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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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# Lean Product Development—Faster, Better ... Cleaner?

**Abstract** To address this challenge, lean product development has emerged to become the leading improvement methodology for companies toward the creation of a competitive advantage on innovation and technology leadership. While lean product development has its origin in the best practice studies of Japanese car manufacturers such as Toyota, it has been further elaborated in defence and aerospace organizations over the last two decades, and recently empirical evidence has become available for successful introductions in sectors different from the traditionally-studied environments. The primary purpose of this work is to untangle the fuzziness that still surrounds lean product development and to ground the key aspects of lean product development based on insights from six studies published in a special issue of the *Engineering Management Journal* on this topic. This demonstrates how better and faster product development can be achieved through the integration of lean principles with the best of more traditional new product development (NPD) practices, into a holistic system that can be characterised by value-focused and risk-based decision making, the socio-technical integration of people and process, improved project, pipeline and portfolio management, optimized knowledge management, and the creation of a learning organization. Unfortunately, while the increasing global competition offers the potential to improve the quality of life for many, the spirit of faster, better, and cheaper also threatens to endanger the future of our planet as a whole. As the majority of a product's social and ecological impacts are committed in the design phase, it, therefore, seems imperative to investigate the integration of lean product development and eco-design principles. As a result, this work also explores the symbiosis of both approaches through the identification of tools and methods that can support the triple bottom-line goals for a sustainable future of life and business.

**Keywords:** lean product development, sustainability engineering, responsible design

## 1 Introduction

As new product development can result in breakthrough innovation, product repositioning, or cost reduction activities (Crawford & Benedetto, 2008), it is of strategic importance to most if not all organizations. Without new products, organizations are not able to sustain their revenue, to defend their position in current market, or to develop new markets (Griffin, 1997). Cooper (2000) found that US firms generated 50% of their sales revenues and 40% of their total profits from new products. However, many organizations keep struggling with their product development initiatives. According to Barczak, Griffin, and Kahn (2009), only 59% of new products introduced by US organizations are actually successful, a success rate has remained nearly unchanged since the mid-1990s. This is an alarming failure rate, making the continuous improvement of new product development processes key to a healthy organization.

To address this challenge, lean product development has emerged to become the leading methodology for companies toward the creation of a competitive advantage on innovation and technology leadership. To untangle the fuzziness that still surrounds lean product development after two decades of research, the *Engineering Management Journal* (*EMJ*) launched a special issue on this topic in 2011. The six papers of the special issue allow foregrounding the key aspects of lean product development that seem to be vital for technology-oriented organizations, which are urged to reduce time to market in a race for faster, better, and cheaper in the current global competitive economy.

Unfortunately, the spirit of faster, better, and cheaper also threatens to endanger the future of our planet as a whole. As the majority of a product's social and ecological impacts are committed in the design phase, this paper wants to explore the symbiosis of lean product development and eco-design through the identification of both similarities and differences between key principles and practices. For this purpose, firstly, we provide an overview of the history

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of lean product development and the key insights that emerge from the special issue of *EMJ*. Secondly, we provide a summary of the key principles of green engineering and discuss how they align with the fundamental principles of lean thinking. Finally, the paper explores similarities and common benefits, while at the same time identifies the potential difficulties with the integration of both development perspectives.

## 2 Lean product development history

The first two seminal studies that introduced the importance of applying lean principles to product development date from the early 1990s, i.e. *The Machine That Changed the World*" (Womack, Jones, & Roos, 1990) and *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry* (Clark & Fujimoto, 1991). Whereas the initial contributions had a strong emphasis on principles and the best practices from Japanese car manufacturers such as Toyota, lean product development (LPD) has been further elaborated in defence and aerospace over the last two decades. More recently however, it has been successfully introduced to various other sectors (Mascitelli, 2011; Oosterwal, 2010; Reinertsen, 2009) and as such, LPD seems to emerge as the leading improvement methodology for companies toward the creation of a competitive advantage on innovation and technology leadership.

