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Considering external and internal Cycles of a Manufacturer for Planning and Evaluating Production Technologies

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Abstract

Anticipating a production company's internal and external influencing factors is seen as key driver of the ability to act appropriately to sustain a competitive advantage within a dynamic market environment. In this connection, some factors within the production environment manifest as temporally and structurally recurring patterns (defined as cycles) and are predictable. Modeling and analyzing the cyclic behavior of products, technologies, and manufacturing resources, for example, facilitates a proactive planning approach to production technologies.

This paper uses the example of the commercial vehicle industry to focus on a manufacturer's internal cyclic influencing factors. Based on the results of an industrial case study and a review of existing methods, a conceptual framework is presented for managing the complex interdependencies of the lifecycle of a product, its components, and production technologies.

Keywords: manufacturing process; production planning; cycle management, commercial verhicle industry

1. Introduction and definitions

The influence of manifold dynamic factors such as competitive pressure, stringent environmental laws, and the accelerated development of technological innovations [2] renders today's industrial environment increasingly turbulent [1]. The factors influencing a manufacturer' decisions and processes can be classified as internal or external [2]. Typical examples of internal factors are the manufacturing resource lifecycle and the maturity of established technologies. External factors involve customers and markets, product substitutes, and political and social impacts.

To compete within such an environment, monitoring and anticipating internal and external influencing factors is seen as a key driver of the ability to act appropriately [3]. Many influencing factors exhibit cyclic behavior and are predictable. Modeling those factors facilitates the identification and implementation of emerging opportunities before the competition does (cf. [4]). The application of alternative production technologies in particular offers great potential for cost reduction [5] and efficiency [6].

Cycles within this context are defined as temporally and structurally recurring patterns comprising defined phases [7]. A prevalent approach to these are lifecycle models, such as the product lifecycle model, which support the forecasting of predictable influencing factors. Triggers, duration, repetition and effects characterize these cycles. The management of interdependencies among multiple cycles in terms of planning, modeling, organizing, and monitoring is understood as cycle management [7].

The term "technology" denotes all of the emerging and established manufacturing processes that are required to produce a product [8]. Technologies are generally based on theories consisting of established findings of scientific research describing causes and their effects [9]. Technologies are embedded in manufacturing resources (cf. figure 3) for real-life application. This work focuses on technologies and their underlying manufacturing resources, which are referred to below as production technologies.

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Extensive research is being conducted on individual external cyclic influencing factors using, for instance, lifecycle models of markets, products, and business (cf. [10]). Internal cyclic influencing factors need to be considered to continuously estimate the need to replace a production technology due, for example, to manufacturing resources' declining suitability or wearing out. Moreover, the documentation and visualization of cycles' dynamic behavior (including the complexity arising from the interdependencies) are the main objectives of this publication.

2. Cycle management and technology planning

In the sequel, the need for further research occasions focus on internal influencing factors and their interdependencies with external factors (cf. [2]). The use of individual, mainly external, cycles in the context of strategic management is already established in industrial practice (cf. 11]). Particularly with regard to the production environment, the product, technology, and manufacturing-resource lifecycles are considered [12]. Relevant concepts and methods are briefly presented thereafter to identify shortcomings verified by an industrial case study.

2.1. Relevant cycles influencing the production environment

Developed during the 1950s (cf. [13, 14]), the product lifecycle has been established in industry to guide strategic decision-making. Manifold frameworks were developed each comprising three to seven phases [11]. The four-stage model of the market lifecycle (introduction, growth, maturity, and decline [15]) is the most prominent and is already well documented in the scientific literature (cf. [16]). Initially developed to describe the behavior of a product from the marketing perspective, researchers have extended the model to integrate the viewpoint of production and its associated processes [17].

Ryan and Riggs [18] thus developed the five-element product wave (design engineering, process engineering, marketing, production, and end of life) taking a manufacturer's different internal perspectives into consideration. Klenter [19] presented a so-called “systemic product lifecycle concept”, explicitly mentioning the stage of the manufacturing cycle for the first time. Hagen [20] details the manufacturing-cycle concept by presenting an idealized six-stage process model (initial batch, ramp-up, serial production, ramp-down, and after-series production). Underlying technologies and manufacturing resources are included in the consideration to evaluate manufacturing processes from the viewpoint of production technologies management.

