State of the Art - Lean Development

U. Dombrowski, T. Zahn, S. Schulze
Institute for Production Management and Enterprise Research, Langer Kamp 19, Braunschweig, Germany
u.dombrowski@tu-bs.de, thimo.zahn@tu-bs.de, sven.schulze@tu-bs.de

Abstract
The role of product development is becoming increasingly important to overall business success. Therefore it is necessary to establish fast, efficient and reliable product development processes. One approach to reach this goal is the implementation of lean thinking in the development processes, e.g. the establishment of a Lean Development System (LDS). LDS are based on the Toyota Product Development System, but also include additional aspects. This paper describes and evaluates the basic approaches of lean development in a literature review.

Keywords:
Lean Production, Lean Development, Lean Innovation, Toyota Product Development System, Global Product Development

1 INTRODUCTION

Manufacturing enterprises must continually improve their processes in order to stay competitive. In the past enterprises have implemented Lean Production Systems (LPS) based on the Toyota Production System (TPS) in order to improve productivity and flexibility [1-3]. An LPS is created using lean principles. Although the application of LPS is not restricted to specific processes or departments, the LPS-principles have mainly been applied in production, assembly, logistics, maintenance, and quality management [2]. In most cases lean principles are not applied to other important processes in the enterprise.

There is a lack of sophisticated concepts available for implementing lean thinking in product development, although product development is rapidly becoming a more important factor in strategic business success than production [4]. In order to reach a sustainable and long-term competitive advantage, it is important for manufacturing enterprises to develop innovative and - from a customer point of view - reasonably priced high quality products in the shortest time possible [5-6]. Enterprises like Toyota which work according to lean thinking in product development develop higher quality products with significantly shorter time-to-markets and for lower costs. [4]. In comparison to its competitors, Toyota is twice as fast, twice as efficient and twice as profitable [7]. This paper starts with a literature review focusing on the application of the lean thinking in product development and the creation of Lean Development Systems (LDS). Afterwards, the LDS concepts presented are evaluated according to criteria like whether a systematic implementation concept is given.

The paper is divided into four parts. First the development process with the most important phases is presented and the goals of product development are identified. Second, the criteria enabling an evaluation of LDS-concepts are formulated. Third, existing LDS-concepts are described from a literature review and evaluated according to the chosen criteria. Finally a summary identifies further areas of research.

2 PHASES AND GOALS OF PRODUCT DEVELOPMENT

Product development is defined as "the process, until a product can be used: Starting with the product planning and the search for ideas, the definition of the product, respectively with the single part production: starting with the order up to the delivery of the product at the customer" [8]. The product development process can either start with an indefinite customer or a determined customer [6]. During the development process, the lifecycle-related characteristics of a product, with increasing degrees of concretion and decreasing insecurity, are determined concerning structure, design and materials [8].

2.1 Phases of product development

Underlying every product is a lifecycle extending from the first idea to the final disposal of the product [9]. The product lifecycle can roughly be divided into three phases: development, market presence, and disposal. Product development itself can be divided into five phases. In practice these phases will overlap instead of taking place in sequence. The specification of the product development process depends on many factors, such as the product, the organization of the enterprise and the available resources. [10]

Not every manufacturing enterprise has its own research department. Nevertheless, there is an essential interest in using new discoveries for one's own enterprise. The goal of research is to systematically gain knowledge in terms of scientific and engineering discovery [11].

Product planning represents the interface between customer and the manufacturing enterprise. Based on market expectations and customer requirements, product planning systematically develops ideas for new innovative products or services while taking the business strategy into account. By determining unique product characteristics, these ideas can be made more specific [12]. Product planning ends with a decision about whether a product concept will be realized and the corresponding development project for that product [12].

The development of an appropriate realization concept, which includes all product functions, is carried out during the subsequent design and development [12]. Here the structure, design, material and lifecycle of the product are determined based on the functional requirements of product planning [8]. Concurrently, a prototype is manufactured and tested.

