Lean product development – enabling management factors for waste elimination

Anja Schulze*

Technology and Innovation Management, ETH Zürich,
Scheuchzerstrasse 7, 8092 Zurich, Switzerland
Fax: +41 44 632 1875
E-mail: aschulze@ethz.ch
*Corresponding author

Thorsten Störmer

Technology and Innovation Management, ETH Zürich,
Scheuchzerstrasse 7, 8092 Zurich, Switzerland
E-mail: tstoermer@ethz.ch

Abstract: Lean development is a promising approach in new product development (NPD). However, despite the successful application of lean thinking and its principles to manufacturing, the adoption of the lean approach to product development is a quite novel undertaking. In this paper, we develop and test hypotheses pertaining to the elimination of waste, which is one of the major objectives of lean management. In particular, our study focuses on the question: What management factors are enablers for the elimination of waste in the context of NPD? We identified:

1. employee training
2. coaching
3. constructive failure treatment as effective means.

Furthermore, implications for management practice are considered. Testing our hypotheses, we refer to data from 108 firms in the automotive supplier industry in German-speaking countries, i.e., Germany, Austria, Switzerland and Liechtenstein.

Keywords: lean development; lean product development; lean innovation; new product development; NPD; waste elimination; process efficiency; automotive supplier industry.

Reference to this paper should be made as follows: Schulze, A. and Störmer, T. (2012) 'Lean product development – enabling management factors for waste elimination', *Int. J. Technology Management*, Vol. 57, Nos. 1/2/3, pp.71–91.

Biographical notes: Anja Schulze is the Head of the Swiss Center for Automotive Research (Swiss CAR) at the ETH in Zürich. Her research interests lie in innovation, new product development and technology management with a special consideration of the automotive industry. Moreover, she has published in leading journals such as the *Journal of Management*, *Research Policy*, the *European Management Journal*, and others.

Thorsten Störmer is a PhD candidate in his final year at the University of St. Gallen (HSG), Switzerland. He is undertaking his doctoral research in the field of technology and innovation management. In his research, he deals with market orientation and lean thinking in the scope of technology and new product development. Currently, he works as a Research Assistant at the Chair of Technology and Innovation Management of the ETH Zurich.

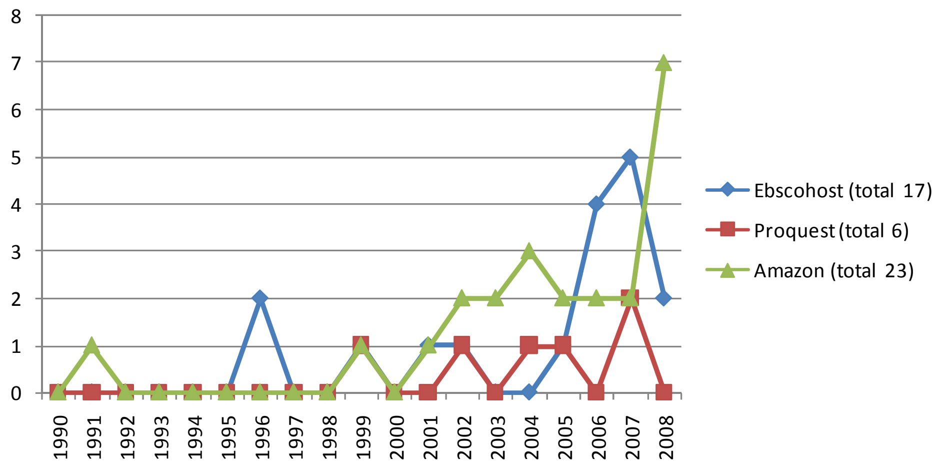
1 Introduction

Currently, new products are vital to the long-term survival and prosperity of companies (Cooper and Kleinschmidt, 1990). Moreover, as Peter Drucker stated, for some scholars an enterprise's fundamental choice can be reduced to 'innovate or die'. Increasingly, being successful is not dependent on a single successful product, but the continuous development of outstanding products – great quality products with compelling customer value, and extraordinary efficiency (Wheelwright and Clark, 1995). In addition to strategic and organisational options, one of the most important drivers for repeated new product success is an efficient development process (Cooper and Kleinschmidt, 1995). Process management aims at the creation of such a process. It entails practices such as mapping and structuring development activities, improving them, and linking them (Benner and Tushman, 2003; Salomo et al., 2007). Process management changed the former view of organisations as a collection of departments with separate functions and outputs to a view of them as systems of interlinked processes that cross functions and link organisational activities (Benner and Tushman, 2003). In particular, researchers and practitioners alike have been focusing on value-adding activities, pursuing the objective of efficiency with faster product development, fewer engineering hours, improved manufacturability of products, etc. (Brown and Eisenhardt, 1995).

However, in the course of a firm's development project, more than just defined value-adding activities are performed. As a recent study revealed, around 50% of the costs incurred in new product development (NPD) tend to be spent on wastes which occur due to non-value-adding activities during the development process (Kearney, 2003). Other sources declare that many development efforts' value-added time is as low as 5% of the total cycle time [Garvin, (1998), p.35; Kato, 2005; McManus, 2004). With these pre-conditions, it is hard to succeed on the competitive market. Among other things, lean development has recognised this large potential. By approaching the development process holistically, and mapping and managing non-value-adding activities (i.e., wastes) as well, it offers a new and promising perspective. Overall, while process management addresses potential non-value-adding activities by designing the process as perfectly as possible, lean development attacks them by analysing the processes as they are performed, and detecting and deleting non-value-adding activities.

In their seminal work Womack and Jones (1997) argued for an application of lean management organisation wide. But lean management has been applied mainly in manufacturing and "[t]he application of the lean principles to new product development is a novel undertaking" [Haque and James-Moore, (2004), p.2]. This is reflected in the literature on lean product development, which is not as widespread as the lean production and manufacturing literature respectively (Baines et al., 2006).

Figure 1 Development of lean development literature[1] (see online version for colours)



Overall, lean development aims to "[…] develop a seamlessly flowing product development value stream with minimal waste […]" [Anand and Kodali, (2008), p.196].

There are a number of authors who have identified types and categories of wastes in NPD such as, for example, rework due to changing priorities or requirements, redundant development, unclear decision criteria, and a lack of required information (Anand and Kodali, 2008; Bauch, 2004; Morgan, 2002; McManus, 2004). Consequently, researchers have been able to investigate the composition of the obstacles blocking the seamless flow of projects through the development process. Moreover, research has been done on the causes of these obstacles, i.e., on waste and effective methods and tools to omit this waste.

Nevertheless, there are still management and leadership questions without a clear answer. One such question is: Who should remove the waste? The literature provides mixed answered. While some authors argue for a task force (Cooper, 2008; Kearney, 2003), others plead for the involvement of all employees (Liker, 2004; Liker and Meier, 2007). The resulting questions are now: How will these people initially be enabled to do so? How will they be enabled to do so in the long run? What are the critical pre-conditions? This paper will shed light on these questions and contribute to finding answers.

