INTRODUCING CONSTRAINTS TO ENHANCE INTEGRATION AT THE DESIGN-MANUFACTURING INTERFACE OF NEW PRODUCT DEVELOPMENT

Bix, Susanne
University of Wuppertal, Germany

Abstract

Enhancing integration at the design-manufacturing interface in new product development is increasingly important for industrial players to keep up with shorter product lifecycles and innovative dynamics. While abundant research addresses the topic, industrial adoption remains incremental. The paper identifies insufficient recognition of organizational factors and over-emphasized complexity as possible hindrances in industrial application of existing theory. A new approach is outlined that introduces constraints as stimuli to consider manufacturability aspects in the design process. Recent observations in new venture creation and the psychological nature of design processes serve as inspiration. The approach is developed in the empirical context of electrified powertrain systems; initial analyses indicate significant potential for enhanced integration. Explorative case studies are planned to identify constraint designs and forms of organizational embedding that are able to influence product and process engineering. CAD software add-in, motion-time system analyses and manufacturing cost projections are developed as proxies to be introduced as constraints in the design process.

Keywords: Design process, Integrated product development, Organizational processes, Entrepreneurship, Complexity reduction

Contact:
Susanne Bix
University of Wuppertal
Chair of Technology and Innovation Management
Germany
susanne.bix@uni-wuppertal.de

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 2: Design Processes | Design Organisation and Management, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION AND PROBLEM STATEMENT

Shorter product life cycles, growing product variety and accelerated innovation dynamics increase the internal and external complexity of new product development (NPD) processes in large-scale industrial environments, particularly when radical innovation and technology are involved. Optimizing the NPD process and outcome for different objectives has been the ambition of a broad range of research in the context of Design for X and integrated product development, with the design-manufacturing interface being particularly pronounced. In spite of abundant research as well as continuously increasing CAx support and data integration, which should seemingly further facilitate integration efforts between design engineering and manufacturing, substantial challenges remain. Industrial application of existing methods remains low in many cases as described in recent research efforts, and integration of the manufacturing perspective in design engineering exhibits deficiencies (Ehrlenspiel and Meerkamm 2013, Schuh et al. 2013, Claus et al. 2015).

This paper employs qualitative research to analyse integration following a framework of coopetitive behaviour and introduces an alternative approach to steer complex NPD processes towards a manufacturability-optimized outcome by introducing "constraints" for producibility into the design process. The approach is inspired by an entrepreneurship perspective and takes into account often-neglected factors of organizational embedding and human behaviour and strives towards complexity reduction.

The approach is developed in the large-scale industrial context of electrified powertrain system development and production of a German car manufacturer. The innovative nature of the considered technology as well as its volatile market dynamics constitute a fruitful environment for the applied explorative research methodology with particular sensitivity towards the empirical context. The proposed approach builds on the existing research body and aims at extending present theory. The terms "producibility" and "manufacturability" are used interchangeably throughout the paper.

Research questions to guide the study are:

- How is current integration at the manufacturing-design interface of NPD evaluated from a cross-functional coopetition perspective?
- How does the introduction of producibility constraints impact coopetitive behavior at the manufacturing-design interface?
- Which constraint designs of producibility constraints are able to enhance coopetitive behavior at the manufacturing-design interface?
- Which forms of organizational embedding of producibility constraints are able to enhance coopetitive behavior at the manufacturing-design interface?

Introducing constraints to the NPD process and building on those to encourage innovative solutions and to consider manufacturability concerns is at the core of the research. Discussing the approach in the light of the ICED17 subtheme "Design to embrace resource limitations" provides an interesting notion.

2 STARTING POINT: EMBRACING POTENTIAL SHORTCOMINGS OF EXISTING THEORY FOR INDUSTRIAL APPLICATION

In 2007, Gill asked "Adoption of Design Science by Industry — Why so Slow?". A range of research efforts addresses this question likewise and confirms that the implementation of existing design theory in industrial practice has been slow and incremental, in particular for integrated product development along the design - manufacturing interface (Björk and Ottoson 2007, Lindemann et al. 2001, Grabowksi 1997, Ehrlenspiel and Meerkamm 2013, Jürgens 2000, Jahn et al. 2002, Lorenz 2008, Claus et al. 2015). While respective reasons are manifold, two streams of argumentation stand out in criticising existing methods: Insufficient consideration of "soft" factors which take account for human behaviour and which are organizational in nature on one side and over-emphasized complexity on the other side.