The technology-lifecycle model describes the evolutionary development of a production technology's varying competitive potential throughout the latter's lifetime [3]. The framework is also applied to determine the maturity of manufacturing technologies (see [21, 22] for instance).

The bathtub curve is a common tool for describing the operation period of simple machines and devices [12, 23]. The ideal type of manufacturing-resource lifecycle comprises three distinct phases: early failure, random, and wear-out period [24]. However, empirical analysis of modern and more complex equipment suggests that six patterns of failure describe the lifecycle in a realistic scenario [23, 25, 26].

2.2. Cycle-oriented frameworks for planning production technologies

A considerable amount of scientific literature documents analyses of specific characteristics of the product lifecycle that production technologies (or production processes) need to exhibit to provide competitive advantages. The majority of approaches taken can be classified as research into manufacturing-strategy development (cf. [27]). Focusing on the synchronization of technology planning with product development (cf. [28, 29]), only a few contributions consider internal cyclic influences from the viewpoint of production-technology management. Special attention was paid here to lifecycle frameworks developed for evaluating technologies and processes.

Abernathy and Townsend [30] developed a descriptive model of process evolution over time. For each stage of the manufacturing-process lifecycle (uncoordinated, segmental, and systemic), important implications were derived that managers should be aware of.

Hayes and Wheelwright [31] noted that manufacturing processes have to be aligned with the corresponding challenges of each product-lifecycle stage. The authors presented the “product-process matrix” linking process and product evolution corresponding to its lifecycle stages.

Focusing on manufacturing practices, Magnan et al. [32] conducted an empirical investigation into the most appropriate actions with respect to specific stages of the product lifecycle.

Considering multiple products following different lifecycles, Ferro and Aguilar-Saven [33] presented comparative tables and recommendations supporting the decision-making which manufacturing processes to implement.

Aurich and Barbian [34, 35] separated a product's market lifecycle and production period. They introduced the concept of the production cycle (also known as the production period) as the interval between the start and end of production.

Considering internal and external cyclic influencing factors, Greitemann et al. [29] presented (based on [36]) a dynamic model comparing competing technologies over time.

2.3. Shortcomings and the need for further research

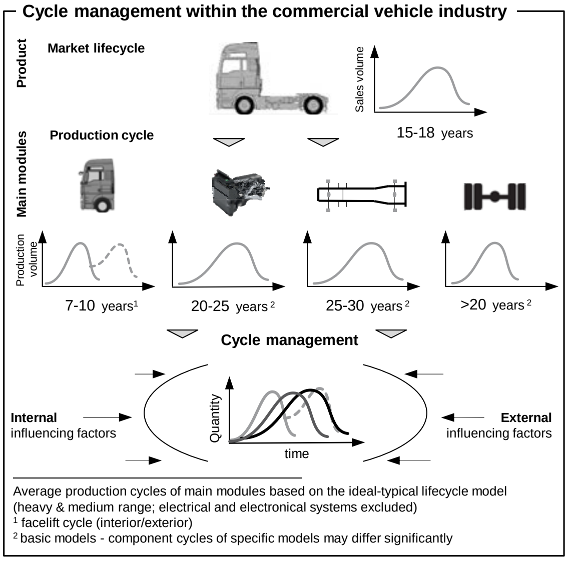
The review shows that the majority of the aforementioned approaches focus on the product lifecycle for planning production technologies from a marketing perspective. Thus, they implicitly assume that the lifecycle of every single component produced within the company matches the products' market lifecycle. In some industries, multiple cyclic influencing factors render differentiation among product lifecycles a complex, uncertain task (cf. chapter 3) requiring a more detailed framework. Most frameworks exit on a conceptual level and empirical investigations of industrial practice involving them are scarce.

Moreover, technologies are examined without considering the need to replace established machines due to age, wear-out, or breakdown [37]. Although this may not directly affect the market-oriented product lifecycle, the need to implement new machines and technologies associated with engineering and ramp-up activities influences the underlying manufacturing process's cycle stage. Managing production technologies requires both production- and market-oriented perspectives. A holistic perspective supports companies when managing the complex interdependencies of external and internal cyclic influencing factors and when acting appropriately to achieve competitive advantages.