Our article is structured as follows: The next section presents the definition of waste, its identification, and elimination. In addressing the previously posed management questions, three important management factors – employee training, coaching, and constructive failure treatment – are introduced. Hereafter, hypotheses are developed. The research methods and empirical results are subsequently presented. This is followed by a discussion of the results and their implications for management. In the final section, the study's limitations and directions for further research are discussed.

2 Elimination of waste in product development: definition – detection – deletion

2.1 Definition of waste and value

A widely accepted definition of waste is the categorisation of Womack and Jones (1997), who assign all activities within a firm to three types:

Type 1 Activities that add value, which is determined by the customers' perspective. Value-adding activities are activities for which the customer would be disposed to pay a portion of the final product price.

Type 2 Activities, which are non-value-added work, but are necessary to enable value-adding activities under the present working conditions (or 'necessary waste'). In other words, 'waste' is something for which the customer is not willing to pay (Karlsson and Ahlstroem, 1996a).

Type 3 Non-value-adding activities which are unnecessary and are thus defined as 'pure waste'. Examples of waste within production processes are the transportation of parts, inventory, and/or defective workmanship which results in rework.

In order to create a seamlessly flowing value stream, Type 3 activities need to be eliminated, while Type 2 activities need to be avoided or be made as efficient as possible (Pessôa, 2008). Although the focus of the original waste typology was on production, it can be applied to NPD (Ohno, 1988; Ward et al., 2007). Nevertheless, the product development process' characteristics differ from those of the manufacturing process. These differences are of importance regarding the applicability of this waste typology. NPD can be understood as an information-based factory (Pessôa et al., 2007), or as a process aimed at creating a 'recipe' for producing a new product (Reinertsen, 1999). Moreover, product development is as a creative and iterative problem-solving process. Value is generated within this process if the gained information improves this product recipe's quality, in the sense that

a the performance level of the final product increases, or

b the risk and uncertainty that the final product will not meet its requirements are reduced (Browning et al., 2002; Pich et al., 2002; Schrader et al., 1993).

Hence, activities like testing, experimenting, or trying can result in valuable new information (Browning, 2003; Reinertsen, 1998; Thomke, 2001). More precisely, designers create useful information while assessing which kind of solutions will work and sometimes, even more importantly, which not (Nightingale, 2000). All these activities that to some extent result in iteration loops would certainly be described as 'pure waste' if they were to occur within production. There, iterations are generally classified as 'rework', thus clearly a Type of waste that should be eliminated (Ballard, 2000). However, in product development, iterations cannot per se be classified as waste. Someone has to distinguish between valuable iterations (or positive iterations), which generate useful information to improve the product recipe's quality, and non-valuable iterations (or negative iterations), which only lead to an increase in time and costs. Consequently, all iterations "which can be eliminated without loss of value or causing failure to complete the project" are wasteful [Ballard, (2000), p.1]. Examples of waste in NPD are (Bauch, 2004):

- over processing (e.g., unnecessary product features, details regarding the accuracy of information)
- transport/handoffs (e.g., excessive data traffic, ineffective communication)
- inventory (unnecessary prototypes, excessive data storage).

Overall, waste in product development is harder to define and identify than in production. The identification of waste thus becomes a more sophisticated objective. We therefore agree with Browning (2003, p.50) that one needs to "[j]ust think of the entire process in economic terms: Remove Type 3 activities and make everything else as productive as possible". Consequently, in our study, we define waste as solely Type 3 activities.

2.2 Detection and deletion of waste

An explicit classification, if a single activity is waste or value-adding work is often only possible by regarding the NPD process in its entirety. The determination of waste in NPD therefore requires a holistic system perspective (Browning, 2003). A systematic detection of waste is mainly based on an analysis of the value stream. In this respect, value stream mapping has proved itself. This method is basically aimed at mapping the process' current state and then systematically identifying waste to create an improved future state vision of the process (McManus and Millard, 2002). Having identified a waste occurrence, the next step towards avoiding unnecessary activities is to investigate its causes. Removing the causes is aimed at a sustainable waste deletion.

To find such causes, enterprises like Toyota relies on the 'five Whys technique'. They ask 'why' (as many as five times) whenever waste is identified to get to its root (Pessôa, 2008). In addition, standards are adjusted, or a number of tools and techniques are deployed to achieve a sustainable deletion of waste. Examples of tools are: quality function deployment (QFD), design structure matrix (DSM), set-based engineering (SBE), or conjoint analysis. These tools are supportive of identifying and removing non-value-added activities. Although these tools have proved themselves as advantageous, they are mainly a certain technical method of detecting and removing waste. In addition besides these tools, a firm's development system comprises other elements like leadership and management factors as well which is fostering the identification and removal of waste. Hence, to be effective in sustainably eliminating waste, the deployment of tools and methods needs to be accompanied by a few management factors.

3 Elimination of waste in product development: enabling management factors

Anand and Kodali developed "a framework representing the modus operandi, the system to be developed, the activities to be carried out" when eliminating waste in engineering (2008, p.207). Their framework for 'lean NPD' builds upon and systematises the literature which focuses on tools and techniques aimed at waste elimination in product development. Examples of such tools are a pull system for test results, or 5-S for documents and prototypes. These tools and techniques are very important. In order to be effective, however, they have to be deployed consequently and sustainably.

To achieve deployment (i.e., the elimination of waste), some scholars argue that management time and attention should be focused on the construction of a development system that does not allow deviations (i.e., waste) to occur (Perrow, 1984). Reinertsen takes this to the extreme by stating that such systems are designed to be operated by 'fools' (1997). In other words such a system would be close to perfection – regardless of the employees working in this environment. An alternative view is based on the comprehension of the development system as a socio-technical system (Emery and Trist, 1960; Luhmann, 1995). This implies that the deployment of such a system is equally dependent on creating a workable system and populating it with excellent people. Nevertheless, if the expert people running such a set-up are removed, one is left with a system which will soon grind to a halt, if it runs at all in the first place (Fleck, 1997). Hence, rather than knowledge of the basic 'hardware' itself (i.e., knowledge of the tools, techniques, and their effects), other components – called informal or more precisely contingent knowledge – are necessary for the effective deployment of such a system (Fleck, 1997). This means that management time must be devoted to people and their development, since people specifically need this particular form of knowledge to run the system. This contingent knowledge has not been directly or explicitly addressed to the same extent that knowledge of tools and techniques has, but plays a crucial and, so far, underappreciated role in product development and innovation (Fleck, 1997). Contingent knowledge has the following characteristics: It is

- *distributed:* rarely concentrated in one person, but widely distributed throughout an organisation
- *apparently trivial:* under-valued
- *accidental:* embodied in the specific context of the product development process.