After the design and development phase, the industrial engineering team plans and controls all technical and organizational tasks necessary for an economic production. The link between industrial engineering and manufacturing and assembly is the start of production. This step is divided into the pilot series, comprising of a preproduction and zero series, and the serial production ramp-up. The purpose of the pilot series is to identify and eliminate any problems which have not been detected in the previous phases of development in order to ensure that all quality objectives are met at the start of production [13].

The final phase of the product development process is manufacturing and assembly. Lean thinking in this phase is accounted for in LPS and therefore is not considered in the LDS concepts. LDS is only applicable from product planning through industrial engineering.

2.2 Goals of product development

Basically, the product development process is part of a manufacturing enterprise, whose main goal is making profit. Successful performance in the market is a result of fulfilling customer requirements while differentiating from competitors. [14] Current literature derives the goals of product development from the general goals of an enterprise. According to [15] and [16] the goals are:

- High quality of products respective services
- Low costs during product development
- Low product lifecycle costs
- Short time-to-market
- High degree of sustainability (social, ecological, economical)
- High degree of innovation
- High product and service acceptance of the customers

3 CRITERIA FOR THE EVALUATION OF LDS-CONCEPTS

The implementation of LPS principles has led to great successes in manufacturing and assembly departments [2]. However, the promotion of the lean thinking in adjacent business processes like product development has not been done, or only fragmentarily pursued. There are many reasons for the absence of lean thinking in adjacent business processes. For one thing, the processes of product development differ significantly from manufacturing, assembly, logistics, maintenance and quality processes. For instance, many enterprises are not aware of the definition of value creation and waste in product development as here material flow comes second to information flow. Furthermore, during product development employee creativity is of particular importance. Employees are given scopes of development which cannot be automatically classified as waste during the creative process. An application of LPS principles to product development without adjustment is consequently not possible [4]. LDS concepts must be derived systematically and tailored to the LPS concept in order to achieve an optimally integration with downstream processes such as manufacturing and assembly. During the development and implementation of a lean development concept it must be ensured that there are no conflicting goals between the LDS-principles and the LPS-principles.

In order to evaluate the approaches described in literature in a systematic and structured way, objective criteria are necessary. Five criteria could be identified which, in part, match the requirements for the implementation of a lean production system as described in [2,4].

3.1 Criterion 1: Development of specific LDS-principles

The continuous and integrated orientation of all development activities according to specific principles is a central criterion of lean product development. These principles have to be used as fundamental guidelines to convey the LDS philosophy and to ensure integrity. Meanwhile, the specific requirements of product development must be taken into consideration (see above). In the following discussion of concepts either existing LPS principles are directly transferred, slightly adjusted, or specific development principles are derived.

3.2 Criterion 2: Integrated perspective and field of application

A systematical application of LDS principles to all phases of product development will ensure an integrated elimination of waste. Focusing on individual activities of product development and implementing individual methods without any linkage to other methods during the optimization efforts should be avoided. Thus, LDS concepts have to take all phases of product development into account, starting with research, product planning, design and development through industrial engineering, including the start of production. Moreover, the interfaces between different departments, especially towards manufacturing and assembly, should be taken into consideration to achieve synchronization with LPS rules, standards, methods and tools. Furthermore, the scope of LDS concepts should be extended to all activities and relevant support processes. Relevant support processes include project management [17], knowledge management [18], supplier management [19], quality management [20] and variant management [21].

3.3 Criterion 3: Enterprise-specific selection and configuration of methods and tools

Because there are differences in culture and philosophy among enterprises, and also product and branch specific peculiarities within enterprises it is not possible to define a universally valid LDS. Imitating a successful LDS from another enterprise will not necessarily lead to success because each company may have different requirements. Instead, it is necessary to configure an enterprise specific LDS for each application. This fact is congruent with the configuration of an LPS, which also must obey the specific requirements of the enterprise [1,22]. Using established LDS concepts each enterprise must select its own methods that will meet its specific requirements. LDS methods should be catalogued in a way such that an enterprise can select a method and customize it according to its requirements.