A model supporting the cycle-oriented planning of production technologies needs to consider the effect of internal and external influences on both the product (or individual component) lifecycle and on the manufacturing-process cycle. For example, applying an alternative technology may affect only the process cycle while a law impacts the product lifecycle. Besides this academic perception, business practice also justifies the need for further research into managing cycles within the production environment - as the following industrial example demonstrates.

3. Industrial practice of managing cycles

Qualitative (1) and quantitative (2) data was gathered in cooperation with a leading manufacturer of commercial vehicles to prepare the following case study. Figure 1 presents the resulting ideal-typical cycles.



Average production cycles of main modules based on the ideal-typical lifecycle model (heavy & medium range; electrical and electronical systems excluded)

[1] facelift cycle (interior/exterior)

[2] basic models - component cycles of specific models may differ significantly

Fig. 1. Challenges of cycle management in production.

Eight semi-structured expert interviews were conducted (1) with branch experts and specialists working in the product development, product management, production, and competitor's analysis department. The "product" (truck) was initially separated into its four main modules: the drivers cab, the engine (or power train), the chassis, and the axles (figure 1).

A truck's market lifecycle is typically considerably longer than a passenger car's. By default, the duration of the main modules' production cycles doesn't equal that of the product's market lifecycle. This is primarily attributable to two reasons. First, when introducing a new truck model, some components (or even modules) remain nearly unchanged to reduce development costs. This results from lower branch-specific demand and extremely price-sensitive customers considering a commercial vehicle as a capital good. Second, political and legal impacts such as those from CO_2 limits or requirements imposed on cabin structure mainly affect a truck's individual component and result in asynchronous market-cycle changes.

From the customer's viewpoint, this means that a truck's main modules are substantially modified independently a new truck model being introduced. For example, introduction of the Euro 6 emission standard affected mainly the engine or power train, while improved crash performance mostly involved the driver's cabin.

This situation calls for analyzing quantitative data (2) within the production environment. The "engine" was thus chosen by way of example since it illustrates well the increasing number of external cyclic influences occurring within the past ten years (cf. table 1).

Table 1. Internal and external cyclic influencing factors.

Year	2006	2008	2013	2014	2015
Emission standard	EU4	EU5	EU6	EU6	EU6
Influence	External	External	External	Internal	Internal
Trigger	Legal	Legal	Legal	PM	PM

PM: product management (new type or major product changes); ***-excerpt-***

The production cycle of an individual component was derived using quantitative data about the production volume of five types of engines (March 2006 until March 2016). Here, the introduction of a new emission standard initiates the relaunch of a production cycle (product ramp-up; cf. chapter 4) starting with a reengineering effort.

The progressions of comparable engines' production volumes in different lifecycle stages were combined to derive the entire production cycle of an engine (up to 30 years). As fig. 2 illustrates, the schematic production cycle of an engine is not identical to the product lifecycle from the market perspective.

The typical ramp-up curve becomes evident when introducing a new engine type. The series-production phase at high volume is obvious for several years while achieving the projected capacity. Influencing factors (the introduction of a new emission standard necessitating a successor in this example) cause production volume to decrease significantly, but stabilizes at low volume for many years while serving niche markets. This type of engine remains in series production (production perspective) until it reaches the end of production. Foreign customers (outside of the EU) often order the latest truck model (from market perspective) with an engine fulfilling only previous emission standards.

These analyses clearly show that exclusively considering the product lifecycle (marketing perspective) is insufficient for production-technology planning. Considering the actual and future progression of recurring patterns at the module and component level helps to avert misguided investments. An example is the premature automation of manufacturing processes although high flexibility is needed (cf. [17]).

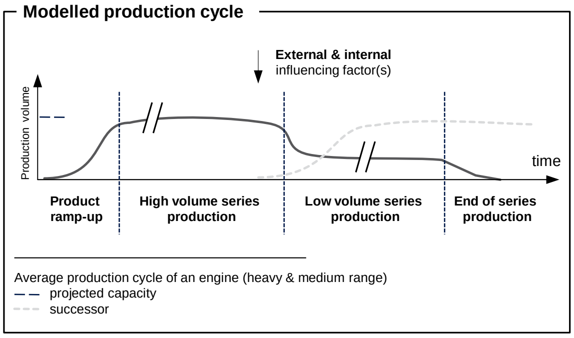


Fig. 2. Derived production cycle of an engine.

