexity, dimension, tolerance, surface quality, material flexibility and production volume, cf. [24].

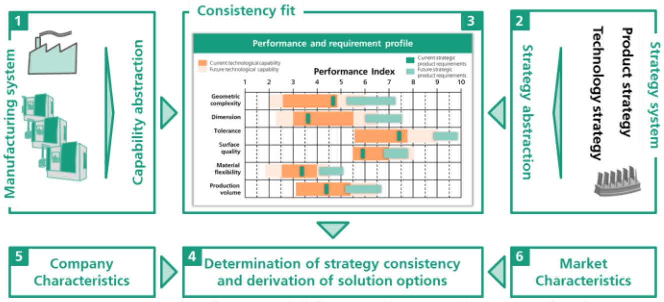

Figure 3: Technology model for matching production technology capabilities with strategic product requirements

In the first model the technologies of the manufacturing system are described and analyzed. Thereby the machine characteristics as well as the process know-how are respected. In addition, different technologies can be combined to specific process chains resulting in technological competences. As requested, single manufacturing technologies or technological competences are then abstracted for each performance parameter resulting in a scope illustrating the current and future technological capabilities.

Similar the strategy system in the second model is abstracted. The strategy system consists of the product strategy and its technology strategy. The product strategy illustrates what products shall be placed in what market and contains therefore a rough product concept. Whereas the product technology strategy explains the strategic purposes like the required technological performance, e.g. leader or high performer or the technological timing, e.g. pioneer or late follower, cf. [10]. With the product and the technology strategy the strategic products requirements can be derived. These strategic requirements also need to be abstracted to the technology performance parameters, e.g. using the quality function deployment.

In the model 3 the actual consistency fit takes place by using the six technology performance parameters from indices 1 to 10. In the model the current and future technological capabilities as well as the current and future strategic product requirements are respectively fitted. For the current product requirements a reference product is used. Therefore the current state-of-the-art is shown and the necessary technology change can be derived. The scopes of the future requirements are wider than the current reference requirements due to the blurry and rough product concept.

With this fit, in model 4 the strategy consistency can be determined. If no consistency occurs for specific performance parameters, necessary fields of action are identified to achieve feasibility. Respecting the company characteristics (model 5), e.g. budget size or know-how, as well as the market characteristics (model 6), e.g. anticipated sales flow, possible options for business action can be derived, e.g. adapting the strategic product concept or purchasing new manufacturing technologies. To do so external production technologies can be additionally entered in the technology model to check whether a the consistency gap can be filled. If external production technologies allow achieving a full consistency fit, then the company has identified a strategic technology need.

V. CONCLUSION

The manufacturing performance has a high impact on the business performance. The manufacturing and technology capabilities and competencies therefore need to be considered in the business and product strategy. Furthermore, the feasibility and the consequences of a new product concept on the production system need to be identified. Managing business directors, on the one hand, need to know the production capabilities in order to set an effective business and product strategy. On the other hand production managers require the information whether future production capabilities fulfill the strategic product requirements. To achieve both requirements the company´s strategy system needs to be consistent in order to achieve competitive advantages. Consistency results when the company strategies mutually fit and when the strategy system suitably fits the company´s capabilities.

In literature methods exist which illustrate the synchronization and integration of product, production and technology planning. Often the main focus is the operative planning level when a product concept with specific geometric features already exists. Task of the production is mainly to support product development. Possible effects of a new product on the existing production system are not in main focus. A consistency fit of the product strategy and the production capabilities in the strategic planning is not given.

The presented approach illustrates how the requirements of the product strategy and the manufacturing technologies can be matched in a consistency fit. To do so generic technology performance parameters are used as translation instruments. By abstracting the future product concept and its technology strategy the strategic product requirements can be derived. A reference product is used to show the current state-of-the-art. For the production analysis the geometrics and the process know-how of the existing manufacturing technologies are abstracted in order to derive the current and future manufacturing capabilities. By adding the characteristics of the company and the market to the consistency fit possible options for further business actions can be derived. This way it can be checked whether the product strategy is effective and realistic in terms of feasible production. Furthermore the business planning can be supported with knowledge about necessary technology acquisition costs. Also the production planning is prepared earlier to acquire new technology know-how to fulfill the requirements of an up-coming new product. In future research the abstraction of product and technology strategy needs to be clarified more in detail. Furthermore it needs to be verified whether the technology model is capable of characterizing the capabilities of an entire production system consisting of process chains and not just of a single production technology.

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