3.4 Criterion 4: Specification of a implementation process

Since the implementation of an LDS involves a fundamental change in the organization and culture of the development department, a well structured implementation process is required. Furthermore, the implementation will take several years since reorganization and employee education is required. To a large extent, obstacles arising during the implementation of LDS include planning mistakes, an inadequate business culture, leadership mistakes, a lack of methodological skills, and an ineffective organizational structure [23]. In order to overcome these obstacles, the LDS concepts must be implemented in a structured manner.

3.5 Criterion 5: Methods and tools to evaluate the success of implementation

During the implementation of a lean development system, it is important to detect problems immediately. Even in realized pilot projects, it is necessary to determine the success of the measures applied before the start of the roll out. Therefore, key performance indicators, an audit system, or stage models are necessary to evaluate the implementation. The evaluation methods should be included in the LDS concept.

By formulating the five criteria necessary for LDS-conception it is possible to evaluate the LDS concepts of the literature review and their practical application in enterprises.

4 LITERATURE REVIEW OF LDS-CONCEPTS

In this section, several LDS concepts are presented and evaluated based on the previously described criteria. The selection of concepts was based on a literature review. Due to the fast paced dynamic of this field and the multitude of concepts available, this paper has selected only the most common and distinctive LDS concepts to review.

4.1 Lean Product Development System (LPDS) according to Morgan and Liker

The Lean Product Development System (LPDS), according to Morgan and Liker [4], describes product development at the Toyota Motor Corporation. The investigative results have been summarized in thirteen principles and are categorized according to four subsystems: Process, Skilled People, Tools and Technology.

The Process subsystem comprises all activities and operations accumulating in the product development from product planning to the start of production. The value stream ranges from customer requirements and product ideas to the final draft of the product which is handed over to the production. The subsystem comprises the following principles:

- Establish customer-defined value to separate value-added activity from waste
- Front-load the product development process while there is maximum design space to explore alternative solutions thoroughly
- Create a leveled product development process flow
- Utilize rigorous standardization to reduce variation, and create flexibility and predictable outcomes

The Skilled People subsystem is comprised of the employees involved in product development. There are six principles in this subsystem:

- Develop a chief engineer system to integrate development from start to finish
- Organize to balance functional expertise and cross-functional integration
- Develop towering technical competence in all engineers
- Fully integrate suppliers into the product development system
- Build in learning and continuous improvement
- Build a culture to support excellence and relentless improvement

The third subsystem includes all Tools and Technologies used during product development. This subsystem supports employees with the completion of their tasks. The principles are:

- Adapt technology to fit your people and processes
- Align your organization through simple, visual communication
- Use powerful tools for standardization and organizational learning

Apart from the principles, the LPDS provides hints about the integration of subsystems and explains approaches to culture change.

The LPDS according to Morgan and Liker, represents the currently most widely recognized approach to the systematization of LDS. The concept comprises essential contents by [24-30].

The principles within the LPDS are conclusive, structured and explained in subsystems like the Toyota system that LPDS is based on. The LPDS principles share similarities with common principles of Lean Production Systems. For example, the principle of a continuous improvement process and standardization can also be found in the LPDS. Therefore, criteria 1 and 2 are met by the concept because of the integrated perspective which covers the entire product development process and the supporting processes. Furthermore it offers structured references about the implementation (criterion 4). However, criteria 3 and 5 are only partly fulfilled. The concept does not provide any standardized catalogues of methods to facilitate selection and customization. There is also a lack of methods and tools for evaluating the implementation and success of the measures.

4.2 Lean Product and Process Development according to Ward

In his book, "Lean Product and Process Development," Ward presents a further concept for a Lean Development System [7]. First he defines how value and performance should be interpreted and measured in the framework of product development and which types of waste occur in product development. Then the LDS "as practiced by Toyota and its suppliers" is summarized to five principles. These principles are

- Value focus: Focus on creating knowledge and hardware for consistently profitable
- Embody this focus in entrepreneur system designers (ESDs)
- Support ESD with set-based concurrent engineering (SBCE)
- Support SBCE with cadence flow and pull project management
- Support flow and pull management with teams of responsible experts

Additionally, an overview of the success factors of a sustainable implementation of the LDS is given.