2.1 Insufficient recognition of organizational factors

Regarding organizational aspects, the following relationship may be derived from literature: An increasing need for specialization in technology dynamics fosters the formation of distinct cultures with considerate differences between the "design engineering culture" and the "manufacturing engineering culture", respectively. Already Burns and Stalker (1961) suggest to adopt a perspective of anthropologists to describe communication specialities and differences in mindset between design engineers and manufacturing engineers. Ettlie and Stoll (1990), Wheelwright and Clark (1992), Jürgens (2000) and Dougherty (1992) emphasize the resulting interpretative barriers and identify the education system as initial root cause for the "elite formation" of design engineers hindering integrated product development. Ettlie and Stoll (1990) bring up the case of Japan, where engineering education fosters cooperation between manufacturing and design, with the resulting ability to design manufacturing-ready products, often envied by Western corporations.

The resulting cultural gap impedes communication and cooperation between the functional groups, which, under the notion of information stickiness as identified by Teece (1999) and von Hippel (1994) in this context, further aggravates functional integration.

Typical organizational mechanisms in large corporations work as additional obstacles at the design-manufacturing interface, notably power distribution that disadvantages manufacturing, functional organization structures, functional career paths and incentivization (Paashuis 1998, Jürgens 2000, Wheelwright & Clark 1992). Regarding the latter, Teece (1999) attests principal-agent distortions, because managers responsible for a certain product development are often with a tenure too short to bear the manufacturing consequences of this product, while information asymmetry in complex technical projects is given. Likewise, companies provide insufficient incentives to early manufacturing involvement, as they tend to reward fire-fighting more than foresighted optimization.

Many researchers conclude that collaborative structures for integrated NPD as suggested by theory have been implemented in many cases, however have remained ineffective due to missing recognition of these organizational factors.

2.2 Over-emphasized complexity for industrial application

Empirical surveys to examine the acceptance of NPD methods in industrial applications of both Ehrlenspiel and Meerkamm (2013) and Grabowski (1997) state "high theoretical burden" and "high implementation effort" as important reasons for low implementation. Minnaar (2012) evaluates concurrent engineering, as one of the prominent methods enhancing integration at the design - manufacturing interface, to be "hugely complex".

The insufficient consideration of the real context in industrial environments is broadly criticised: "Unfortunately much research into design is undertaken by researchers who don't have real insights into or knowledge of its practice" (Gill 2007). Lindemann et al. (2001) and Bichlmaier (2000) postulate the need for pragmatic and less abstract methods to optimize NPD.

Psychological examinations of the engineering design process support the notion of striving towards simplicity: Hacker (2002) found that the cognitive design process does not always follow a stepwise systematic process (as requested in the VDI 2221 norm as an example of German industrial standards), but takes "opportunistic" shortcuts based on previous experiences.

In addition, existing methods may not necessarily support the emergence of radical innovations but tend to reinforce the status quo and promote only incremental innovation (Schuh et al. 2013, Teece 1999).

2.3 Going beyond interface management research

The integration of production and design in NPD can be described in large parts as a typical interface problem, with the latter being fundamentally addressed in management research (as examples, see Albach 1992, Albach 1994, Brockhoff 1995, Trott 2012, Schmidt-Tiedemann 1988). Nevertheless, the research questions at hand require going beyond extant interface management research for several reasons outlined in the following.

While the interface between R&D and marketing has been thoroughly researched, the R&D - production interface is often neglected in existing studies (Song et al. 1997, Brettel et al. 2011). Furthermore, we follow Olson et al. (2001) postulating that for successful cross-functional NPD integration, mere interaction and communication may be "a necessary but not a sufficient condition for functional integration". This suggests the need for a deeper understanding of function-specific targets and mechanisms at the production-design interface than interface management research is likely to offer. Finally, extant empirical research evaluating interface integration is prevailingly quantitative, often relying on large-scale surveys (e.g., Olson et al. 2001, Brettel et al. 2011, Song et al. 1997). Potential shortcomings of employing such presuppositional, yet unidirectional instruments for complex phenomena such as cross-functional integration will be highlighted in 4.1. The paper proposes qualitative research as a methodical alternative to generate a deeper understanding, details are likewise provided in 4.1

