Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 52 (2016) 198 – 203
www.elsevier.com/locate/procedia

Changeable, Agile, Reconfigurable & Virtual Production

Proactive Management of Production Technologies: A Conceptual Framework

Alexander Schönmann[a]*, Josef Greitemann[a], Gunther Reinhart[a]

[a]*Technical University of Munich, Institute for Machine Tools and Industrial Management (iwb), Boltzmannstraße 15, 85748 Garching, Germany*

* Corresponding author. Tel.: +49-89-289-15486; fax: +49-89-289-15555; *E-mail address:* alexander.schoenmann@iwb.mw.tum.de

Abstract

To gain competitive advantages within the growing challenges of the dynamic market environment producing companies must be agile, anticipative and adaptive. Current and future manufacturing requirements need to be fulfilled in the best manner. Consequently, the appropriateness of the applied production technologies has to be analyzed continuously. In order to identify technological need for action timely the interdependencies of temporally and structurally recurring patterns (defined as cycles) within the production environment have to be contemplated. Modeling and analyzing these cycles (e.g. technology lifecycle, manufacturing resource lifecycle) facilitates a proactive planning and an evaluation approach of production technologies. Therefore, this paper presents a conceptual framework supporting the timely adequate identification and evaluation of alternative production technologies to enhance the performance of producing companies.

Peer-review under responsibility of the scientific committee of the Changeable, Agile, Reconfigurable & Virtual Production Conference 2016
Keywords: Manufacturing process; Production planning; Technological modernization; Cycle management

1. Introduction and Definitions

Decreasing profit margins [1], growing customer demands, shortened product lifecycles [2] and accelerating rates of technological change [2, 3] are key challenges for today's manufacturing companies. Zaeh et al. ([2] based on [3]) divided the factors influencing decisions and processes of a producing company into external (e.g., new products and substitutes, political and social impacts) and internal factors (e.g., production resources and established technologies). Especially production technologies are seen as the key driver for cost reduction [1] and efficiency [4] in manufacturing.

In order to assure enduring competitiveness [5] it is essential to continuously detect whether the established technologies will fulfil current and future requirements or if promising alternatives exist [6]. Since the development of requirements resulting from the production environment is hardly predictable investments in suitable technologies in terms of effort and time is a complex and uncertain task [7]. These investments are necessary from a company's perspective if there is a technological need for action. In this context, technological need for action (also referred to as technological modernization activities) is defined as the demand for the replacement of a production technology due to a decline in its suitability (properties deficit), wear out of manufacturing resources (substitution need) as well as progressed technology's maturity (substitution potential).

The term "technology" denotes all emerging and established manufacturing processes that are required to produce a product [8]. Technologies are generally based on theories consisting of valid findings of scientific research describing causes and their effects [9]. For real life application of technologies, they are embedded in manufacturing resources (cf. Figure 1). Subsequently, technologies and the underlying manufacturing resources are focus of this work and are referred to as production technologies in the following.

To remain competitive manufacturers have to monitor and anticipate external and internal influencing factors to be able to act appropriately [10]. Some factors are predictable while others are not [2]. Lifecycle models support the forecast of predictable factors. Cycles are temporally and structurally recurring patterns that can be separated in defined phases.

Peer-review under responsibility of the scientific committee of the Changeable, Agile, Reconfigurable & Virtual Production Conference 2016
doi:10.1016/j.procir.2016.08.011

These are determined by triggers, duration, repetition and effects [11]. The management of interdependencies of multiple cycles in terms of planning, modelling, organizing and monitoring is understood as cycle management [11].