The approach focuses on the contents applied by Toyota. Some of the contents described in [4] are taken into consideration and explained in detail. It should be mentioned that the work offers approaches for the evaluation of waste, value and performance. Ward has defined principles, fulfilling criterion 1. The field of application is not described in depth; therefore criterion 2 cannot be evaluated. Criterion 3 is not fulfilled. There are several hints for the implementation (criterion 4) and the evaluation for the success (criterion 5), but not an integrated concept.

4.3 Lean Innovation according to Schuh, Lenders et al.

The term Lean Innovation according to [31-32] stands for a systematic application of lean thinking in innovation management and product development. Lean Innovation should help to avoid waste in the processes of product development and direct all processes and contents towards the customer. In order to reach these goals several principles have been conceived and developed. The Lean Innovation principles can be categorized as: "position unambiguously", "structure early", "synchronize easily" and "adapt securely". The principles according to [32] are described below.

To ensure competitiveness and to support the selected business strategy, continuous control and adaptation of the planned products and product range is necessary. With the help of the "position unambiguously" principle these goals shall be reached. The "position unambiguously" principle includes the following sub principles:

- Strategic positioning
- Evident hierarchization
- Roadmapping

An important aspect of product development is the control of the complexity of different projects and activities by structuring early. There are three sub principles integrated in the "structure early" principle.

- Control of the solution space
- Design of the product architecture
- Assortment optimization

A continuous and consistent synchronization of all activities during product development is necessary to achieve stabile processes with a maximum use of the project's internal and external synergies. The principle "synchronize easily" includes three sub principles.

- Pulsing
- Consistency of information
- Optimization of the value stream

The "adapt securely" principle calls for the ability to adapt products to changing requirements during the entire product life cycle and includes:

- Continuous improvement
- Release-engineering
- Innovation controlling

The fundamentals and principles are described in many different publications with different focuses and degrees of detail. These variations make the application of lean development principles in product development and their support processes difficult. Other aspects, mentioned in [4] or [7], e.g. supplier integration, are only marginally considered. Therefore it is not clear which principles should be applied for supplier integration. Furthermore, the presented principles are often not true principles but rather tasks or methods. For example, the principles "innovation controlling" and "assortment optimization" represent tasks. The fact that the principles and methods are constantly evolving makes their application problematic. Due to these facts, the criterion 1 is fulfilled only partially. In the course of lean product development a basic and comprehensive modification of structure and content of the process has taken place. The focus of this approach is on the product planning, and later steps in the process are neglected (criterion 2). A methodical selection and configuration of the methods is not published yet (criterion 3). The presented approach offers a rough concept for the implementation and measures the degree of implementation though a maturity level scale (criteria 4 and 5).

4.4 Lean Software Development according to Poppendieck and Poppendieck

Software engineering also features approaches based on the lean thinking. One of the most popular approaches is the Lean Software Development concept according to [33]. This concept is based on seven principles and 22 corresponding tools:

- Eliminate waste
- Amplify learning
- Decide as late as possible
- Deliver as fast as possible
- Empower the team
- Incorporate integrity
- See the whole

In [33], the individual principles and the tools related to software development are presented (criterion 1). However, the origin of the Lean Software Development principles and the determination of the compilation of the 22 tools are not explained. Topics like standardization, continuous improvement, and quality related elements are almost not taken into consideration. Due to the focus on software development, the field of application is not as it is described in criterion 2. Additionally, there is a lack of solutions supporting criteria 3 and 5. The concept does define success factors, which give some indication of implementation methods specific to the size of an enterprise (criterion 4).