3 PROPOSED IDEA TO ENHANCE INTEGRATION: INTRODUCING "CONSTRAINTS" FOR PRODUCIBILITY INTO THE DESIGN PROCESS

The approach that is introduced in this paper takes the identified shortcomings as a starting point and integrates them into a method to influence the NPD process from a manufacturability perspective that strives for simplicity in industrial application. The underlying idea is to avoid any intensive involvement in the intricate loops and interaction schemes of the NPD process. Instead, stimuli in form of "constraints" expressing producibility concerns are introduced to the design process. The idea of "constraining" the innovation process is inspired by new venture creation, where resource constraints (often money, expertise or time) are a common feature of reality. The emergence of radical innovations may be partially owed to these constraints, as Amazon CEO and founder Jeff Bezos suggests (Pareek et al. 2016):

> *"I think frugality drives innovation, just like other constraints do. One of the only ways to get out of a tight box is to invent your way out."*

The impact of constraints on creative design processes is discussed broadly recently, see Lampel et al. (2014), Lombardo (2014), Korhonen and Välikangas (2014) and Sull (2015).

3.1 Psychological background

Relevant psychological foundations can be found in von der Werth and Weinert's (2002) examinations of the cognitive design process. The cognitive problem solving process takes place within the "problem space", which includes all theoretically possible solutions. However, the actual problem solving focusses on only a frictional part of it, i.e. denominated "search space". Typical analytical engineering methods tend to reduce the search space, e.g. by systematically analysing options and eliminating illicit ones. Introducing stimuli such as questions, analogies or the suggested "constraints", on the contrary, extend the search space and allow for more creative solutions. In connection with the wording "constraint", this may at first sound counterintuitive. Given that the suggested "constraints" serve as stimuli to consider downstream requirements during the design process rather than as limiting factors in the actual product design, the notion becomes clearer. Von der Werth and Weinert (2002) also find that asking the right questions encourages design engineers to considerate adjacent topics and potential consequences of their design, further suggesting the use of stimuli for enhanced design - manufacturing integration.

3.2 Relating to requirements engineering

The suggested approach is building on the existing research in the field of requirements engineering. Constraints that express producibility concerns in a simplified way ultimately represent requirements towards the product and process that is being developed. According to the classification of Weber (2007), who distinguishes "characteristics" which can be directly determined by the designer from "properties" which cannot be directly influenced by the designer, the suggested producibility constraints are considered to be "properties". This differentiates the suggested method from state-of-the-art requirements engineering as used in industrial applications, which focuses on technical product definitions and their interrelationships and tends to keep track of secondary "properties" in separate systems (Mayer-Bachmann 2008).

Notably, the creative potential in introducing *property* constraints (as opposed to *characteristics* constraints) to the NPD process lies exactly in the indirect nature of influenceability, encouraging the designer to think outside of his/her typical boundaries.

3.3 Focus on context-sensitivity

Taking account for contextual specifics in large-scale industrial settings and assessing organizational factors that support or impede cooperation at the design-manufacturing interface are predominant objectives of the research project at hand. This requires engaging in empirical research before completing the theoretical body of the proposed method. In consequence, a qualitative explorative research methodology is chosen which will be described in more detail in the subsequent section.

4 RESEARCH DESIGN

4.1 Research methodology

Case study research is employed to generate an in-depth understanding of the actual interface integration of design and production in a large-scale industrial setting and to act out the proposed idea of introducing constraints to enhance integration. Complexity and richness of the phenomenon in focus suggest taking a qualitative approach (Eisenhardt and Graebner 2007, Yin 2013, Siggelkow 2007). Partially contradictory results of large-scale quantitative surveys studying cross-function NPD integration (e.g. compare Neubauer (2008) with Song and Swink (2002)) point towards the same direction. The author's persuasion, that shortcomings of existing methods are strongly interrelated with the real-life work surrounding (see 2.1 and 2.2), emphasises capturing and analysing the context as central aspects for research success; again suggesting a qualitative approach. Lastly, the idea of introducing constraints is new and fairly unformed. Qualitative research will help to understand possible working mechanisms of the new method and to generalize outcomes towards theoretical contributions. For the latter, qualitative observations from semi-structured interviews as well as direct and participative observations will be codified and analysed following Gioia (see Gioia et al. 2012, Flick 2005, Corbin and Strauss 1990). Propositions for theory extension will hence be developed in a recursive manner. Qualitative research will selectively be complemented by quantitative assessment where this supports reasoning (Yin 2013, Gibbert et al. 2008).