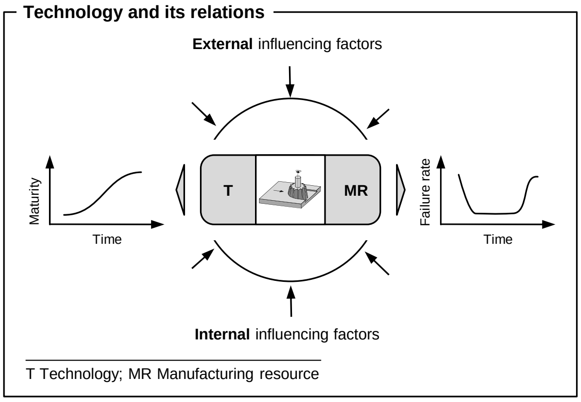

Fig. 1. Internal and external influencing factors

2. Cycle Management in Manufacturing

The understanding and use of singular cycles in the context of manufacturing is already established, whereby the product, technology and manufacturing resource lifecycle and their interactions, as shown in Figure 2, are almost regarded [12]. Subsequently, relevant lifecycle concepts and methods dealing with the cycle-oriented planning of technologies are analyzed to derive shortcomings.

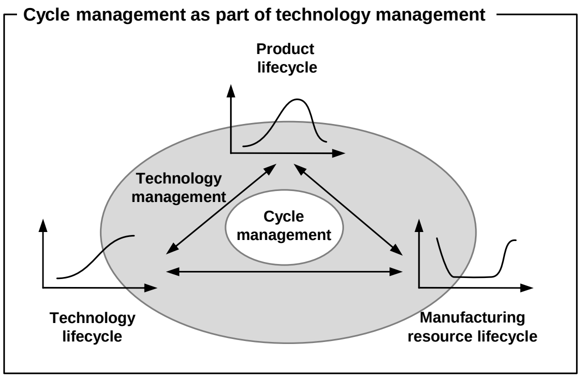

Fig. 2. Cycle Management in the context of technology management

2.1. Production-related lifecycle concepts

The concept of the product lifecycle [13, 14] for strategic decision-making is well established in industry (cf. e.g. [11, 15, 16]). Each stage of the lifecycle (introduction, growth, maturity and decline [17]) was already studied in detail. Besides, this lifecycle concept was empirically analyzed (cf. [18]). Furthermore, it was noted that the manufacturing processes have to be in line with the corresponding challenges of each product lifecycle stage [19].

The technology lifecycle [20] can be visualized using the bell-shaped curve [21] or the S-curve model [22]. Thereby, production technologies pass through an evolutionary development, which can be separated into several stages of maturity qualitatively (e.g. [21, 22]) or quantitatively using questionnaires (e.g. [23, 24]) and patent data (e.g. [25]). Depending on the lifecycle stage (innovation, key, standard, displaced technology), the production technology provides varying competitive potential [10].

Another well-accepted tool concerning the lifecycle management of manufacturing resources is the bathtub curve [12, 26]. The curve represents the idea that the operation period of simple machines or devices comprises three distinct phases (early failure, random and wear out period) [27]. However, modern manufacturing equipment is more complex, which results in changes of failure patterns over the lifetime. Moubray [26] developed six patterns of failure for describing the manufacturing resource lifecycle.

On a more abstract level, special attention was paid to the concept of the factory lifecycle developed by Schmenner [28] as well as the production system lifecycle (cf. [29]). The core idea of these concepts is that production facilities are long life products, which need to be adapted continuously to changing market environments [30].

The dynamics of process and product innovation were examined on a conceptual level. This resulted in a consistent pattern of variables, which will change due to the company's product or process development [31]. But the various characteristics of cycles in manufacturing increase the complexity of harmonizing those [10].

To deal with the complexity of cycles, especially their interdependencies and dynamics in a production environment, Stahl et al. [32] used transition adaptive recurrent Fuzzy Systems. Therefore, a rule base and a simulation scenario were developed visualizing the ideal type of behavior of relevant influencing factors.

Based on a System Dynamics model Plehn et al. [33] developed a dynamic cycle network focusing on change-relevant influences on manufacturing systems. As a result, quantitative relationships between the modelled elements have been analyzed.

The presented concepts focus the strategic management of a producing company and are often not related to specific parts of a production system (e.g. manufacturing resources). Supporting the deduction of concrete need for action to improve the competitiveness of a producing company requires a higher degree of details.