Following the clear need from industry to explore efficient and effective ways to develop new products, there has been an increasing number of publications on LPD (León & Farris, 2011), demonstrating the growing popularity of the field. Unfortunately, many contributions very often lack scientific depth and theoretical underpinnings. To further stimulate the scientific debate about LPD, *EMJ* launched a special issue on the topic in 2011.

## 3 Insights from the *EMJ* special issue on LPD

The six papers of this special issue try to define what exactly LPD is, how it relates to other new product development (NPD) approaches, whether there is real empirical evidence of the success of LPD, and last but not least, how to successfully introduce LPD in various industry settings. Whereas it is not the purpose of this work to provide a comprehensive summary of these papers, there are a number of insights that emerge from the special issue that are important to investigate whether LPD and environment friendly techniques, such as green engineering and eco-design, should be considered as complimentary or conflicting approaches.

Following a structured literature review designed to understand LPD within the general product development (PD) context, León and Farris (2011) mapped the current themes in LPD research to seven knowledge domains that arise from the literature. This allowed them to enumerate principles and practices proposed to address core PD problems, and to identify areas for further research within and across the domains.

The first insight that emerges from this, relates to the importance of the traditional lean thinking principles to product development. The literature covered in the knowledge domain "lean principles" demonstrates that identifying value, mapping the value stream, improving flow, transitioning to pull, and striving for perfection, all remain highly relevant even in a product development context (Haque & James-Moore, 2004; Hines & Rich, 1997). This has more recently been confirmed by Oppenheim, Murman and Secor (2011), who provided a valuable overview of various lean enablers for systems engineering categorized following the traditional principles introduced by Womack and Jones (2010).

Several authors, however, have warned the research community about the need for refocusing lean principles and considering their limits before any deployment attempt across product development settings (e.g., Browning, 2003; Cusumano, 1994). The six other domains (performance-based, decision-based, process-modeling, strategy, supplier/partnership, knowledge-based) discussed by León and Farris provide an interesting set to summarize some important reflections when applying lean principles in product development.

Firstly, it is important to notice that whereas eliminating waste may be a powerful instrument to optimize value in production, in product development the focus needs to shift first toward the identification of value from a customer perspective. As a result, there are many LPD contributions that either propose methods to evaluate the effectiveness and efficiency of LPD practices at single and/or multi-project levels (performance-based domain, e.g., Haque & James-Moore, 2004), or focus on the techniques to support decision-making through value assessment and risk management (decision-making domain, e.g., Ward, Liker, Cristiano, & Sobek, 1995).

Secondly, when it comes to identifying the value stream, two important reflections need to be made. Firstly, there is a strong focus on fast learning cycles to overcome initial knowledge gaps (Radeka & Sutton, 2007). When these gaps emerge in the later stages of the product development process, they can cause significant rework loops leading to both budget overruns and excessive delays. Secondly, to reduce time to market and to optimize performance of the whole organization, it is essential to focus both on product and process development from the start of the project. This implies that both product and service characteristics need to be considered at the early stages of the development process. Papers within the process-model domain have typically provided recommendations for activity sequencing, concurrent engineering, and front loading (e.g., Browning, 2002; Eppinger, Whitney, Smith, & Gebala, 1994).

However, both the work of Liker and Morgan (2006; 2011) and the word of Letens, Farris and Van Aken (2011) clearly demonstrated that when introducing LPD in organizations, it is imperative to take a systems view. In their contribution to the *EMJ* special issue (Liker & Morgan, 2011), *Lean product development as a system: A case study of body and stamping development at Ford*, Liker and Morgan described how recently Toyota's LPD systems view of integrating people, process and tools was applied with great success at Ford Motor Company, providing as such significant evidence of the robustness and portability of Toyota's LPD system. Building on best practices from both the LPD and NPD literature, Letens et al. (2011) further clarified that this system spans the various levels of the organization. Through a case study in an engineering department of the Belgian Armed Forces, they identified the characteristics of a multilevel framework that are essential to achieve breakthrough results at the functional project and portfolio level of the organization.