A single-case embedded design case study is conducted; the case setting is a German automotive original equipment manufacturer. The products which are examined regarding their NPD process are electrified powertrain systems that are developed and produced by the respective company. Start of production is 4 years from the point of time where research efforts begin; hence the study covers several phases along the development process from the early concept phase onwards. Expected production volumes qualify the setting as large-scale industrial.

The structure of the case study is as follows: First, an in-depth understanding of the current integration between design and production is created. To generate expounding insights, collaboration at the interface is explained with the help of coopetition, a concept that assumes joint occurrence of cooperation and competition (Ghobadi 2012). Details are provided in 4.2.
Subsequently, the introduction of constraints to enhance integration is simulated in the experimental setup as described in 4.3. As a last step, potential enhancements in integration resulting from the introduction of constraints will again be analysed based on the dimensions of coopetition.
Analytic generalizations to be made from research results will lastly be formulated to contribute to existing theory on the design-production interface of new product development.

4.2 Cross-functional coopetition

Coopetition, assuming the simultaneous occurrence of cooperative and competitive behaviour between different actors, can be found at different levels of collaboration, including countries, enterprises or business departments (Luo et al. 2006, Tsai 2002). Having emerged as a solitary research field initially with the work of Brandenburger and Nalebuff (1996), it features a range of research studies on all levels today (see Ghobadi 2012 or Bengtsson and Kock 2014 for an overview). Theoretical antecedents include game theory, the resource-based view and social network theory (Strese et al. 2016). Different conceptualizations of relevant coopetitive dimensions are laid out in extant research; the present paper follows Luo et al. (2006) and assumes three constructs framing coopetitive behaviour at a intrafirm level: Cross-functional cooperative intensity as "the extent of the frequency and closeness of lateral social interactions among functional areas" (Luo et al. 2006), cross-functional cooperative ability as "the ability to assimilate […] in lateral interactions among functional areas" (Luo et al. 2006) and cross-functional competition as "the degree to which departments compete both for limited tangible and intangible resources" (Luo et al. 2006).

4.3 Experimental setup: Introducing constraints

The experimental setup within the case study comprises three embedded case studies, each of them presenting another producibility constraint which is introduced in the NPD process. The case studies differ in their respective constraint design; details are provided in subsections 4.3.1 to 4.3.3.

For each case study, ~15 active participants in the respective NPD process are interviewed, covering product design engineers, process design engineers and manufacturing engineers. Insights resulting from the interviews serve as inputs for theory extension as described in 4.1.
The case studies examine three different constraint designs differing by their "level of abstraction", expressing the degree to which the design engineer can influence the respective features following Weber's classification (Weber 2007). Additionally, Organizational factors that support or impede enhanced integration at the design - manufacturing interface of NPD are interrogated in each case study interview. For all different constraint designs, questions regarding the organizational embedding follow the same structure.

Introducing producibility constraints requires a certain amount of preparatory work. The largely abstract notion of producibility needs to be expressed in a concrete and quantified way in order to serve as a constraint in the design process. Certainly, the abundant research on DFM, DFMA, axiomatic design and related theory provides a broad range of options. While the author builds largely on this research to formulate the constraint design, the ambition of this study is to strive for simplicity and suitability for the considered empirical context. Hence, three constraint designs are developed, which make use of producibility "proxies" that are meaningful in the considered empirical setting.

4.3.1 Type, number and variety of fasteners

The choice of fasteners that design engineers make for the functional product design has a significant impact on required assembly time. While certain fastener types are easier to assemble than others (e.g. clips as compared to screws) and require a qualitative classification, number and variety of fasteners should simply be minimized from a manufacturability perspective.
For the case study, a classification of fastener combinations that can be used for electrified powertrain systems is developed, evaluating fasteners with regard to ease of assembly. Additionally, a software add-in for the CAD tool used by the respective design engineers is programmed, which enables visualizing the evaluation of the chosen fastener combination instantaneously during the design process.