For a differentiation between the essence of contingent knowledge and other knowledge forms, see Table 1.

Table 1 Contingent knowledge

Contingent knowledge differs from…
• *formal* knowledge in that it lacks systematic codification and is concrete rather than theoretical. It is a form of informal knowledge, perhaps, but tends to remain tied to the context, rather than being informally passed on as more or less generalisable 'rules of thumb' or 'tricks of the trade'; it is very specific to the particular situation.
• *informal* knowledge in that it is more accidental, and less systematically arranged around some set of tasks or technologies. Contingent knowledge may appear to be a form of *tacit* knowledge when mediated by one individual.
• *tacit* knowledge in that it is more related to the particularities of the context rather than cognitive or motor skills.

"Contingent knowledge can be critical for smooth operation" [Fleck, (1997), p.391] (i.e., seamless flow without waste). For example, "[t]he effective acquisition and exploitation of contingent knowledge is regarded to be a key factor in the success of Japanese manufacturing practices. The widespread use of charts such as Ishikawa diagrams for accumulating information about the causes of problems or defects [i.e., waste …] is a pertinent example" [Fleck, (1997), p.393]. Hence, successful product development requires the harnessing and exploitation of the contingent knowledge of waste elimination. However, the distributed, accidental, and under-valued character of contingent knowledge entails challenges. Managerial action or support is needed.

In line with this consideration, Liker, in his famous book *The Toyota Way* (2004), highlights that management principles, aimed at boosting the exploitation and dissemination of contingent knowledge, are one of the most important tesserae of Toyota's Lean Management approach. Pursuing this approach, we build upon the Toyota Way's Principles 9 and 10 'Add value to the organisation by developing your people'. Accordingly, we propose developing employees through training and coaching (Liker, 2004) within an environment in which failures are treated constructively, which is also considered a consistent characteristic of the best product development organisations (Reinertsen, 1997).

Summing up, supplementing the literature on techniques for waste elimination in product development (Anand and Kodali, 2008; Oppenheim, 2004), we propose and investigate the following three enabling management factors for waste elimination:

1. *Employee training for waste elimination* comprises teaching how to distinguish value-adding, non-value-adding but necessary, and non-value-adding and not necessary activities (i.e., 'pure waste') in engineering, which is a not a trivial exercise (Browning, 2003). Moreover, processes and behaviour are standardised to not only eliminate waste on the spot, but also persistently (Womack and Jones, 1997). If there is standardisation, adjustments are made accordingly. Another part of the employee training for waste elimination is teaching how to transform insight into where waste occurs to standards.

2. *Employee coaching* in an organisational setting refers to a trusted friend or counsellor (i.e., senior manager), who gradually teaches the novice (i.e., employee) the organisational ropes (Evered and Selman, 1989). However, on the one hand, the prevailing management paradigm focuses strongly on control, order, and compliance, resulting in people becoming objectified, measured, and expended. On the other hand, coaching refers to the managerial activity of creating, through communication only, the climate, environment, and context that empower individuals and teams to generate results. Work results arise from the quality of the communication (speaking and listening) between managers and their people during on-the-job experience and problems (Evered and Selman, 1989). Thus, contingent knowledge is mainly fostered by means of functional expertise, but also by means of themes such as how to detect or handle waste (Sobek et al., 1998). In addition, coaching supplements training activities (Evered and Selman, 1989). At Toyota, for example, engineers receive most of their training through intensive mentoring by means of direct supervision by senior engineers, although the company also runs a training centre with experienced Toyota engineers as instructors (Sobek et al., 1998). As mentoring closely resembles coaching (Evered and Selman, 1989), we use the terms interchangeably.

3. *Constructive failure treatment*: Waste in engineering comprises, for example, the redundant development of parts, information forwarded to the wrong people and/or working on designs never used (Anand and Kodali, 2008), and is often perceived as failure. There are, however, two types of failure: Those that generate knowledge and

those that do not. When a design fails because engineers try something new that does not work, they generate new knowledge (Petrosky, 1985; Browning, 2003; Thomke, 2001; Nightingale, 2000). When a design fails because they ignore something that they already know they should do, this is not generating new knowledge but waste (Reinertsen, 1997). The constructive treatment of failure takes this differentiation into account. While wasteful failures are detected in order to eliminate them from the design process, knowledge generating failures are managed with care. Information about these failures and the knowledge gained through them are communicated openly and widely. In addition, organisations understand that failure as a result of prudent risk taking is a key source of valuable knowledge. Hence, such failure is treated as such, i.e., it is publicised internally (Reinertsen, 1997).

4 Hypotheses

4.1 Employee training

The first step to eliminating waste is to understand and specify those activities of a process that add value for the customer (Womack and Jones, 1997). Product development projects' activities need to be assigned to the three activity types mentioned above:

1 those that add value

2 those that do not, but are necessary to enable value production ('necessary waste')

3 those that do not and are unnecessary ('pure waste').

Product development processes do, however, differ from production and other business processes in various ways. Product development is a problem-solving process to which terms like 'iterative' and 'creative' apply. Designers may start with one design, find that it is deficient in several ways, and change it (Braha and Maimon, 1997). Analysing, testing, experimenting, and verifying can create valuable knowledge (Reinertsen, 1998; Thomke, 2001; Thomke and Bell, 2001). Nevertheless, all of these activities may be considered 'waste'.

Judging intuitively and without the relevant training or experience from, for example, manufacturing on which to build, employees tend to brand many such activities as waste. A lack of training therefore leads to required activities being eliminated. Thus, when an interdisciplinary group attempts to categorise product development activities according to the three types, it is usually experiences passionate debate. Consequently, product development activities seem to be difficult to classify [Browning, (2003), p.50]. Furthermore, no one wants their activity to be branded as non value adding, whether it is necessary or not (Browning, 2003). This attitude leads to waste not being assigned as such.

The literature on employee training for a lean production system supports this observation. It moreover shows that a major problem, experienced during the introduction of lean manufacturing concepts, is employee commitment to their activities. Obtaining employees' active participation is another problem, which can, however, be encouraged by effective employee training (Chen et al., 1994; Chen et al., 1993; Mehra and Inmann, 1992). Panizzolo (1998), too, states that the human resource factor, which included employees' integration in quality improvement processes, is enhanced by employee training and is one of the most important factors in respect of the successful implementation of lean principles. Kabst et al. (1996) support this statement, arguing that lean management is focused on the individual in the organisation, with employees being recognised and promoted on the basis of their creativity, social competence, intellectual capacity, and commitment. In a quantitative-empirical study, these authors furthermore showed that lean management organisations involve their employees in training activities to a greater degree than non-lean management organisations. In addition, Herron and Hicks (2008) argue that merely copying Japanese management principles is pointless, due to the tacitness and contingency tied to a successful implementation of these principles. Instead, Japanese management principles, such as waste reduction require, training provided by, for example, 'master engineers'. In line with this awareness, Oppenheim (2004, p.369) declares that lean NPD is "sufficiently different from traditional product development (PD) programs that all participants should receive a proper training in that process. […] They should be trained to identify and rebel against PD waste." To sum up, we consequently argue that training targeted at the elimination of waste will enrich engineers' skills, which will lead to an effective waste elimination in product development.