4.5 Lean Development according to Balle and Balle

In "Lean Development: A Knowledge System" Balle and Balle describe a system divided into different categories [34]. There are four key factors concerning product development, which are meant to describe the goals of every development process. The factors are

- Listen to the voice of the costumer
- Limit late engineering changes
- Master the flow of drawings and tool elaboration
- Focus on quality and cost in production

In order to reach these goals, and consequently a high customer satisfaction, short time-to-market and low costs in several so called layers of the process must be realized. Within the practice layer the authors identified the elements of technical careers, pull communication, continuous improvement, and supplier integration from lean manufacturing practices. Furthermore, the organizational layer with the component platform center, and the culture layer comprising the knowledge-based paradigm, is identified. In the process layer the elements of frontloading with "concept with chief engineer", delaying key decisions with "system design with set-based engineering", reducing variability by "detailed design with standards", and using lean principles from production with "prototypes and tools with lean manufacturing" have to be considered.

The concept by Balle and Balle includes aspects of [4] and [7]. However, the contents are structured differently. The "aims of every development process", which can be seen as principles (criterion 1), and the categorization in different layers, allow a structured detailing of the components. In the same way a rough draft of all phases is carried out. However, the concept does not offer either structured method descriptions (criterion 3), an implementation systematic (criterion 4) or evaluation methods (criterion 5). The field of application is not described in depth; therefore criterion 2 cannot be evaluated.

4.6 Innovative Lean Development according to Schipper and Swets

Schipper and Swets assume that it is not only the principles of lean manufacturing - like flow, pace, pitch, and elimination of waste - that contribute to a successful product development process [35]. Instead, the principles of LPS are combined with the contents of ''structured innovation'' to an LDS. Within the integrated concept of Innovative Lean Development the following six principles have been identified:

- Identify and fill user gaps
- Use multiple learning cycles
- Stabilize the development process
- Capture knowledge
- Use rapid prototyping
- Apply LPS-principles, including learning cycles and visual boards

The authors particularly focus on using fast learning cycles to create, implement, and maintain a learning culture. The concept of Innovative Lean Development has an integrated field of application since it includes the whole process, from the product planning as the starting point of product development up to the ramp-up (criterion 2). Furthermore it discusses aspects of cultural change. In contrast, there are only a few contents linked to methods and there is a lack of concrete instructions for action (criterion 3). Furthermore, some elements of lean development, and other concepts known as central LDS elements (e.g. supplier integration, frontloading, set-based-engineering), are not described in detail. It is not clear whether the six principles serve to support the cultural change, or if the product development process (support processes, activities, and methods) should be designed in accordance with the principles in order to make it more innovative and lean (criterion 1). Neither the implementation, nor the evaluation of the implementation success is described in depth (criterion 4 and 5).

4.7 Lean Development based on Lean Production

Apart from the highlighted concepts, there are approaches for the systematization of lean development in [36-38] based on the principles for lean production defined by Womack and Jones [22]. The principles are:

- Value
- Value Stream
- Flow
- Pull
- Perfection

These approaches emphasize different points (e.g. the implementation) and offer a systematic but superficial transfer of the principles. The approaches focus on the transfer of the principles without providing detail about the methods. Therefore in most cases, only criterion 1 is fulfilled. The additional criteria are neglected in the concepts.

4.8 Lean Development based on PTC

Another approach to the design of product development processes is shown in [39]. This concept is composed of six initiatives:

- “Frontloading“: Shifting important decisions into the earliest possible phase of product development.
- Visual planning and completion
- Standardization of working-processes
- Systematic gathering and reuse of knowledge
- Partnership with manufacturing service providers and suppliers
- Efficient coordination of development processed and results

These six initiatives can be used as principles for lean development systems, fulfilling criterion 1. Frontloading, which also has been published in other papers [40], is mentioned explicitly. The field of application is not described (criterion 2). In addition, the approach does not offer any structured derivation of methods (criterion 3), proceedings for implementation (criterion 4), or evaluation methods (criterion 5).