4.3.2 Assembly time

Motion-time systems used in industrial engineering allow assessing the required manufacturing time for a certain product design in a standardized and reproducible way. For the case study, a Microsoft Excel-based tool is developed that allows calculating required assembly time from CAD files based on MTM (methods-time measurement) building blocks.

4.3.3 Variable manufacturing costs

A broad range of factors influences the variable manufacturing costs, regarding both process design (e.g. degree of automatization, required number of machine operators, shift model, line balancing) and product design (e.g. assembly time, quality requirements, product handling). For the case study, a Microsoft Excel-based tool is developed that allows a multivariate approximation of variable manufacturing costs depending on the chosen process and product design.

5 FIRST RESULTS: SETTING THE BASELINE FOR EMPIRICAL RESEARCH

In order to assess optimization potential for the empirical case study research, the status quo of integration at the design - manufacturing interface in the empirical context at the German car manufacturer is assessed. Insufficient consideration of manufacturing in the early stage of the development process is quantified by means of a detailed analysis of a product's design regarding its manufacturability. Qualitative aspects of the current collaboration at the design - manufacturing interface are examined based on semi-unstructured interviews with employees involved in the NPD process and provide a base for initial hypotheses on the organizational embedding dimension. The results, detailed in the subsections 5.1 and 5.2, display considerate potential for optimization and set the baseline for the empirical application of the suggested new approach.

5.1 Quantitative assessment

For a development product which will be further assessed in the case studies to follow, the CAD model of the current product design is assessed regarding its manufacturability. Ease of assembly of the chosen fasteners, required assembly time based on a comprehensive MTM analysis and manufacturing costs based on the current process design are evaluated.
For identified issues of manufacturability, alternative product design solutions are provided and likewise quantitatively evaluated, e.g. alternative fastener combinations or adjustments regarding the product geometry that would facilitate the assembly procedure.

Figure 1 summarizes important results of the quantitative analysis. Identified manufacturability issues are grouped in three frequent issue patterns:

- *Fastener combinations (type, number, variety):* Screws, clips, plug types and lugs chosen by product design engineers for which an alternative manufacturability-optimized fastener combination was identified.
- *Prioritizing material costs over manufacturing costs*: Attachment parts or product sections were designed to optimize material costs, neglecting resulting higher manufacturing costs. This represents a typical conflict of goals with product engineers optimizing material cost and manufacturing engineers optimizing manufacturing costs.
- *Process engineering-related issues*: Features in process design for which an alternative manufacturability-optimized solution was identified.

Classification of manufacturability issues	Assembly time before manufacturability optimizations (min)	Assembly time after manufacturability optimizations (min)	Potential for manufacturability optimization (% of full assembly time)
Fastener combinations (type, number, variety)	28,3	3,4	23,1%
Prioritizing material costs over manufacturing costs	8,0	0,6	6,9%
Process engineering - related issues	7,5	2,8	4,3%

Figure 1. Quantitative analysis of potential assessment

5.2 Qualitative assessment

In the following, initial observations of current challenges at the design - manufacturing interface as described by the interview partners are summarized.

- Manufacturing representatives are only selectively involved during earlier phases of NPD, process engineers assume the responsibility to identify and discuss manufacturability issues.
- Comprehensive quantitative analyses of product design regarding manufacturability tend to be avoided due to high effort requirements of existing methods.
- Cooperation of manufacturing and product engineering is believed to be only effective if quantitative targets are set and tracked in existing project management cockpits.
- Existing qualitative checklists to ensure a manufacturability-optimized product and process design are perceived as an end to themselves without real impact on manufacturability.
- Linking product-process-causalities represents a major challenge due to divided responsibility of process and product engineering.
- On an operational level, points of friction between manufacturing and design are scarce; NPD organisation provides few occasions for competition at eye level.

- Hierarchical power is often required to solve issues at the design - manufacturing interface due to strong functional orientation and insufficient power of integrating project managers.

6 OUTLOOK

Empirical case study research will be conducted throughout 2017. Results and analytic generalization are expected to contribute to existing theory on integrated new product development at the design - manufacturing interface as well as on cross-functional competitive behaviour.
Seizing the context of large-scale industrial settings is at the core of the research. Exposing dependencies of the proposed method on specific context features is pursued as another aspect of result interpretation.