Nevertheless, what seems to be intuitive at first sight, turns out not to be. While we argue that effective waste elimination, including the relevant adjustment of processes, needs to be done by the engineers who are actively working on development projects, others employ a separate team to do so. At GM, Sobek et al., (1998) observed that western companies have a separate group that develops and maintains the details of the standardised process. Others argue, for example, for a 'lean design team' charged with identifying design improvement opportunities (Kearney, 2003). A separate group, who defines and develops improvements for development processes, has often been observed (Sobek et al., 1998).This differs at a lean development system such as that which Toyota uses. Instead of just training a special group of employees or management and holding them responsible for waste elimination, successful firms like Toyota invest heavily in training all their engineers (Liker, 2004; Liker and Meier, 2007). Similarly, Karlsson and Ahlstrom (1996b) mention that all employees should be charge of detecting failures, of finding the cause of a fault, and of initiating the adjustment of processes or procedures. These arguments are in line with those of Leonard-Barton (1992), who states that the skills and knowledge embodied in people are the most relevant core capabilities in NPD.

Summing up, we agree that training targeted at the elimination of waste will enrich engineers' skills. Moreover we argue that the knowledge and skills pertaining to value and waste identification and lean thinking of all the involved engineers have to be built through training if an effective waste elimination is to be achieved in product development. Consequently, we also build on the perception of waste elimination as contingent knowledge that is not within the developer's immediate power, but that is distributed widely throughout the organisation. Overall, we assume that training employees involved in NPD (i.e., mainly engineers) in respect of waste identification and elimination is positive related to the elimination of waste within product development. Hence, we hypothesise:

H1 The training of all product development employees is positively related to the elimination of waste in product development.

4.2 Employee coaching

Knowledge on how to identify and eliminate waste can be classified as contingent knowledge. Furthermore, certain implications flow from considering waste elimination as embodied in a specific situation. In particular, it requires a form of learning that is distinct from pure training. Instead, it requires on-the-spot learning (Fleck, 1997). Coaching is an effective means of meeting this requirement, as it builds on communication (speaking and listening) between managers and their people regarding on-the-job experience and problems (Evered and Selman, 1989). While training is needed to lay the foundations for an understanding of waste, its determination, detection and elimination, it cannot impart situational or contingent knowledge comprehensively. On the other hand, coaching, as communication, which includes listening, giving praise and pointing out areas for improvement between supervisor and employee, can take place when needed (Krug, 1999). Moreover, coaching entails setting positive and effective examples, which are also a source of contingent knowledge since an example is always tied to a specific situation. At Toyota's lean development system, Spear (2004) observes that managers coach their employees during their day-to-day work. In this sense, mangers act as enablers guiding their employees in their daily business, in learning, in problem-solving activities as well as in activities regarding the elimination of waste.

For many observers coaching seem as a kind of meddling that stifles new engineers' creativity and learning. One could argue that experienced employees or managers are 'blind' to some process wastes, as they have become used to it over many years. Consequently, companies move in the opposite direction, preaching empowerment with superiors acting as distant facilitators rather than as coaches or supervisors. However, we argue with Ellerman (1999) that building contingent knowledge requires active learning. This can include the use of mentors, apprenticeship, imitation, and guided learning-by-doing. The active learning process requires learners to take an active role in acquiring knowledge, rather than having it fed to them. Since such learning is contextual and builds on prior knowledge, the new knowledge gained by employees will differ from that of the coach (Bollinger and Smith, 2001; Ellerman, 1999). In addition, coaching as applied in a lean management context, does not purport provide answers to every employee question. Instead, guidance is given by means of Socratic leadership, comprising an iterative questioning and problem-solving process (Spear and Bowen, 1999). Toyota's managers, who seem to avoid making decisions for their subordinates, are exemplary of this method. They rarely tell subordinates what to do, answering questions with questions. They force engineers to think about and understand the problem before pursuing an alternative. It's not a boss-subordinate but a student-mentor relationship (Sobek et al., 1998). This method is supported by a study undertaken by Krug (1999). He states that many engineering managers interviewed reported how wasteful and unproductive their firms were by simply not taking the time to coach junior-level staff. Accordingly, this author concludes: "The ability to coach your project team members and coworkers comprises a set of people skills that has become an increasingly valuable commodity in today's market place" [Krug, (1999), p.13].

In this context, we therefore argue that coaching will significantly enhance the elimination of waste in development processes, which leads to our second hypothesis:

H2 Coaching is positively related to the elimination of waste within the product development process.

4.3 Constructive failure treatment

Engineering and product development are often associated with iterations and experimentation, with some activities yielding the insight that certain combinations or constructions do not work (Petrosky, 1985; Nightingale, 2000); i.e., the prospected way of engineering failed.

Overall, we have a strong human bias to value successes more than we do failure. This is exemplified in that in most organisations failure is stigmatised and employees do not want to be associated with it. However, this tendency to treat failure as the enemy is relatively new. Robert Stephenson, one of the great engineers in the early industrial revolution, for example, strongly advocated discussing failure in the engineering literature. He wrote: "A faithful account of those accidents, and of the means by which the consequences were met, was really more valuable than a description of the most successful work" (Petrosky, 1985). Similarly, Jones and Stevens (1999, p.167) state that "a thorough analysis of innovation failure probably provides a more useful lesson in the management of innovation than stories of success against the odds." This perception is also held by astute firms that safeguard value their failures as well as they do their successes, basing this behaviour on the notion that both contain knowledge. For example, a firm in the appliance industry experimented with a new technology and found that it would not work. The firm treated the experiments' results as proprietary, since it believed that knowledge of design failures is as important as knowledge of design solutions. Years later, a competitor entered the market with that particular technology, which proved to be unreliable. The competitor was forced to recall its product at a cost of millions of dollars (Reinertsen, 1997). Consequently, lean product development perceives failure and problems as a natural part of the product development process and as opportunities to learn, grow, and improve efficiency in development the process (Liker and Morgan, 2006b).