4.9 Lean Product and Process Development (LeanPPD)

The research project Lean Product and Process Development (LeanPPD) considers four main blocks [41]:

- Lean self-assessment tool
- Product development value mapping tool
- Knowledge-based engineering
- Set-based Lean design tool

The lean self-assessment tool provides key performance indicators, helps to identify the starting point of the company, and helps to measure the success of the transformation to lean development. The value mapping tool helps to display the processes according to their value creation. The knowledge provision was identified in the project as main feature in the lean development. All decisions in a development project should be based on proven knowledge and experience. The knowledge based engineering tool will support knowledge acquisition and re-use of previous projects to support the application of lean development. The set-based lean design tool helps to identify the lean product design which can be manufactured in a LPS. [41]

The project is not completed as of the present, therefore some of the tools were only drafted and the exact function has not been published yet. Up to now there have been no principles defined (criterion 1). The field of application is widespread, but not described in detail (criterion 2); and the selection of tools and methods was not described (criterion 3). The implementation process (criterion 4) has not yet been published. The lean self-assessment-tool can be used to measure the success of the implementation (criterion 5).

4.10 Lean Development approaches in enterprises

The LDS concepts described and evaluated in sections 4.1 - 4.9 are based on theoretical approaches. At the same time some enterprises have developed their own approaches for increased efficiency in product development by implementing rules and standards based on lean principles. Two representative innovative enterprise approaches are presented here. According to [42], Robert Bosch GmbH (rank 5) and Siemens AG (rank 3) are innovative enterprises with a high number of patent applications in Europe in 2009.

Robert Bosch GmbH operates with the Bosch Product Engineering System (BES) [43], which focuses on product development and its environment. Product development is optimized through the use of best practice-processes and qualified employees. Principles of the BES according to [44] are:

- Market and customer orientation

- Employee orientation
- Process orientation
- Continuous improvement
- Innovation orientation
- Knowledge orientation
- Project orientation

In contrast, according to [45] the Siemens AG has defined different fields of action within particular categories of lean development. These categories are:

- Leadership-principles and strategy
- Product lifecycle management
- Supply chain management
- Customer relationship management
- Project and performance management
- Human resources and continuous improvement

For example, the category of product lifecycle management consists of frontloading, reliable operational processes and synchronous operations. There are different methods specifically designed for every field of action.

Both of these approaches are enterprise-specific (criterion 3) and not a universally valid concept. There are lean principles defined as mentioned in criterion 1. The field of application is the whole product development process and parts of the support processes (criterion 2). The implementation (criterion 4), and the evaluation of the success (criterion 5) are not described.

4.11 Summary of evaluations

Criterion 1 "Development of specific LDS-principles": The variety of principles within the LDS concepts shows that several different influencing factors have been taken into consideration. Some approaches, especially those of [4] and [7] are based on principles of Toyota. Other authors suggest that lean development represents the application of lean production principles. In addition to these two directions, mixed concepts have been developed taking "implied principles" into consideration, which have proven themselves valuable in product development practices in the past. In general, nearly every concept has LDS principles, despite the variety in content and detail.

Criterion 2 "Integrated perspective and field of application": In general, the principles defined are described in a way that allows a standardized application and hence suggest coverage of all product development phases as well as their support processes. However, most concepts lack specific descriptions of the field of application for the support processes, making them difficult to evaluate.

Criterion 3 "Enterprise-specific selection and configuration of methods and tools": LDS concepts partly offer a specification of the particular LDS principles and sporadically describe methods. A methodology for a systematic selection of methods, an integrated description of activities, and corresponding methods and tools do not exist.

Criterion 4 "Specification of an implementation process": Only in some concepts, e.g. [4], does a comprehensive process exist for the implementation of a Lean Development System that takes into account planning, corporate culture, leadership, knowledge, and organizational structures.

Criterion 5 "Methods and tools to measure the success of implementation": Key performance indicators, an audit system, or stage models for the evaluation of the implementation of LDS are mentioned in some approaches. But even there, a detailed description is missing.

As shown in table 1 no approach fulfills all requirements identified as necessary for a lean development concept. Therefore further research has to be carried out.