2.2. Cycle-oriented planning of production technologies

The suitability of a technology to fulfil a specific production task is changing over time [34]. Furthermore, some manufacturing resources are always in need of replacement due to obsolescence, wear-out or breakdown [35]. Although the need for continuous assessment and technological modernization of established production technologies is mentioned in literature (cf. [34, 35]) only few methods consider this fact. The majority of approaches for planning production technologies focus on the synchronization of technology planning regarding product development by comparing alternative technologies at a single point in time (cf. [36, 37]).

In order to plan the modernization of a process technology systematically and timely, Swamidass [34] proposes so called Technology Characteristic Curves. Based on estimated data for cost, quality and flexibility the suitability of alternative technologies can be compared graphically over a period in time. Thus, the modernization point can be distinguished qualitatively.

Reinhart & Schindler [6] developed a static technology chain calendar using a multi-criteria evaluation approach. Thereby, the evaluation results of a technology chain's suitability, e.g., maturity and profitability, for each alternative are visualized over the total planning horizon taking uncertainties into account.

Considering internal and external cyclic influencing factors, Greitemann et al. [37] extended the technology chain calendar to a dynamic model forecasting the technology chain´s suitability. As a result, alternative chains can be compared to ascertain the right period in time to switch the technology.

Hon & Xu [38] directly address the relationship between the product lifecycle and the manufacturing resources. Based on a simulation model, bottlenecks within the manufacturing system are identified and reconfiguration activities (e.g. better tooling and additional machines) are discussed.

The production structure calendar developed by Reinhart & Reinhart & Pohl [39] provides a strategic tool for planning and visualizing adaptions of the manufacturing system. Therefore, the product and manufacturing resource lifecycles are modelled qualitatively considering external cyclic influences of a manufacturing company.

Karl et al. [40] developed a methodology to evaluate the strategic reconfigurability of assembly manufacturing resources. Cyclic factors like product or technology lifecycles are considered in order to influence the resource lifecycle.

Summarizing, the interdependencies of the technology and the manufacturing resource are not well considered. The majority of the mentioned approaches focus either the manufacturing resource or the technology. An integrated approach on the tactical level of the technology management needs to consider both aspects simultaneously.

2.3. Shortcomings

Based on the review of existing methods and frameworks three future areas of activity are derived and justified in the following: (1) quantitative modelling of internal cyclic influencing factors, (2) linking technologies to manufacturing resources as well as (3) identifying technological need for action proactively.

(1) Extensive research is being carried out studying single external cyclic influencing factors (e.g. lifecycle models of markets, products and business [41]). But for documenting and visualizing dynamic behavior methods have to cope with the complexity arising from the interdependencies of cycles [11]. As demonstrated above there exist only few methods considering the interdependencies of product, technology and manufacturing resource lifecycle of a manufacturing company. Besides, most of them are still on a conceptual level dealing with qualitatively modelled or schematic recurring patterns, not referencing specific technologies or resources. The interdependencies of external and internal cyclic influencing factors (e.g. production cycle of a product [42, 43]) and resulting competitive advantages need to be further investigated. The production cycle in this context comprises the time interval from start of production of a component until its end. The production stages of a component (or even product) are not necessarily equal to the product lifecycle from marketing perspective and even focus different strategic objectives (cf. [42]).

(2) The aforementioned approaches outline technologies not considering the age, maintenance costs or downtimes of established machines. Vice versa, relevant methods focusing on cycle-oriented planning of manufacturing resources do not consider the assessment of available alternative production technologies. There is a missing link in thinking of alternative production technologies for existing products. Especially industries and companies faced with product lifecycles over ten years (e.g. commercial vehicle or mechanical engineering industry) need to modernize their production technologies continuously independent of product innovations [cf. 44].

(3) The importance of technological modernization activities of manufacturing processes is seen as a key driver to gain competitive advantages (cf. [44, 45]) without reference to company's R&D expenditures [46]. The acquisition of innovative technologies and manufacturing resources from external supplier is a valid source for non-R&D-intensive firms modernizing their production structure (cf. [47]). However, methods supporting the continuous identification of technological need for action concerning established manufacturing processes are scarce. For this purpose both the strategic and operational level of technology management must be taken into account. Talonen & Hakkarainen ([48, 49]) bring forward the argument, that due to the large shift between these two dimensions, a tactical level in the management of technology is required. "The essence of the tactical level is to provide conditional strategic agility in a shorter response time" [48, p. 4]. Therefore this level is particularly suitable for continuous planning of technological modernization activities within the midterm horizon.