A specific component's production cycle (defined based on [34, 35], section 2.2) has to be contemplated when managing production technologies. The product lifecycle in this context may exhibit very different cyclic behavior, especially regarding production volume over time. The requirements and properties profile of a component's production technologies [36, 38], for example, can therefore be heterogeneous over time compared to those of the products' assembly process. Current and future production requirements need to be satisfied in the manner to best ensure enduring competitiveness. Established production technologies must continuously be assessed according to the progression and stages of the production cycle.

These results support the need to link the market-oriented product lifecycle to a module's or individual component's production cycle. Internal cyclic influences affecting the manufacturing process cycle are transparent, considering the lifecycle stage of applied technologies and manufacturing resources. The conceptual framework for cycle-oriented technology planning is subsequently presented, explicitly addressing the need for a holistic perspective.

4. Framework of cycle-oriented technology planning

As stated in the previous chapter, a holistic framework is necessary for documenting and visualizing the dynamic behavior of cycles (including the complexity arising from the interdependencies). This should start from the market-oriented view of the product also considering the lifecycle stage of established technologies and manufacturing resources [cf. 39]. Moreover, differentiation of influencing factors concerning their effect on the corresponding product and/or process cycle stage needs to be taken into account [40, 41]. Laick [41] defined three basic types of ramp-ups depending on the cause and degree of adaption: product, process, and series ramp-up. The introduction of a new product into an existing manufacturing process, for example, requires a product ramp-up while a manufacturing-process change (not directly affecting the product) is regarded as a manufacturing ramp-up (cf. [42]). Influencing the manufacturing process cycle (e.g. replacement of machines leading to a manufacturing ramp-up) does not by default lead to a change in a component's production-cycle stage. Likewise, Almgren [43] points out that there may be no need for an extended start-up phase in situations where the degree of change in the product or production is minor.

A conceptual framework comprising five levels of cycle management is subsequently developed (figure 3) based on previous work (cf. chapter 2) and the industrial example presented (cf. previous chapter). This framework adequately supports the planning of production technologies, especially the management of internal and external cyclic influencing factors within the production environment.

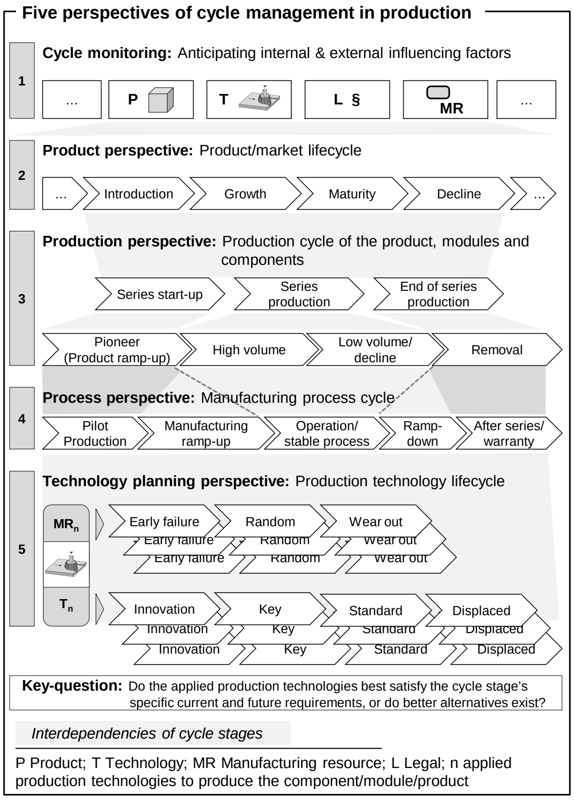


Fig. 3. Conceptual framework of cycle-oriented technology planning.

The purpose of the *first, encompassing level* (figure 3; cf. [19]) is to monitor and anticipate internal and external influencing factors such as new products and substitutes, political and social impacts, and available production technologies [2]. The cycle information sheet [7] and cycle networks [44], for example, are appropriate tools supporting this task.

The *second level* describes the product lifecycle from the market perspective. As already mentioned, manifold frameworks were developed comprising the stages from product development to recycling (cf. [11]).

The four-stage model of the market lifecycle (introduction, growth, maturity and decline [15]) is the focus within this paper.