As such, both contributions provide the evidence of topics that have received a focused interest in the literature, relating to the strategic domain (that is, product platforms and portfolio management, e.g., Cusumano & Nobeoka, 1998), the supplier domain (i.e., tapping from the innovation potential of suppliers, e.g., Ro, Liker, & Fixson, 2008), and the knowledge-based domain, that explores techniques to optimize knowledge transfer and learning networks (e.g., Dyer & Nobeoka, 2000; Nonaka & Takeuchi, 1995).

Besides recognizing different orientations in the interpretation of lean principles in a product development context, it is equally important to identify key practices that support the implementation of these principles. For that purpose, Hoppmann et al. (2011) used content analysis to investigate existing LPD practices and to integrate them into a coherent framework of eleven LPD components that are highly interwoven. Their work suggested that only the concurrency of the components leads to high performance in PD. Table 1 provides an overview of the components and illustrates how they mapped onto the domains that were identified by León and Farris (2011).

The importance of the integration of these techniques is further illustrated by Nepal et al. (2011). Their work also testified of the need for specific tools such as Design Structure Matrix and Product Development Value Stream Mapping to support the analysis of the underlying complexity of PD and the elimination of wasteful rework. Beauregard et al. (2011) provided clear empirical evidence that even in aerospace, work needs to be done to fully understand the influence of multitasking, concurrency, task size, task value, and budget decision making on LPD performance.

**Table 1**

*Lean Product Component within the Prominent Knowledge Domains of LPD*

| Prominent knowledge domain | Lean product component |
|---|---|
| Decision making | 1. Strong project manager<br>2. Specialist career path<br>3. Rapid prototyping, simulation and testing<br>4. Set-based engineering |
| Process domain | 5. Workload leveling<br>6. Responsibility-based planning and control<br>7. Simultaneous engineering<br>8. Process standardization |
| Knowledge-domain | 9. Cross-project knowledge transfer |
| Supplier domain | 10. Supplier integration |
| Performance-based domain | NA |
| Strategy domain | 11. Product variety management |

All together, the papers of the *EMJ* special issue on LPD demonstrated that whereas the five fundamental principles of lean thinking provide a strong backbone for introducing lean in product development, it is equally important to tune these principles to the product development context through the use of several specific interrelated techniques. These techniques reside from domains (León & Farris, 2011) or components (Hoppmann, Rebentisch, Dombrowski, & Zahn, 2011) that need to be integrated into a coherent organizational system (Liker & Morgan, 2011) that spans all levels of the organization, requiring intense collaboration and effort from multiple stakeholders (Letens, Farris, & Van Aken, 2011). This emphasizes the importance of taking a socio-technical perspective when introducing LPD in organizations and clarifies the challenges behind the overall lean transformation that is needed to render LPD successful beyond the single project level.

## 4 Sustainability engineering

Whereas the previous section strongly promotes LPD as a catalyst for achieving economical success through NPD, organizations are experiencing an increasing pressure to also assume their responsibility with regard to the environment and the society as a whole. Corporate social responsibility implies organizations demonstrate at a minimum compliance with the spirit of law, ethical standards and international norms. In a broader sense however, it encourages organizations to develop a positive impact on the environment and its stakeholders: customers, investors, employees, and communities. The relevance of engineering and design toward the achievement of triple bottom line goals (economical, environmental, social) becomes trivial once it is realized that the design phase of a new product controls the factors that account for 60%

to 80% of the desired impact of the product, that is, performance, cost and equally important, impact on the environment. As a result, sustainable engineering refers to the integration of social, environmental, and economic considerations into product, process, and energy system design from the very first stage of the product development process. However, as most of the literature on sustainability seems to primarily address concerns for environmental issues (Seuring & Müller, 2008), this paper will focus on the principles of green engineering and eco-design to identify similarities and contrasts with LPD.