2.4. Objectives of the proactive management approach

Focusing especially on the quantitative modeling of dynamic interdependencies regarding internal and external cyclic influencing factors, this approach goes far beyond existing methods of Production Technology Management. Paying particular attention to specific cycles by linking the production, technology and manufacturing resource lifecycle enables the proactive identification of technological need for action.

Proactive Management of Production Technologies (PMPT) is characterized by continuously assessing established production technologies as well as identifying, evaluating and acquiring technological alternatives and capabilities in advance of needs (cf. [9, 50, 51]). This also includes the assessment of manufacturing resources and the integration of tasks of investment planning [51], whereby the latter signifies coordination of activities [50].

2.5. Benefits of cycle-oriented Production Technology Management

Some decisions cannot be made correctly in the long term, e.g. at the beginning of the product lifecycle, and have to be revised at specific lifecycle stages [42]. The understanding and the modelling of production-relevant cyclic influencing factors give advantage for detecting, scheduling and assessing technological needs for action [11]. The consideration of current and future requirements of recurring patterns helps to avoid mistaken investments. For example, the premature standardization and automatization of production processes to lower costs during a products growth stage, although high flexibility in a dynamic market environment is needed [42]. Furthermore, both the conscious synchronization and asynchronization of implementing alternative product and production technologies can be controlled by visualizing cyclic behavior of relevant influencing factors. Further on, cycle-stage specific competitive advantages (cf. [43]) and the estimation of the entering date can be derived by modeling cycles. This supports evaluating the suitability of the currently used production technologies and identifying the technological need for action timely if necessary.

3. Proactive Management of Production Technologies

The framework is designed as a method including four steps, shown in Figure 3: (1) Systematization of the product and process structure, (2) Modelling of production-relevant cycles, (3) Identification of technological need for action and the (4) Evaluation of alternatives.

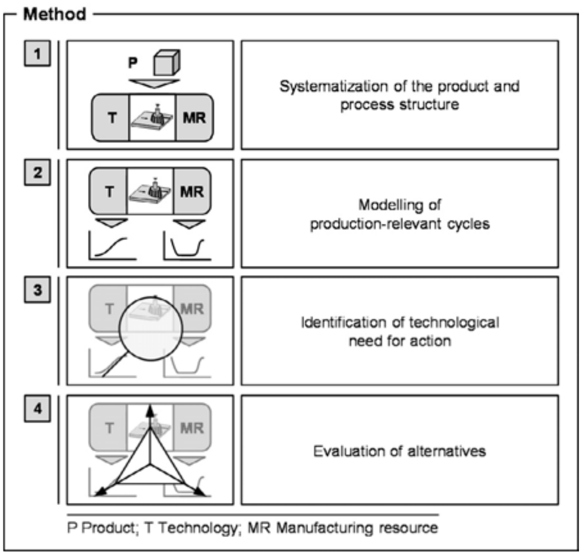

Fig. 3. Overview of the method

3.1. Systematization of the product and process structure

In the first step, both the product and the process structure have to be analyzed. The former is required to systematically gather information of the actual stage of the production cycle of a component. Since the same component is often part of various products, the correlation between components and products is regarded to model the production cycle quantitatively in the following step. The lifecycle of a component often differs from that of the product. For example, the lifecycle stage of axles or motors of a commercial vehicle do not automatically change when introducing a new truck model and vice versa. Therefore, the production cycle of a component is by default not identical to the products lifecycle. Once the established production technologies are recorded, they are assessed. The assessment is based on the property-profile model developed by Reinhart & Schindler [6] and Karl et al. [40]. For maintaining and structuring the gained knowledge about the product-process structure company-wide, an ontology is appropriate (cf. e.g. [52]). An ontology includes a formally structured representation of relevant knowledge, relations and rules [52].