Considering the production perspective, the model's *third layer* describes the company-specific production cycle of a product, its modules, or individual components, depending on the analysis' purpose. Three distinct stages are distinguishable here (cf. [45]): series start-up, series production, and end of series production. Increasing the level of detail, four sequential production-cycle phases can be assigned: pioneer (product ramp-up and growth), high volume series production, low volume series production and decline, as well as removal (based on [34, 35]).

The *fourth layer* takes the perspective of the manufacturing process cycle into account. Five process phases are considered (based on [20, 43, 46, 47]: pilot production/process engineering, manufacturing ramp-up, operation/stable process, ramp-down, and after series/warranty.

The applied production technologies, and associated cycles, are embedded in the *fifth layer*. The manufacturing resources' current lifecycle stage is expressed using the bathtub-curve concept or the six-patterns-of-failure behavior distinguishing early failure, random, and wear-out period [24, 23]. The evolutionary development of technologies is expressed as stages of maturity (innovation, key, standard, and displaced technology) (cf. [3]).

The *key question* is: “Do the applied production technologies best satisfy the cycle stage's specific current and future requirements, or do better alternatives exist?”

5. Application example

To answer this key-question, it is important to get an overview of the existing *interdependencies* (cf. fig. 3), as illustrated in the following example. The developed framework is applied to determine the suitability of the established technologies and manufacturing resources. In the process, current and future challenges posed by production tasks are derived using cycle models.

Due to a new emission standard (which represents an external cyclic influencing factor), a new engine production cycle (*production perspective*) can begin independently of the product-lifecycle stage (*product perspective*).

A manufacturing ramp-up (*process perspective*) is also necessary at the pioneer production stage in this specific example. The established production technologies (*technology planning perspective*) can also be assigned to a lifecycle stage, for example, to the wear-out phase (*manufacturing resources*) and displaced technology (*technology*).

On the one hand, this information base supports the decision-making process whether the established production technologies are supporting ramp-up activities and meeting the challenges of subsequent cycle stages in the best possible manner or better alternatives exist. On the other hand, the framework indicates the appropriate time for replacement activities. The continuous determination of the most promising manufacturing alternative assures enduring competitiveness [36].

Applying the framework supports the interdisciplinary cooperation among and exchange of important domain information about the products, the state of the equipment, and the manufacturing processes (cf. [39]). All involved parties can be assured a uniform and objective information base serving as a solid foundation for discussions and decision-making. Furthermore, the holistic perspective facilitates a conscious synchronization or desynchronization of product and process adaptations over the planning horizon. Interdependencies among cycles as well as domain-specific perspectives can be easily visualized and shared. Integrating the current lifecycle stages of the established manufacturing resources and technologies allows the timely identification of needs for replacement and investment.

6. Conclusion and outlook

Reviewing the literature on the cycle-oriented management of production technologies reveals that many scientific approaches consider only the market-oriented product-lifecycle model. No integrated framework is available for describing cycle stages with a technology-management orientation from multiple perspectives within the production environment. Internal and external influencing factors, as well as their interdependencies, need to be considered in a more detail here. Presenting an industrial case study of cycle management within the commercial vehicle industry verified the identified need. A conceptual framework to support the cycle-oriented planning of production technologies was developed based on the review of established approaches and the insights gained through industrial practice. The holistic approach comprises five perspectives of cycle management in production: cycle monitoring, product, production, process, and technology planning perspective.

Further research activities will initiate cross-industry validation and refinement of each stage. Furthermore, a cycle-stage-specific technology requirements profile comprising specific evaluation criteria needs to be developed. This enhancement will enable a continuous technology-evaluation approach resulting in the timely identification of technological need for action.

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References

[1] Wiendahl, H.-P., ElMaraghy, H.A., Nyhuis, P., Zäh, M.F., Wiendahl, H.-H., Duffie, N., Brieke, M., 2007. Changeable Manufacturing - Classification, Design and Operation. CIRP Annals - Manufacturing Technology 56 (2), 783–809.

[2] Zaeh, M.F., Reinhart, G., Karl, F., Schindler, S., Pohl, J., Rimpau, C., 2010. Cyclic influences within the production resource planning process. Prod. Eng. Res. Devel. 4 (4), 309–317.

[3] Zäh, M.F., Reinhart, G., Pohl, J., Schindler, S., Karl, F., Rimpau, C., 2009. Modelling, Anticipating and Managing Cyclic Behaviour in Industry, in: Zäh, M.F. (Ed.), 3rd International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2009). Munich, Germany, October 5th - 7th, 2009. Utz, München, pp. 16–43.