However, constructive failure treatment does not mean that all failures should be treated sympathetically. There are also failures that can be assigned to pure waste. They occur through product development activities that simply consume time and resources without producing knowledge or value, because the knowledge about these failures was already available in the firm. Accordingly, efficient organisations attack these failures and seek to banish them from the development process sustainably. Firms that practice constructive failure treatment differentiate between two types of failure – first-time failures and repetitive failures – and manage them differently. First, they have the organisation learn about *first-time failures*, which stem from experimentation with novel and innovative products or ways of design, thus fostering the growth of technical expertise. In particular, firms recognise such failures as containing valuable knowledge. They therefore have knowledge of first-time failures disseminated throughout the organisation. Some firms do not only publicise, but even celebrate failures as knowledge gained by prudent risk taking. The effect is twofold. First, a firm builds up expertise rapidly. Second, waste is eliminated sustainably because the same experiment is not repeated time and again. The latter effect is achieved by the consequent effort to avoid *repetitive failures*. Not only is the knowledge gained by first-time failures shared, also checklists are used and process standards are adjusted to ensure that the same lesson does not have to be learned more than once. This reasoning is in line with Oackland's (1993) argumentation for lean production. He states that failures are sought to prevent them from reoccurring by openly discussing them and by actively seeking their causes to prevent them occurring in future, thus contributing to the elimination of waste.

Hence, we propose that the constructive treatment of failures by not only regarding them as learning potential, but also as waste will contribute to eliminating waste sustainably. Overall, we derive the following hypothesis:

H3 Constructive failure treatment is positively related to the elimination of waste in product development.

5 Methods

5.1 Sample and data collection

The sample consisted of 108 firms, from each of which we obtained data on one NPD project. The firms are mainly located in Germany, Switzerland, and Austria and belong to the automotive supplier industry. This industry was chosen for various reasons:

1. Compared to other industries, this industry has adopted a pioneering task in applying lean in its production and development processes (MacDuffie and Helper, 1997; Baines et al., 2007). Furthermore, for a large-scale survey the number of appropriate firms in this industry is far more than the number of available automotive original equipment manufacturers (OEMs).
2. By concentrating on one industry, we minimised inter-industry effects.
3. The industry is very important in the European economy.

Through a pre-survey by telephone, 244 potential firms were identified for participation. Enterprises had to meet two criteria for participation. To ensure that they had sufficient data on NPD, they must have developed at least three new products within the last three years. Second, by asking the respondent to state their position (e.g., CTO; vice president of R&D) and their experience (e.g., time the respondent has been working for the firm), we ensure that our informant was eligible. Data collection continued for six weeks and yielded 108 useable questionnaires.

5.2 Level of analysis and measures

All constructs are examined at the project level, based on the assumption that for the respondent aspects relating to the elimination of waste are realistic as well as more concrete on a project level. The respondents were asked to first select a project P, in respect of which they answered a questionnaire. The selected project was a typical or representative one with regard to the firm's development activities. In addition, the project needed to have been completed within the last three years to ensure that the informants were still with the firm and would remember the details of the project.

5.2.1 Dependent variable

The operationalisation of 'waste elimination' is based on Haque and James-Moore (2004). These authors describe the key characteristics of a product development process that satisfies the 'value stream and waste elimination' principle. Some key characteristics are clearly defined processes that provide value for the customer and the usage of value stream analysis to identify waste and/or non-value-adding activities. As prerequisites for such a process, the authors identify the definition and application of a value stream management philosophy, as well as the usage of waste identification methods and tools. Our construct for the elimination of waste is to some extent based on these prerequisites. Hence, in the context of the present study, the construct consists of three items where we asked questions regarding the systematic identification of waste within the product development project (item 1). Second, we asked whether all project engineers had been involvement in this waste identification process (item 2). Finally, we asked if the identified waste was subsequently eliminated by, for example, adapting the process standards (item 3) (see Table 2 for a list of all items).

Table 2 Measures

Elimination of waste (Cronbach's alpha: 0.830)	
Item 1	During our project P, we have had a systematic identification of non-value-added work (so-called muda, waste)
Item 2	All project employees have been strongly involved in the identification of waste in project P.
Item 3	The identified waste has been consequently eliminated (e.g., by the adaptation of process standards).
Employee training (Cronbach's alpha: 0.834)	
Item 4	All employees of project P received training concerning waste analysis.
Item 5	All employees of project P received training concerning standardisation.
Item 6	All employees of project P received training concerning lean thinking.
Coaching (Cronbach's alpha: 0.722)	
Item 7	All senior managers in project P understood the day-to-day business of their employees in detail.
Item 8	All senior managers of the project P have coached their employees well in their improvement activities.
Item 9	All senior managers of the project P have coached their employees well in the challenges of their day-to-day business.
Constructive failure treatment (Cronbach's alpha: 0.686)	
Item 10	During our project P, we had the attitude that failures can be helpful in order to learn from these.
Item 11	During our day to day work in project P we talked openly about those things that went wrong.
Item 12	All problems in project P were traced to their roots.

5.2.2 Independent variables

- *Employee training*: Whether all the project members had training in lean development was captured by three items questioning the training received pertaining to waste analysis, lean thinking, and standardisation (items 4–6). Here, we built on the works of Womack and Jones (2005, 1997), as the authors declare that training is required for companies to become lean. In more detail, the authors strongly recommend training employees in lean thinking, identifying and eliminating waste, and in preserving the achieved improvements by adjusting the standards.

- *Coaching*: Since coaching in the lean sense might differ from the normal interpretation of coaching, we referred to the qualitative work done by Spears and Bowen (1999) and Spears (2004) when developing our coaching items. In their in-depth case study, these authors identified the typical behaviour patterns of coaches working for Toyota. Their main observation was that these coaches actively support their employees in their improvement activities [e.g., Spears and Bowen, (1999), p.102]. Furthermore, these coaches challenge employees' way of executing their daily business, thus initiating improvement activities (i.e., the identification and elimination of waste) [e.g., Spears and Bowen, (1999), p.103]. In addition, these coaches have a deep technical knowledge and understanding of their employees' work (Spears and Bowen, 1999; Spears, 2004). Hence, our ´coaching´ factor comprises items asking question in respect of senior managers' coaching of employees in their daily business and in the problem-solving process (item 8, 9) to investigate whether coaching had been undertaken during the project. Moreover, as effective coaching requires understanding that in which a person is being coached, we questioned the coaches' (i.e., senior management's) technical understanding by asking if they understood their employees' daily business in detail (item 7).
- *Constructive failure treatment*: Based on Putz et al. (in print), we define that a positive failure-learning culture has to at least fulfil the three following requirements:
  1. an attentive and open attitude towards failure and potential failure sources so that failure is detected rapidly and immediately
  2. a constructive and faithful attribution of failures to potential originators to find the potential root of the problem
  3. a deep and consistent failure analysis to determinate the cause of an error.

Referring to the first two requirements, in item 10, we question the attitude project members have had towards failure, also keeping in mind that a somewhat positive attitude fosters a constructive failure treatment. In item 11, we ask whether the communication about failure was an open one. This item, like the previous one, contributes to fulfilling the first two requirements. Finally, in item 12, which refers to the third requirement, we ask whether all problems were traced to their source.