Furthermore, the author expects to make suggestions on whether the proposed approach may work for properties other than manufacturability as well. For other properties that often struggle to find consideration in product engineering, such as "environmental friendliness" or "ease of maintenance", the approach could possibly find further applications.

REFERENCES

Albach, H. (1992), "Innovation Management and Operations Research", in Bühler, W., Feichtinger, G., Hartl, R.F., Radermacher, F.J. and Stähly, P. (Eds.), *Papers of the 19th Annual Meeting* / Vorträge der 19. Jahrestagung, Operations Research Proceedings, DGOR Deutsche Gesellschaft für Operations Research e.V, Vol. 1990, Springer, Berlin, Heidelberg, pp. 1–25.

Albach, H. (1994), *Culture and technical innovation: A cross-cultural analysis and policy recommendations*, Research report / The Academy of Sciences and Technology in Berlin, Vol. 9, De Gruyter, Berlin.

Bengtsson, M. and Kock, S. (2014), "Coopetition—Quo vadis? Past accomplishments and future challenges", *Industrial Marketing Management*, Vol. 43 No. 2, pp. 180–188.

Bichlmaier, C. (2000), *Methoden zur flexiblen Gestaltung von integrierten Entwicklungsprozessen, Zugl.*: München, Technische Universität, 2000, Produktentwicklung, Utz Wiss, München.

Björk, E. and Ottosson, S. (2007), "Aspects of consideration in product development research", Journal of *Engineering Design*, Vol. 18 No. 3, pp. 195–207.

Brandenburger, A.M. and Nalebuff, B.J. (1996), Co-opetition: 1. *A revolutionary mindset that combines competition and co-operation; 2. The game theory strategy that's changing the game of business*, 1st ed., Doubleday, New York, NY.

Brettel, M., Heinemann, F., Engelen, A. and Neubauer, S. (2011), "Cross-Functional Integration of R&D, Marketing, and Manufacturing in Radical and Incremental Product Innovations and Its Effects on Project Effectiveness and Efficiency", *Journal of Product Innovation Management*, Vol. 28 No. 2, pp. 251–269.

Brockhoff, K. (1995), "Schnittstellen-Probleme: Sechs Fälle aus der Wirtschaftspresse", in Brockhoff, K. (Ed.), *Management von Innovationen: Planung und Durchsetzung: Planung und Durchsetzung, Erfolge und Mißerfolge ; Fallstudien mit Lösungen, Lehrbuch*, Gabler, Wiesbaden.

Burns, T. and Stalker, G.M. (1961), *The management of innovation*, 3. ed., Oxford University Press, Oxford.

Claus, T., Herrmann, F. and Manitz, M. (Eds.) (2015), *Produktionsplanung und –steuerung: Forschungsansätze, Methoden und deren Anwendungen*, Springer Berlin Heidelberg, Berlin Heidelberg.

Corbin, J.M. and Strauss, A.L. (1990), B*asics of qualitative research: Techniques and procedures for developing grounded theory*, Fourth edition, Sage, Los Angeles, London, New Delhi, Singapore, Washington DC, Boston.

Dougherty, D. (1992), "Interpretive Barriers to Successful Product Innovation in Large Firms", *Organization Science*, Vol. 3 No. 2, pp. 179–202.

Ehrlenspiel, K. and Meerkamm, H. (2013), *Integrierte Produktentwicklung: Denkabläufe, Methodeneinsatz, Zusammenarbeit*, 5., überarb. und erweiterte Aufl., Hanser, München.

Eisenhardt, K.M. and Graebner, M.E. (2007), "Theory building from cases. Opportunities and challenges", *Academy of Management Journal*, Vol. 50 No. 1, pp. 25–32.

Ettlie, J.E. and Stoll, H.W. (1990), *Managing the design-manufacturing process*, McGraw-Hill engineering and technology management series, McGraw-Hill, New York.

Flick, U. (Ed.) (2005), *Qualitative Forschung: Ein Handbuch, Rowohlts Enzyklopädie*, Vol. 55628, Orig.-Ausg., 4. Aufl., Rowohlt, Reinbek bei Hamburg.

Ghobadi, S. (2012), *Coopetitive knowledge sharing in cross-functional software development teams*.