3.2. Modelling of production-relevant cycles

After the product and process structure is defined and well documented, production-relevant internal and external cyclic influencing factors have to be modelled. Based on prior publications, the product lifecycle (respectively the production cycle), the technology and the manufacturing resource lifecycle are regarded as the most important ones (e.g. [2, 12]). For modelling these cycles a company needs to collect quantitative data from different sources of at least the past 10 years, especially from manufacturing planning (e.g., production volume), maintenance (e.g., failure rate of equipment), product management (e.g., influencing factors) and sales (e.g., sales volume). The data is used for statistical determination of recurring patterns over time and finally to improve the forecast of cycles. Since the lifecycle of components often differ from those of the product, the focus lies on the production cycle, which is the important one in view of the Production Technology Management (compared to the product lifecycle in view of marketing). While the technology lifecycle is modelled by applying the method for defining the maturity of production technologies [24], the manufacturing resource lifecycle is modelled according to Moubray [26] considering quantitative data for describing the failure performance of a specific machine.

3.3. Identification of technological need for action

Temporally and structurally recurring patterns, as modelled in step 2, support the prediction of future behavior of e.g. manufacturing resources. This helps to derive technological need for action timely. As stated in section 1, the technological need for action can be classified (cf. Figure 4) according to (1) substitution potential, (2) substitution need and (3) deficits concerning properties. In order to identify technology's properties deficit timely, a prospective technology-oriented requirement profile has to be derived from the modelled production cycle of a component. The work of [6, 19 and 42] serve as a solid foundation by showing phase-specific characteristics important to the company´s competitive situation, for instance, to meet the phase-specific requirements of evaluation criteria like quality, technology maturity, technology potential, profitability and flexibility [6].

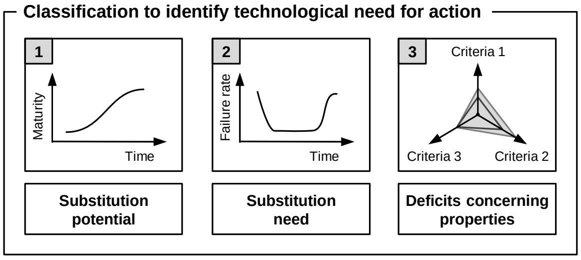

Fig. 4. Classification to identify technological need for action

Prospective distinctions of the cycle-derived requirement profile and the existing profile of properties of a process chain (cf. step 1) show future technological need for action. In addition, the current phase of the manufacturing resource and technology lifecycle show specific needs for technological modernization if necessary. A high failure rate of a manufacturing resource, under consideration of the age, implies the end of the lifecycle (substitution need), for example. Due to limited financial resources, a prioritization of identified needs for technological substitutions has to take place.

3.4. Evaluation of alternatives

Once the needs for technological substitution are prioritized potential alternative production technologies have to be identified and evaluated systematically. A specification of requirements for the technology and/or manufacturing resource must be created containing the following information amongst others: materials to be processed, rough geometry dimensions, weight and shape as well as expected number of units [53]. This specification serves as a basis to match the aforementioned requirements with the technology’s capabilities. Finally, the identified production technologies have to be evaluated based on criteria such as technology maturity, technology potential and profitability.

4. Conclusion and Outlook

Manufacturing companies are facing a dynamic market environment resulting in tough global competitive conditions. In order to stay competitive production technologies are seen as a key driver for efficiency in production and the development of competitive advantages. However, a technology´s suitability is changing over time. Therefore, it is an essential task to continuously detect whether the established technologies will fulfil current and future requirements or if there are promising alternatives available. Going far beyond existing methods of production technology management this approach pays particular attention to production-relevant cycles by linking the production, technology and manufacturing resource lifecycle. The need for technological modernization of manufacturing processes can be identified proactively integrating the assessment of manufacturing resources and the tasks of investment planning. Supporting this purpose, a conceptual framework and a method consisting of four steps are presented.

First, both the established products and the associated production technologies have to be analyzed and assessed. Subsequently, the production-relevant internal and external cyclic influencing factors have to be identified and modelled. The derived prospective technology-oriented requirements profile will show technological need for action timely. To ensure the systematic identification of suitable alternative technologies a specification of requirements is derived based on the prioritization.