5.2.3 Control variables

We controlled the number of core project team members (i.e., team size), as it is an important structural variable, which potentially influences the quality of a team's collaborative task process and project success (Campion et al., 1993; Gladstein, 1984). A large team could possibly have more resources to conduct a systematic analysis of non-value-added activities. Furthermore, we considered the degree of innovation concerning the new product since the higher the degree of innovation in respect of product development, the less idle capacity there is for the identification of non-value-added work. Finally, we include a new product's degree of complexity as a control variable in our analysis, since the higher a new product's degree of complexity, the more the potential non-added value that can be detected.

Table 3 Factor analysis

	Component			
	1	*2*	*3*	*4*
Item 1	0.803			
Item 2	0.844			
Item 3	0.738			
Item 4		0.779		
Item 5		0.900		
Item 6		0.760		
Item 7			0.799	
Item 8			0.743	
Item 9			0.767	
Item 10				0.769
Item 11				0.764
Item 12				0.726

Note: Factor loadings less than 0.500 are not shown.

Each item was provided with a close-end answer referring to project P on a five-point Likert scale (1 = fully agree … 5 = fully disagree). The internal consistency of all the scales was ensured by means of Cronbach's alpha. Reliability figures ranged from 0.686 to 0.834, thus very close to or above the required threshold of 0.70.

Table 4 Regression analysis

	Dependent variable		
	Elimination of waste		
	Correl. coeff. stand.	*t-value*	*Sig.*
Team size	–0.105	–0.667	0.507
Degree of innovation	–0.066	–0.695	0.489
Product complexity	–0.062	–1.061	0.292
Employee training	0.405**	3.889	0.000
Constructive failure treatment	0.274**	2.626	0.005
Coaching	0.154†	1.476	0.072
R sq.ad.		0.320	
F		7.356	
Df		81	

Notes: †Significant at the 0.1 level (one-tailed).
*Significant at the 0.05 level (one-tailed).
**Significant at the 0.01 level (one-tailed).

5.3 Data analysis and results

In testing our hypotheses, we conducted regression analyses with pair-wise exclusion where there were missing data. F has a significance level of 0.995 (7.356 > 4.60). All three constructs were statistically significant at the 0.1 level or higher. Moreover, the factors employees training and constructive failure treatment were strongly significant (at the 0.01 level). The explained variance (adjusted R sq.) was 0.32. This modest explained variance suggests that there are important factors beyond those considered in the current study that impact the dependent factor elimination of waste. (For results see Table 4).

6 Discussion: implications – limitations - expectations

6.1 Implications for theory and practice

This research's empirical results shed light on how different management factors enable the elimination of waste in NPD. More precisely, the results refer to the training of all of a project team's members in lean management through comprehensive coaching by senior managers as well as a constructive failure treatment to supplement the tools and techniques provided by lean management for deployment during product development. Next, implications for theory and practice are provided in respect of each of the named management means.

Regarding *employees training*, the empirical data show that training which provides a lean-specific enrichment (i.e., lean thinking, waste analysis, standardisation) of traditional engineering skills helps to improve the identification and elimination of waste. This finding has an essential practical implication for managers involved in NPD, since instead of assigning 'special task forces' to scrutinise the product development department and its processes for non-value-added activities, management should think about training *all* project members to eliminate waste. This finds support in the adage 'ten eyes can see more than two eyes, 100 eyes can see more than ten eyes'. Furthermore, trained employees are more efficient than attempting to generate of a 'perfect' system to avoid all waste, which is always in any case independent on its operators' training and education (Reinertsen, 1997, 1998). Hence, firms should enable all project team employees to recognise and eliminate waste during product development.

Pertaining to *coaching*, we found that it has a significant influence on waste elimination. As knowledge of waste elimination is contingent, therefore cannot be learned entirely through training, coaching is essential. Furthermore, the growing popularity of coaching leads to the supposition that most managers have improved their skills in listening, setting positive examples, and pointing out areas for improvement. Studies have, however, identified that in respect of a wide range of skills, managers were actually rated lowest in exactly those abilities (Krug, 1999). If coaching is considered a necessity for waste elimination in product development, why are so many managers not applying it? Studies point to four major reasons: Reluctance to confront, fear of offending, fear of failure, and a lack of time, but also that the managers themselves have never been coached and, moreover, have little incentive or accountability to learn to do so (Krug, 1999).

Not only leadership, but also deep technical understanding is essential to coach. For example, at Toyota's lean development system, even higher-level managers are deeply involved in engineering details. Instead of merely managing the development process, managers improve their engineering skills, stay abreast of new technologies, maintain their contacts, develop new ones, and remain involved in the creative process itself (Sobek et al., 1998; Haque and James-Moore, 2004; Liker and Morgan, 2006a). Therefore, the practical implications are that provision should be made to provide senior managers with deep technical knowledge as well as excellent teaching or mentoring skills. With this set of qualifications, project managers can coach their employees effectively to foster sustainable waste elimination.

The relationship between *constructive failure treatment* and the success of waste elimination is less intuitive. The data analysis clarified that the better the two failure types (*repeated* and *first-time*) are differentiated, the more successful waste elimination is. The open communication of failures certainly has an influence on waste elimination. Management should therefore encourage employees to talk about failures made by, for example, making failure communication a part of routine communication. This will ensure that failures are talked about. Moreover, this will provide more opportunities to actively show a positive attitude to *first-time* failures than having to wait until somebody talks about failure.

Furthermore, it is important to trace problems back to their roots. Hence, management should overcome the temptation to simply fight the symptoms but not curing the underlying disease. Despite the time pressure and lack of manpower due to the hard day-to-day business in product development, the big challenge for management is to ensure that problems are really traced to their roots. Only then can waste truly be eliminated. Overall, the managerial challenge is to develop a mechanism whereby such a perspective on NPD failures can be created without the need for a major organisational survival crisis (Lewis, 2001). Here, as Weick (1979) has argued, the concept of continuous improvement in small steps is a sensible method for motivating action because encouraging 'small wins' helps overcome a natural aversion to failure associated with large changes. This underlines the complementary importance of employee training and coaching in respect of constructive failure, as the three activities can be regarded as the fundamentals of continuous waste elimination.

Interesting insights are provided by our *controls*, since contrary to our assumption, not one (project team size, the degree of innovation, or the developed new product's complexity) is significant in our model. An important theoretical contribution by this paper is the *operationalisation* of the constructs employee training, coaching, and failure elimination, which is not offered by the extant literature.

To conclude: The trend towards lean development will continue, as it promises to dramatically improve a company's competitive position by, among other things, eliminating waste sustainably. Its implementation offers the potential for faster product development with fewer engineering hours, the improved manufacturability of products, and higher quality products (Karlsson and Ahlstrom, 1996b). However, while there are a number of tools and techniques for the deployment of lean principles and means in product development, there are a number of management questions associated with it that so have not had a clear answer. This paper addressed this gap. Subsequently, a brief overview of the questions and answers is provided.