Concepts	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Morgan and Liker	●	●	◑	●	◑
Ward	●		◑	◑	◑
Schuh, Lenders et al.	◕	◑	◔	◔	◔
Poppendieck and Poppendieck	◕	○	◔	◕	◔
Balle and Balle	●		○	○	○
Schipper und Swets	◑	●	◔	○	○
Based on Lean Production	●	○	○	○	○
Based on PTC	●	○	○	○	○
LeanPPD	○	○	○	○	◑

Table 1: Summary of the evaluation of the LDS concepts

5 SUMMARY

In order to stay competitive, enterprises are forced to minimize waste in their processes and focus on value creation with integrated thinking. The implementation of the lean thinking in all business processes is a promising approach. However, there are a multitude of concepts for the implementation of lean principles in product development. This paper provides a literature review and an evaluation of some of the common approaches to lean development.

There is a strong disagreement regarding the contents and proceedings within the scope of Lean Development Systems. Although some concepts provide approaches for the configuration of a LDS, there are very few scientific studies published, which can be used to draw conclusions concerning the individual principles and method as well as their conduciveness to success. Especially the criteria concerning the implementation of a LPS and the measurement of the success lack suitable solutions.

6 REFERENCES

[1] Dombrowski, U., Crespo, I., Zahn, T., 2009, Adaptive Configuration of a Lean Production System in Small and Medium-sized Enterprises, CARV09.

[2] VDI 2870, 2010, Ganzheitliche Produktionssysteme, im Gründruck, Blatt 1, VDI-Gesellschaft Produktion und Logistik.

[3] Warnecke, H.J, Hüser, M., 1995, Lean Production, International Journal of production economics, 41: 37-43.

[4] Morgan, J.M., Liker, J.K., 2006, The Toyota Product Development System, Integrating People, Process, and Technology, Productivity Press.

[5] Sorli, M. Stokic, D., 2009, Innovating in Product/Process Development, Springer-Verlag.

[6] Ehrlenspiel, K., Kiewert, A., Lindemann, U., Hundal, M., 2006, Cost-efficient design, Springer Verlag, 1st edition.

[7] Ward, A.C., 2007, Lean Product and Process Development, The Lean enterprise Institute.

[8] Ehrlenspiel, K., 2009, Integrierte Produktentwicklung. Denkabläufe, Methodeneinsatz, Zusammenarbeit, Hanser Fachbuchverlag, 4. aktualisierte Auflage.

[9] Pahl, G., Beitz, W., Feldhusen, J., Grote, K.-H., 2006, Engineering Design: A systematic approach, Springer Verlag, 3rd edition.

[10] N. du Preez, D. Lutters H. Nieberding: Tailoring the Development Process According to the Context of the Project. CIRP Design Conference 2008, Enschede Netherlands.

[11] White, M., Bruton, G., 2010, Strategic Management of Technology and Innovation, South-Western, 2nd revised edition.

[12] VDI Verein Deutscher Ingenieure, VDI 2220, 1980, Produktplanung: Ablauf, Begriffe und Organisation, VDI-Gesellschaft Produkt- und Prozessgestaltung.

[13] Terwiesch, C., Loch, C.H., 1999, Managing the Process of Engineering Change Orders, The Case of the Climate Control System in Automobile Development, Journal of Product Innovation Management, 2: 160-172.

[14] Krause, F.-L., Jansen, H. 1999, Optimization of Product development by Key Figures and simulation, Proceedings of the CIRP International Seminar of the STC Design, 69-79.

[15] Ulrich, K.T., Eppinger, S.D., 2008, Product design and development, McGraw-Hill, 4. int. edition.

[16] Kara, S., Lu, M., 2009, Multi-Dimensional Requirement Analysis for Sustainable Product Development, 7th CIRP Sustainable Manufacturing, 277-281.

[17] Levardy, V.; Browning, T.R., 2009, An Adaptive Process Model to Support Product Development Project Management. IEEE Transactions on Engineering Management, Vol. 56, No. 4, 600-620

[18] Lawson, B., Petersen, K. J., Cousins, P. D. and Handfield, R. B. (2009), Knowledge Sharing in Interorganizational Product Development Teams: The Effect of Formal and Informal Socialization Mechanisms. Journal of Product Innovation Management, 26: 156–172.