Future research activities will initiate the quantitative modelling of interdependencies of product, technology and manufacturing resource lifecycles within a manufacturing company. A production cycle-oriented requirements model has to be designed, determining company or industry specific influencing factors.

Acknowledgements

The German Research Foundation (DFG) funds this research and development project. We extend our sincere thanks to the DFG for the generous support of the work described in this paper, resulting from the subprojects T2 and B3 in the framework of the Collaborative Research Centre 768 “Managing cycles in innovation processes – Integrated development of product service systems based on technical products”.

References

[1] Schuh, G., Graw, M., Schön, N., 2014. Exploitation-oriented Manufacturing Technology Development. Procedia CIRP 17, 680–685.
[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] 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.
[4] 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.
[5] Klocke, F., 2009. Production Technology in High-Wage Countries – From Ideas of Today to Products of Tomorrow, in: Schlick, C.M. (Ed.), Industrial Engineering and Ergonomics. Springer Berlin, Heidelberg, pp. 13–30.
[6] 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, pp. 391–396.
[7] Brown, S., 2001. Managing process technology – further empirical evidence from manufacturing plants. Technovation 21 (8), 467–478.
[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, Berlin, Heidelberg, pp. 105–115.
[10] 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.
[11] 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.
[12] Pohl, J., 2014. Adaption von Produktionsstrukturen unter Berücksichtigung von Lebenszyklen. 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] Höft, U., 1992. Lebenszykluskonzepte: Grundlage für das strategische Marketing- und Technologiemanagement. E. Schmidt, Berlin.
[16] Zehbold, C., 1996. Lebenszykluskostenrechnung. Gabler, Wiesbaden.
[17] Levitt, T., 1965. Exploit the Product Life Cycle. Harvard Business Review 43 (Nov.-Dec.), 81–94.
[18] Rink, D.R., Swan, J.E., 1979. Product life cycle research: A literature review. Journal of Business Research 7 (3), 219–242.
[19] Hayes, R.H., Wheelwright, S.G., 1979. The dynamics of process-product life cycles. Harvard Business Review 57 (2), 127–136.
[20] Taylor, M., Taylor, A., 2012. The technology life cycle: Conceptualization and managerial implications. International Journal of Production Economics 140 (1), 541–553.
[21] Ford, D., Ryan, C., 1981. Taking technology to market. Harvard Business Review 59 (2), 117–126.
[22] Sommerlatte, T., Deschamps, J.-P., 1985. Der strategische Einsatz von Technologien - Konzepte und Methoden zur Einbeziehung von Technologien in die Strategieentwicklung des Unternehmens, in: , Management im Zeitalter der strategischen Führung. Gabler, Wiesbaden, pp. 37–76.
[23] Brousseau, E.B., Barton, R., Dimov, S., Bigot, S., 2009. Technology maturity assessment of micro and nano manufacturing processes. 4M/International Conferences on Micro Manufacturing, ICOMM, 257–262.
[24] 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.
[25] Greitemann, J., Stahl, B., Michels, N.V., Lohmann, B., Reinhart, G., 2014. Quantitative Model of the Technology Lifecycle for Forecasting the Maturity of Manufacturing Technologies. IEEE Engineering Management Society, Singapore, Chapter 290–294.
[26] Moubray, J., 1997. Reliability-centered maintenance, 2nd ed. Industrial Press, New York.
[27] Klutke, G., Kiessler, P.C., Wortman, M.A., 2003. A critical look at the bathtub curve. IEEE Trans. Rel. 52 (1), 125–129.
[28] Schmenner, R.W., 1983. Every factory has a life cycle. Harvard Business Review 61 (2), 121–129.
[29] Attri, R., Grover, S., 2015. Production system life cycle: An inside story. IJISE 19 (4), 483.