[4] Abele, E., Reinhart, G., 2011. Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen. Hanser, München.

[5] Schuh, G., Graw, M., Schön, N., 2014. Exploitation-oriented Manufacturing Technology Development. Procedia CIRP 17, 680–685.

[6] Klocke, F., Buchholz, S., Stauder, J., 2014. Technology chain optimization: a systematic approach considering the manufacturing history. Prod. Eng. Res. Devel. 8 (5), 669–678.

[7] Koch, J., Plehn, C., Reinhart, G., Zäh, M.F., 2014. Cycle Management for Continuous Manufacturing Planning, in: Zaeh, M.F. (Ed.), Enabling Manufacturing Competitiveness and Economic Sustainability. Springer International Publishing, Cham, pp. 9–12.

[8] DIN 8580:2003-09, Fertigungsverfahren - Begriffe, Einteilung. Beuth, Berlin.

[9] Spath, D., Renz, K.-C., Seidenstricker, S., 2009. Technology Management, in: Schlick, C.M. (Ed.), Industrial Engineering and Ergonomics. Springer Berlin, Heidelberg, pp. 105–115.

[10] Peltoniemi, M., 2011. Reviewing Industry Life-cycle Theory: Avenues for Future Research. International Journal of Management Reviews 13 (4), 349–375.

[11] Höft, U., 1992. Lebenszykluskonzepte: Grundlage für das strategische Marketing- und Technologiemanagement. E. Schmidt, Berlin.

[12] Pohl, J., 2014. Adaption von Produktionsstrukturen unter Berücksichtigung von Lebenszyklen. Doctoral dissertation. TUM. Utz, München.

[13] Dean, J., 1950. Pricing Policies for New Products. Harvard Business Review 28 (6), 45–53.

[14] Patton, A., 1959. Top Managements Stake in the Product Life Cycle. Management Review 58 (6), 9–14; 67–79.

[15] Levitt, T., 1965. Exploit the Product Life Cycle. Harvard Business Review 43 (Nov.–Dec.), 81–94.

[16] Rink, D.R., Swan, J.E., 1979. Product life cycle research: A literature review. Journal of Business Research 7 (3), 219–242.

[17] Susman, G.I., 1990. Product Life Cycle Management, in: Brinker, B.J. (Ed.), Emerging practices in cost management. Warren, Gorham & Lamont, Boston, pp. 225–239.

[18] Ryan, C., Riggs, W.E., 1996. Redefining the product life cycle: The five-element product wave. Business Horizons 39 (5), 33–40.

[19] Klenter, G., 1995. Zeit, strategischer Erfolgsfaktor von Industrieunternehmen. S + W Steuer- und Wirtschaftsverlag, Hamburg.

[20] Hagen, M., 2003. Methoden, Daten- und Prozessmodell für das Ersatzteilmanagement in der Automobilelektronik. Doctoral dissertation. TU Dresden.

[21] Tushman, M.L., Anderson, P., 1986. Technological Discontinuities and Organizational Environments. Administrative Science Quarterly 31 (3), 439–465.

[22] Reinhart, G., Schindler, S., 2010. A Strategic Evaluation Approach for Defining the Maturity of Manufacturing Technologies. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 11 (4), 1291–1296.

[23] Moubray, J., 1997. Reliability-centered maintenance, Industrial Press, New York.

[24] Klutke, G., Kiessler, P.C., Wortman, M.A., 2003. A critical look at the bathtub curve. IEEE Trans. Rel. 52 (1), 125–129.

[25] Bertsche, B., Lechner, G., 2004. Zuverlässigkeit im Fahrzeug- und Maschinenbau: Ermittlung von Bauteil- und System-Zuverlässigkeiten, Springer, Berlin.

[26] Balzer, G., Drescher, D., Meister, R., Heil, F., Kirschek, P., Neumann, C., 2004. Evaluation of Failure Data of HV Circuit-Breakers For Condition Based Maintenance. Proceedings of CIGRE (A3-305).

[27] Chatha, K.A., Butt, I., 2015. Themes of study in manufacturing strategy literature. Int Jrnl of Op & Prod Mnagemnt 35 (4), 604–698.