- Who should remove waste?
  All employees should be given the responsibility.
- How will these people initially be enabled to do so initially?
  Training in lean thinking, waste detection, and deletion is a necessary pre-condition for waste elimination.
- How will they be enabled to do so in the long run?
  Coaching will provide sustainable waste elimination.
- What are the critical pre-conditions?
  Failures have to be differentiated and treated in a constructive way.

6.2 Limitations and further research

First of all, the modest explained variance suggests that there are important factors beyond those considered in the current study. Further research should therefore try to identify more influencing management factors affecting the elimination of waste. This would help to obtain a greater understanding of the issue.

Secondly, "[w]hatever the perspective, the elimination of waste is the principle that is traditionally at the heart of a Lean approach" [Baines et al., (2006), p.1540]. Consequently, by focusing on waste elimination and efficiency, lean development addresses the productivity of development activities, rather than creativity. Contrary to this, we argue that the elimination of waste frees up resources which can be deployed in creative activities. However, the focus of lean management must not be restricted to 'liposuction' activity (waste reduction), but address product development as a larger system (Pessôa et al., 2007). Future research should consider the effects of introducing flow (Reinertsen, 1997) or pull to product development. In respect of the latter, Smith and Reinertsen (1991) described how the 'pull' approach can be applied to information and, if established in a development team, only the downstream persons can ask for whatever information they need. However, empirical testing of such conceptual thinking is still required.

Thirdly, this study only considers firms from the automotive industry. Taking the investigation further to other industries would contribute to a more general understanding.

Acknowledgements

The financial support of the GFF Research Fund (Grundlagenforschungsfond) at the University of St. Gallen is gratefully acknowledged.

References

Anand, G. and Kodali, R. (2008) 'Development of a conceptual framework for lean new product development process', *International Journal of Product Development*, Vol. 6, pp.190–224.

Baines, T., Lightfoot, H., Williams, G.M. and Greenough, R. (2006) 'State-of-the-art in lean design engineering: a literature review on white collar lean', *Proceedings of the Institution of Mechanical Engineers*, *Part B: Journal of Engineering Manufacture*, Vol. 220, pp.1539–1547.

Baines, T.S., Williams, G.M., Lightfoot, H. and Evans, S. (2007) 'Beyond theory: an examination of lean new product introduction practices in the UK', *Proceedings of the Institution of Mechanical Engineers*, *Part B: Journal of Engineering Manufacture*, Vol. 221.

Ballard, G. (2000) 'Positive vs. negative iteration in design', *8th International Conference on Lean Construction*.

Bauch, C. (2004) 'Lean product development: making waste transparent', Diploma thesis, Massachusetts Institute of Technology, Cambridge.

Benner, M.J. and Tushman, M.L. (2003) 'Exploitation, exploration, and process management: the productivity dilemma revisited', *Academy of Management Review*, Vol. 28, pp.238–256.

Bollinger, A.S. and Smith, R.D. (2001) 'Managing organizational knowledge as a strategic asset', *Journal of Knowledge Management*, Vol. 5, pp.8–18.

Braha, D. and Maimon, O. (1997) 'The design process: properties, paradigms, and structure', *Systems, Man and Cybernetics*, *Part A*, IEEE Transactions, Vol. 27, pp.146–166.

Brown, L.S. and Eisenhardt, M.K. (1995) 'Product development: past research, present findings, and future directions', *Academy of Management Review*, Vol. 20, pp.343–378.

Browning, T.R. (2003) 'On customer value and improvement in product development processes', *Systems Engineering*, Vol. 6, pp.49–61.

Browning, T.R., Eppinger, S.D., Co, L.M.A. and Fort Worth, T.X. (2002) 'Modeling impacts of process architecture on cost and schedule risk in product development', *Engineering Management*, IEEE Transactions, Vol. 49, pp.428–442.

Campion, M.A., Medsker, G.J. and Higgs, A.C. (1993) Relations between work group characteristics and effectiveness: implications for designing effective work groups', *Personnel Psychology*, Vol. 46, pp.823–847.

Chen, I.J., Chung, C-S. and Gupta, A. (1994) 'The integration of JIT and FMS', *Integrated Manufacturing System*, Vol. 5, pp.4–13.

Chen, I.J., Gupta, A. and Walter, O.R. (1993) 'Understanding the human aspects of flexible manufacturing systems through management development', *Journal of Management Development*, Vol. 12.

Cooper, R.G. (2008) 'Perspective: the Stage-Gate® idea-to-launch process-update, what's new, and NexGen Systems*', *Journal of Product Innovation Management*, Vol. 25, pp.213–232.

Cooper, R.G. and Kleinschmidt, E.J. (1990) 'New product success factors: a comparison of 'kills' versus successes and failures', *R&D Management*, Vol. 20, pp.47–63.

Cooper, R.R. and Kleinschmidt, E.J. (1995) 'Benchmarking the firm's critical success factors in new product development', *Journal of Product Innovation Management*, Vol. 12, pp.374–391.

Ellerman, D.P. (1999) 'Global institutions: transforming international development agencies into learning organizations', *The Academy of Management Executive (1993–2005)*, pp.25–35.

Emery, F.E. and Trist, E.L. (1960) 'Socio-technical systems', *Management Science, Models and Techniques*, Vol. 2, pp.83–97.

Evered, R.D. and Selman, J.C. (1989) 'Coaching and the art of management', *Organizational Dynamics*, Vol. 16–32.

Fleck, J. (1997) 'Contingent knowledge and technology development', *Technology Analysis & Strategic Management*, Vol. 9, pp.383–398.

Garvin, D.A. (1998) 'The processes of organization and management', *Sloan Management Review*, Vol. 39, p.33.

Gladstein, D.L. (1984) 'Groups in context: a model of task group effectiveness', *Administrative Science Quarterly*, Vol. 29, pp.499–517.

Haque, B. and James-Moore, M. (2004) 'Applying lean thinking to new product introduction', *Journal of Engineering Design*, Vol. 15, pp.1–31.

Herron, C. and Hicks, C. (2008) 'The transfer of selected lean manufacturing techniques from Japanese automotive manufacturing into general manufacturing (UK) through change agents', *Robotics and Computer Integrated Manufacturing*, Vol. 24, pp.524–531.

Jones, O. and Stevens, G. (1999) 'Evaluating failure in the innovation process: the micropolitics of new product development. R&D Management, 29, 167-178.

Kabst, R., Larsen, H. and Bramming, P. (1996) 'How do lean management organizations behave regarding training and development?', *The International Journal of Human Resource Management*, Vol. 7, pp.618–639.

Karlsson, C. and Ahlstroem, P. (1996a) 'Assessing changes towards lean production', *International Journal of Operations and Production Management*, Vol. 16, pp.24–41.