[30] Westkämper, E., Constantinescu, C., Hummel, V., 2006. New paradigm in manufacturing engineering: Factory life cycle. Prod. Eng. Res. Devel. XIII (1), 143–146.
[31] Utterback, J.M., Abernathy, W.J., 1975. A dynamic model of process and product innovation. Omega 3 (6), 639–656.
[32] Stahl, B., Diepold, K.J., Pohl, J., Greitemann, J., Plehn, C., Koch, J., Lohmann, B., Reinhart, G., Zäh, M.F., 2013. Modeling Cyclic Interactions within a Production Environment Using Transition Adaptive Recurrent Fuzzy Systems, in: Bakhtadze, N., Chernyshov, K., Dolgui, A., Lototsky, V. (Eds.), Proceedings of the 2013 IFAC Conference on Manufacturing Modelling, Manangement and Control. Elsevier, IFAC, pp. 1979–1984.
[33] 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.
[34] Swamidass, P.M., 1987. Planning for manufacturing technology. Long Range Planning 20 (5), 125–133.
[35] Ettlie, J.E., 1988. Manufacturing technology policy and deployment of processing innovations. Ann Oper Res 15 (1), 1–20.
[36] 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.
[37] 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.
[38] Hon, K., Xu, S., 2007. Impact of Product Life Cycle on Manufacturing Systems Reconfiguration. CIRP Annals - Manufacturing Technology 56 (1), 455–458.
[39] Reinhart, G., Pohl, J., 2011. Production Structure Calendar - A Strategic Planning Tool. 44th CIRP CMS Conference on Manufacturing Systems, 1 June 2011, Madison, USA.
[40] Karl, F., Reinhart, G., Zaeh, M.F., 2012. Strategic Planning of Reconfigurations on Manufacturing Resources. Procedia CIRP 3, 608–613.
[41] Peltoniemi, M., 2011. Reviewing Industry Life-cycle Theory: Avenues for Future Research. International Journal of Management Reviews 13 (4), 349–375.
[42] 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.
[43] Hayes, R.H., Wheelwright, S.C., 1984. Restoring our competitive edge: Competing through manufacturing. Wiley, New York.
[44] Lay, G., Schirrmeister, E., 2004. Management der Produktionsmodernisierung, in: Barske, H., Gerybadze, A., Hünninghausen, L., Sommerlatte, T. (Eds.), Das innovative Unternehmen. Produkte, Prozesse, Dienstleistungen. Symposion Publishing, Düsseldorf, Kapitel 8.2.
[45] Armbruster, H., Kinkel, S., Lay, G., Maloca, S., 2005. Techno-Organisational Innovation in the European Manufacturing Industry. European Manufacturing Survey Bulletin 1 (December 2005).
[46] Kirner, E., Kinkel, S., Jaeger, A., 2009. Innovation paths and the innovation performance of low-technology firms—An empirical analysis of German industry. Research Policy 38 (3), 447–458.
[47] Som, O., 2012. Innovation without R & D: Heterogeneous innovation patterns of non-R & D-performing firms in the German manufacturing industry. Springer Gabler, Wiesbaden
[48] Talonen, T., Hakkarainen, K., 2005. The Missing Link: The Tactical Level in the Management of Technology, in: Khalil, T.M. (Ed.), IAMOT 2005. 14th international conference on management of technologies, may 22-26, 2005, Vienna, Austria.
[49] Hakkarainen, K., 2006. Strategic management of technology: From creative destruction to superior resilience. Acta Wasaensia. Universitas Wasaensis.
[50] Lindberg, P., 1990. Strategic Manufacturing Management: A Proactive Approach. Int Jrnl of Op & Prod Mnagemnt 10 (2), 94–106.
[51] Ward, P.T., Leong, G.K., Boyer, K.K., 1994. Manufacturing Proactiveness and Performance. Decision Sciences 25 (3), 337–358.
[52] Harms, R., Fleschutz, T., Seliger, G., 2010. Life cycle management of production facilities using semantic web technologies. CIRP Annals - Manufacturing Technology 59 (1), 45–48.
[53] Greitemann, J., Plehn, C., Koch, J., Reinhart, G., 2014. Strategic Screening of Manufacturing Technologies, in: Zaeh, M.F. (Ed.), Enabling Manufacturing Competitiveness and Economic Sustainability. Springer International Publishing, Cham, pp. 321–326.