[19] Monczka R. M., Ragatz G. L., Handfield B., Trent R., J. Frayer D. J., 1997, Supplier Integration into New Product Development: A Strategy for Competitive Advantage, Executive Summary.

[20] Watson, P., Howarth, T., 2010, Quality Management, Hanser Verlag, 4. edition, Munich.

[21] Stocker, S., Radtke, P., 2000, Supply Chain Quality, Hanser Verlag, 1. Auflage, Munich.

[22] Womack, J. P., Jones, D. T., 2003, Lean Thinking. Banish Waste and Create Wealth in Your Corporation, Free Press, 2. Edition.

[23] Dombrowski, U., Crespo, I., Zahn, T., 2009, Common Barriers to Lean Implementation - Practical Experiences and Theoretical Implications, ICPR20.

[24] Morgan, J.M., 2002, High Performance Product Development. A Systems Approach to a Lean Development System, Ph. D. Dissertation The University of Michigan.

[25] Clark K.B., Fujimoto T., 1991, Product Development Performance, Harvard Business School Press.

[26] Womack J.P., Jones D.T., 1994, From Lean Production to the Lean Enterprise, Harvard Business Review, 72: 93-103.

[27] Karlsson, C., Ahlstrom, P., 1996, The Difficult Path to Lean Product Development, Journal of Production and Innovation Management, 13: 283-295.

[28] Kennedy, M.N., 2003, Product Development for the Lean Enterprise - Why Toyota's System is Four Times More Productive and How You Can Implement It, Oaklea Press.

[29] Ward, A.C., Liker, J.K., Sobek, D.K., 1995, The 2nd Toyota Paradox. How Delaying Decisions Can Make Better Cars Faster, Sloan Management Review, 3.

[30] Sobek, D.K., Ward, A.C., Liker, J.K., 1999, Toyota's Principles of Set-Based Concurrent Engineering. Sloan Management Review, 40: 67-83.

[31] Schuh, G., Lenders, M., Rauhut, M., Lean Innovation – Introducing tact time to product development processes, APSM 2010.

[32] www.lean-innovation.de, 2011

[33] Poppendieck, M., Poppendieck, T., 2003 Lean Software Development: An Agile Toolkit for Software Development Managers, Addison-Wesley Longman.

[34] Ballé, F., Ballé, M., 2005, Lean Development. Business Strategy Review, 3: 17-22.

[35] Schipper, T. H., Swets, M.D., 2009, Innovative Lean Development: How to Create, Implement and Maintain a Learning Culture Using Fast Learning Cycles, Productivity Pr Inc.

[36] Walton, M., 1999, Strategies for Lean Product Development. Lean Aerospace Initiative.

[37] Oppenheim, B.W., 2004, Lean Product Development Flow, Systems Engineering, 7: 352-378.

[38] Garza, L. A., 2005, Integrating Lean Principles in Automotive Product Development: Breaking Down Barriers in Culture and Process, System Design and Management Program, Massachusetts Institute of Technology.

[39] Parametric Technology Corporation (PTC), 2007, Mehr Innovation durch schlanke Produktentwicklung, URL: www.innovationsforumautomobil.de.

[40] Thomke, S., Fujimoto, T., 2000, The Effect of “Frontloading” Problem-Solving on Product Development Performance. Journal of Product Innovation Management, 17: 128-142.

[41] Sopelano, A. et al., Applying Lean thinking concepts to New Product Development, APSM 2010.

[42] European Patent Organisation, Top 100 applicants 2009, http://www.epo.org/about-us/office/statistics/top-applicants.html

[43] Robert Bosch GmbH, 2010, online: http://csr.bosch.com/content/language1/downloads/Bosch_House_of_Orientation_de.pdf.

[44] Hönninger, H., 2007, Software im Automobil – Entwicklungsprozesse, Methoden und Tools, URL: www.fh-frankfurt.de/de/.media/~fs_maschinenbau/downloads/software_im_automobil_handout.pdf.

[45] Beitinger, G., 2010, Lean Development bei Siemens Healthcare - Zwei Ansätze – Ein Ziel, 3. Braunschweiger Symposium für GPS.