Karlsson, C. and Ahlstrom, P. (1996b) 'The difficult path to lean product development', *Journal of Product Innovation Management*, Vol. 13, pp.283–295.

Kato, J. (2005) 'Development of a process for continuous creation of lean value in product development organizations', Master thesis, Massachusetts Institute of Technology, Cambridge.

Kearney, A.T. (2003) *The Line on Design: How to Reduce Material Cost by Eliminating Design Waste*, available at www.atkearney.com/main.

Krug, J. (1999) 'People skills: coaching engineers', *Journal of Management in Engineering*, Vol. 13, p.13.

Leonard-Barton, D. (1992) 'Core capabilities and core rigidities: a paradox in managing new product development', *Strategic Management Journal*, Vol. 13, pp.111–125.

Lewis, M.A. (2001) 'Success, failure and organisational competence: a case study of the new product development process', *Journal of Engineering And Technology Management*, Vol. 18, pp.185–206.

Liker, J.K. (2004) *The Toyota Way*, Mc-Graw-Hill, New York.

Liker, J.K. and Meier, D. (2007) *Toyota Talent: Developing Your People The Toyota Way*, McGraw-Hill.

Liker, J.K. and Morgan, J.M. (2006a) *The Toyota Product Development System*, Productivity Press, New York.

Liker, J.K. and Morgan, J.M. (2006b) 'The Toyota way in services: the case of lean product development', *Academy of Management Perspectives*, Vol. 20, pp.5–20.

Luhmann, N. (1995) *Social Systems*, Stanford University Press.

MacDuffie, J.P. and Helper, S. (1997) 'Creating lean suppliers: diffusing lean production throughout the supply chain', *California Management Review*, Vol. 4, pp.118–151.

McmManus, H. (2004) 'Product development value stream mapping manual', Beta Version Ed., *MIT Lean Aerospace Initiative*, Cambridge, MA.

McManus, H.L. and Millard, R.L. (2002) 'Value stream analysis and mapping for product development', *Proceedings of the International Council of the Aeronautical Science*, pp.8–13.

Mehra, S. and Inmann, R.A. (1992) 'Determining the critical elements of just-in-time implementation', *Decision Sciences*, Vol. 23, pp.160–174.

Morgan, J.M. (2002) *High Performance Product Development: A Systems Approach to a Lean Product Development Process*, University of Michigan.

Nightingale, P. (2000) 'The product–process–organisation relationship in complex development projects', *Research Policy*, Vol. 29, pp.913–930.

Oackland, J.S. (1993) *Total Quality Management: The Route To Improving Performance*, Butterworth-Heinemann, Oxford.

Ohno, T. (1988) 'Toyota production system', *Beyond Large-Scale Production*, Productivity Press, Portland.

Oppenheim, B.W. (2004) 'Lean product development flow', *Systems Engineering*, New York, Vol. 7, pp.352–378.

Panizzolo, R. (1998) 'Applying the lessons learned from 27 lean manufactures: the relevance of relationship management', *International Journal of Production Economics*, Vol. 55, pp.223–240.

Perrow, C. (1984) 'Normal accidents', *Basic Books*.

Pessôa, M.V.P. (2008) 'Weaving the waste net: a model to the product development system low performance drivers and its causes', White paper – LAI 08-01, Lean Advancement Initiative Center for Technology, Policy, and Industrial Development Massachusetts Institute of Technology.

Pessôa, M.V.P., Loureiro, G. and Alves, J.M. (2007) 'An approach to lean product development planning', in Loureiro, G. and Curran, R. (Eds.): *Complex Systems Concurrent Engineering*, Springer, London.

Petrosky, H. (1985) *To Engineer Is Human: The Role Of Failure In Successful Design*, St. Martin's Press.

Pich, M.T., Loch, C.H. and Meyer, A.D. (2002) 'On uncertainty, ambiguity, and complexity in project management', *Management Science*, Vol. 48, p.1008.

Putz, D., Schilling, J. and Kluge, A. (in print) Olaf, Fragebogen Zur Erfassung Des organisationalen Klimas für Lernen aus Fehlern, Handbuch wirtschaftspsychologischer Testverfahren Bd.2. W. Sarges.

Reinertsen, D. (1998) 'Testing: annoyance or opportunity', *Electronic Design*, Vol. 46, 64H.

Reinertsen, D. (1999) 'Lean thinking isn't so simple', *Electron Des*, Vol. 47.

Reinertsen, D.G. (1997) *Managing the Design Factory*, Free Press, New York.

Salomo, S., Weise, J. and Gemunden, H.G. (2007) 'NPD planning activities and innovation performance: the mediating role of process management and the moderating effect of product innovativeness', *Journal of Product Innovation Management*, Vol. 24, pp.285–302.

Schrader, S., Riggs, W.M. and Smith, R.P. (1993) 'Choice over uncertainty and ambiguity in technical problem solving', *Journal of Engineering and Technology Management*, Vol. 10, pp.73–73.

Smith, P.G. and Reinertsen, D.G. (1991) *Developing Products In Half The Time*, Van Nostrand Reinhold Chapman and Hall, New York London.

Sobek, D.K., Liker, J.K. and Ward, A.C. (1998) 'Another look at how Toyota integrates product development', *Harvard Business Review*, July–August, pp.36–49.

Spear, S. and Bowen, H.K. (1999) 'Decoding the DNA of the Toyota production system', *Harvard Business Review*, Vol. 77, pp.96–108.

Spear, S.J. (2004) 'Learning to lead at Toyota', *Harvard Business Review*, Vol. 82, pp.78–86.

Thomke, S. (2001) 'Enlightened experimentation: the new imperative for innovation', *Harv Bus Rev*, Vol. 79, pp.66–75.

Thomke, S. and Bell, D.E. (2001) 'Sequential testing in product development', *Management Science*, Vol. 47, pp.308–323.

Ward, A.C., Shook, J. and Sobek, D. (2007) *Lean Product and Process Development*, The Lean Enterprise Institute.

Weick, K.E. (1979) *The Social Psychology of Organization*, Addison-Wesley.

Wheelwright, S.C. and Clark, K.B. (1995) *Leading Product Development – The Senior Manager's Guide to Creating and Shaping the Enterprise*, The Free Press, New York, NY.

Womack, J. and Jones, D.T. (1997) 'Lean thinking', *Banish Waste and Create Wealth in your Corporation*, Touchstone Books, New York.

Womack, J.P. and Jones, D.T. (2005) *Lean Solutions: How Companies and Customers Can Create Value and Wealth Together*, Simon & Schuster.

Notes

1 Procedure: We searched for published works by using the keywords 'lean development', 'lean product development', and 'lean innovation' in the databases of Ebsco, Proquest, and Amazon from 1990 to mid 2008. Overall, the results underline that lean product development is a topic receiving increasing attention in the academic and management literature.