Gibbert, M., Ruigrok, W. and Wicki, B. (2008), "What passes as a rigorous case study?", *Strategic Management Journal*, Vol. 29 No. 13, pp. 1465–1474.

Gill, H. (2007), "Adoption of Design Science by Industry — Why so Slow?", *Journal of Engineering Design*, Vol. 1 No. 3, pp. 289–295.

Gioia, D.A., Corley, K.G. and Hamilton, A.L. (2012), “Seeking Qualitative Rigor in Inductive Research”, *Organizational Research Methods*, Vol. 16 No. 1, pp. 15–31.
Grabowski, H. (Ed.) (1997), *Neue Wege zur Produktentwicklung*, Raabe-Innovationen, Raabe, Stuttgart, Wien.
Hacker, W. (2002), “Konstruktives Entwickeln: Psychologische Grundlagen”, in Hacker, W. (Ed.), *Denken in der Produktentwicklung: Psychologische Unterstützung der frühen Phasen*, Mensch, Technik, Organisation, vdf Hochschulverlag an der ETH; Hampp, Zürich, Mering.
Hales, C. (2001), *Managing through organization: The management process, forms of organization and the work of managers*, 2. ed., Business Press Thomson Learning, London.
Hippel, E. von (1994), ““Sticky Information” and the Locus of Problem Solving. Implications for Innovation”, *Management Science*, Vol. 40 No. 4, pp. 429–439.
Jahn, F., Rückert, C., Gaedeke, O. and Pietzcker, F. (2002), “Konstruieren methodisch lehre - Führt die konstruktionsmethodische Ausbildung schon im Studium zu besseren Lösungen?”, in Hacker, W. (Ed.), *Denken in der Produktentwicklung: Psychologische Unterstützung der frühen Phasen*, Mensch, Technik, Organisation, vdf Hochschulverlag an der ETH; Hampp, Zürich, Mering.
Jürgens, U. (2000), “Toward New Product and Process Development Networks: The Case of the German Car Industry”, in Jürgens, U. (Ed.), *New Product Development and Production Networks: Global Industrial Experience*, Springer, Berlin, Heidelberg, pp. 259–287.
Korhonen, J.M. and Välikangas, L. (2014), “Constraints and Ingenuity: The Case of Outokumpu and the Development of Flash Smelting in the Copper Industry”, in Honig, B., Lampel, J. and Drori, I. (Eds.), *Handbook of Organizational and Entrepreneurial Ingenuity*, Elgar original reference, Edward Elgar Publishing, Cheltenham.
Lampel, J., Honig, B. and Drori, I. (2014), “Organizational Ingenuity. Concept, Processes and Strategies”, *Organization Studies*, Vol. 35 No. 4, pp. 465–482.
Lindemann, U., Stetter, R. and Viertlböck, M., “A Pragmatic Approach for Supporting Integrated Product Development”, *Journal of Integrated Design & Process Science*, Vol. 2001 No. Vol. 5, No. 2.
Lorenz, M. (2008), *Handling of Strategic Uncertainties in Integrated Product Development*, Vol. 2008, Utz Wiss.
Luo, X., Slotegraaf, R.J. and Pan, X. (2006), “Cross-Functional “Coopetition”. The Simultaneous Role of Cooperation and Competition Within Firms”, *Journal of Marketing*, Vol. 70 No. 2, pp. 67–80.
Mayer-Bachmann, R. (2008), Integr*atives Anforderungsmanagement: Konzept und Anforderungsmodell am Beispiel der Fahrzeugentwicklung*, Zugl.: Karlsruhe, Univ., Diss., 2007, Reihe Informationsmanagement im Engineering Karlsruhe, Vol. 2007,2, Univ.-Verl. Karlsruhe, Karlsruhe.
Minnaar, S. and Reinecke, R. (2012), “Concurrent engineering with constraint networks”, *The South African Journal of Industrial Engineering*, Vol. 7 No. 2.
Neubauer, S.O. (2008), *Funktionsübergreifende Integration in hochinnovativen Produktentwicklungsvorhaben*, Zugl.: Aachen, Techn. Hochsch., Diss., 2007, Gabler Edition Wissenschaft Entrepreneurship, 1. Aufl., Gabler, Wiesbaden.
Olson, E.M., Walker, O.C., Ruekert, R.W. and Bonnerd, J.M. (2001), “Patterns of cooperation during new product development among marketing, operations and R&D. Implications for project performance”, *Journal of Product Innovation Managem*ent, Vol. 18 No. 4, pp. 258–271.
Paashuis, V. (1998), “The Organisation of Integrated Product Development”, *Advanced Manufacturing*, Springer London, London.
Pareek, U.N., Venkateswara Rao, T. and Khandelwal, A.K. (2016), *HRD, OD, and institution building: Essays in memory of Udai Pareek*, SAGE Publications India Pvt Ltd, Thousand Oaks.
Schmidt-Tiedemann, K.J. (1988), “Die Tripel-Helix - Ein Paradigma modernen Innovationsmanagements”, in Philips GmbH (Ed.), Unsere Forschung in *Deutschland: IV*, Philips, Aachen-Hamburg.
Schuh, G., Hacker, P.A., Wellensiek, M. and Kitzer, P. (2013), “Linking strategy and roadmap: Integrative design of technology, product and production”, in Schuh, G. (Ed.), *Future Trends in Production, Innovation and Technology Management* (2012), Future Trends in Production, Innovation and Technology Management, Apprimus Verlag, Aachen.
Siggelkow, N. (2007), “Persuasion with Case Studies”, *Academy of Management Journal*, Vol. 50 No. 1, pp. 20–24.
Song, M. and Swink, M. (2002), “Marketing-manufacturing joint involvement across stages of new product development. Effects on the success of radical vs. Incremental innovations”, *Academy of Management Proceedings*, Vol. 2002 No. 1, B1-B6.
Song, X.M., Montoya-Weiss, M.M. and Schmidt, J.B. (1997), “Antecedents and Consequences of Cross-Functional Cooperation. A Comparison of R&D, Manufacturing, and Marketing Perspectives”, *Journal of Product Innovation Management*, Vol. 14 No. 1, pp. 35–47.
Strese, S., Meuer, M.W., Flatten, T.C. and Brettel, M. (2016), “Organizational antecedents of cross-functional coopetition. The impact of leadership and organizational structure on cross-functional coopetition”, *Industrial Marketing Management*, Vol. 53, pp. 42–55.