[28] Phaal, R., Farrukh, C.J., Probert, D.R., 2004. Technology roadmapping - A planning framework for evolution and revolution. Technological Forecasting and Social Change 71 (1-2), 5–26.

[29] Greitemann, J., Stahl, B., Schönmann, A, Lohmann, B., Reinhart, G., 2015. Strategic production technology planning using a dynamic technology chain calendar. Prod. Eng. Res. Devel. 9 (3), 417–424

[30] Abernathy, W.J., Townsend, P.L., 1975. Technology, productivity and process change. Technological Forecasting and Social Change 7 (4), 379–396.

[31] Hayes, R.H., Wheelwright, S.G., 1979. The dynamics of process-product life cycles. Harvard Business Review 57 (2), 127–136.

[32] Magnan, G.M., Fawcett, S.E., Birou, L.M., 1999. Benchmarking manufacturing practice using the product life cycle. Benchmarking 6 (3), 239–253.

[33] Ferro, E.G.L., Aguilar-Saven, S.R., 2004. Manufacturing Strategy Linked to Product Life Cycle, in: Gupta, S., Garg, N. (Eds.), Operations Management 2004: The Expanding Constellation - Complete Papers of the 2nd World Conference on Production and Operations Management. Cancun, Mexico, April 30–May 3, 2004.

[34] Aurich, J.C., Barbian, P., 2004. Production projects – designing and operating lifecycle-oriented and flexibility-optimized production systems as a project. International Journal of Production Research 42 (17), 3589–3601.

[35] Barbian, P., 2005. Produktionsstrategie im Produktlebenszyklus - Konzept zur systematischen Umsetzung durch Produktionsprojekte. Doctoral dissertation. TU Kaiserslautern (2005).

[36] Reinhart, G., Schindler, S., 2012. Strategic Evaluation of Technology Chains for Producing Companies, in: Elmaraghy, H.A. (Ed.), Enabling Manufacturing Competitiveness and Economic Sustainability. Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2011), Montreal, Canada, 2–5 October 2011. Springer, Berlin Heidelberg, pp. 391–396.

[37] Ettlie, J.E., 1988. Manufacturing technology policy and deployment of processing innovations. Ann Oper Res 15 (1), 1–20.

[38] Karl, F., Reinhart, G., Zaeh, M.F., 2012. Strategic Planning of Reconfigurations on Manufacturing Resources. Procedia CIRP 3, 608–613.

[39] Fjällström, S., Säfsten, K., Harlin, U., Stahre, J., 2009. Information enabling production ramp-up. Jnl of Manu Tech Mnagmnt 20 (2), 178–196.

[40] Juerging, J., 2007. Engineering Change Orders Influencing Manufacturing Start-ups in the Automobile Industry, in: Sterman, J. (Ed.), Proceedings of the 25th International Conference of the System Dynamics Society. System Dynamics Society, New York, pp. 2144–2154.

[41] Laick, T., 2003. Hochlaufmanagement: Sicherer Produktionshochlauf durch zielorientierte Gestaltung und Lenkung des Produktionsprozesssystems. Doctoral dissertation. Universität Kaiserslautern, 2003. Lehrstuhl für Fertigungstechnik und Betriebsorganisation, Universität Kaiserslautern, Kaiserslautern.

[42] Nau, B., 2012. Anlauforientierte Technologieplanung zur Auswahl von Fertigungstechnologien. Doctoral dissertation. Apprimus, Aachen.

[43] Almgren, H., 2010. Pilot production and manufacturing start-up: The case of Volvo S80. International Journal of Production Research 38 (17), 4577–4588.

[44] Plehn, C., Koch, J., Diepold, K., Stahl, B., Lohman, B., Reinhart, G., Zäh, M.F., 2015. Modeling and Analyzing Dynamic Cycle Networks for Manufacturing Planning. Procedia CIRP 28, 149–154.

[45] Juerging, J., Milling, P.M., 2005. Interdependencies of product development decisions and the production ramp-up. The 23rd International Conference of the System Dynamics Society, 2005, Boston.

[46] Martinez, S., 2013. The Ramp-Up Process, in: Errasti, A. (Ed.), Global Production Networks. Operations Design and Management. CRC Press, Boca Raton, pp. 249–265.

[47] Slamanig, M., Winkler, H., 2011. An exploration of ramp-up strategies in the area of mass customisation. IJMASSC 4 (1/2), 22.