Sull, D. (2015), “The simple rules of disciplined innovation”, available at: http://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/the-simple-rules-of-disciplined-innovation (accessed 29 July 2016).
Teece, D.J. (1989), “Inter-Organizational Requirements of the Innovation Process”, *Managerial and Decision Economics*, No. Vol. 10, pp. 35–42.
Teece, D.J. (1999), “Design Issues for Innovative Firms: Bureaucracy, Incentives and Industrial Structure”, in Chandler, A.D., Hagstrom, P. and Sölvell, Ö. (Eds.), *The Dynamic Firm*, Oxford University Press, pp. 134–165.
Trott, P. (2012), *Innovation management and new product development*, 5. ed., Financial Times Prentice Hall, Harlow.
Tsai, W. (2002), “Social Structure of “Coopetition” Within a Multiunit Organization. Coordination, Competition, and Intraorganizational Knowledge Sharing”, *Organization Science*, Vol. 13 No. 2, pp. 179–190.
von der Werth, R. and Weinert, S. (2002), “Richtige Fragen sind die halbe Antwort auch beim Konstruieren - Fragesysteme als Hilfsmittel beim Konstruieren”, in Hacker, W. (Ed.), *Denken in der Produktentwicklung: Psychologische Unterstützung der frühen Phasen*, Mensch, Technik, Organisation, vdf Hochschulverl. an der ETH; Hampp, Zürich, Mering.
Weber, C. (2007), “Looking at “DFX” and “Product Maturity” from the Perspective of a New Approach to Modelling Product and Product Development Processes”, in Krause, F.-L. (Ed.), *The future of product development: Proceedings of the 17th CIRP Design Conference*; with 22 tables, Springer, Berlin u.a.
Wheelwright, S.C. and Clark, K.B. (1992), *Revolutionizing product development: Quantum leaps in speed*, efficiency, and quality, Free Press; Maxwell Macmillan Canada; Maxwell Macmillan International, New York, Toronto, New York.
Yin, R.K. (2013), *Case study research: Design and methods*, 5th edition, Sage, Los Angeles, London, New Delhi, Singapore, Washington, DC.