## 5 Environmentally responsible design

The terminology of product design integrating environmental issues has changed over the last two decades. As such the original term, green design (or green engineering), has frequently been replaced by environmentally sound or environmentally sensitive design or eco-design (often used within Europe) and design for the environment (DfE), which seems to be more dominant in the US (Baumann, Boons, & Bragd, 2002). Although there are evolutionary differences reflected in all these terminologies, this work will consider them to be interchangeable for the purpose of this paper.

Similar to LPD, eco-design finds its origin in the late 1980s to early 1990s, focusing initially on two main causes of environmental problems: policy, research, and technology were challenged to find concepts and solutions that would prevent pollution and save resources (Hübner, 2012). Two main research streams emerged from this: cleaner production and eco-design. Cleaner production very quickly found a strong connection with the economic objectives of manufacturers as the development of more efficient production technologies helped to reduce the consumption of resources and thus lowering production costs. As a result, manufacturers immediately felt the benefits of greening their processes. The eco-design of products turned out to be a more complex challenge (Hübner, 2012). Several competing views were proposed, but initially most of them lacked a business perspective, ignoring the financial, managerial and competitive implications of eco-design (Baumann et al., 2002).

A first milestone was achieved when the Industrial Designers Society of America published a catalogue of *12 Facts of Ecological Design* that primarily focuses on the resource reduction and recycling opportunities for industrial design and redesign (IDSA, 1992). As shown in Table 2, these guidelines are not necessary in conflict with any of the principles of LPD, but they certainly do make design decisions more challenging as besides considering the requirements of the end-user; the designer needs to additionally consider perspectives from various other stakeholders (production, distribution, disposal) that in some cases also introduce strict legal constraints. From a lean perspective, this implies that the first two lean principles deserve greater attention. Firstly, it becomes even more important to use lean practices that support identifying value from a multiple stakeholder perspective, and to introduce rapid learning cycles to support the development of knowledge that will enhance our understanding of all involved design tradeoffs. Secondly, as is emphasized within the whole eco-design literature, it becomes evident that the designer needs to consider an extended value stream, covering the complete product and process life cycle from conception to disposal. Analyzing this value stream for potential sources of waste is challenging: It is critical to include a careful analysis of important backflows (rework, service, recycle, and dispose) and to consider the consumption of energy, resources, and environmental waste at every step of the value stream.

**Table 2**

*12 Facts of Ecological Design (IDSA, 1992)*

| No. | Fact of ecological design |
|---|---|
| 1 | Make it durable |
| 2 | Make it easy to be repaired |
| 3 | Design it so it can be remanufactured |
| 4 | Design it so it can be reused |
| 5 | Use recycled materials |
| 6 | Use commonly recyclable materials |
| 7 | Make it simple to separate the recyclable components of a product from the none-recyclable components |
| 8 | Make products more energy/resource efficient |
| 9 | Eliminate the toxic/problematic components of a product or make them easy to replace or remove before disposal |
| 10 | Use product design to educate on the environment |
| 11 | Work toward designing source reduction-inducing products (i.e., products that eliminate the need for subsequent waste) |
| 12 | Adjust product design to reduce packaging |

This implies that when optimizing flow (the third principle of lean) new techniques, such as design for disassembly (DfD) and design for recycling (DfR) need to be considered to eliminate environmental waste. As such, various engineering disciplines typically engage in four approaches to improve processes and products, making them more efficient from an environmental standpoint: product enhancement, waste reduction, materials management, and pollution prevention. As a result, similar to LPD, green engineering seeks to integrate numerous disciplines to develop a holistic (i.e., systemic) view of the ecosystem throughout the whole life cycle of the product. Life cycle analysis (LCA) is considered to be an essential instrument to simultaneously minimize environmental impacts while maximize benefits for social and economic stakeholders. As such, LCA becomes the missing link between eco-design and a larger sustainability perspective that considers all elements of the triple bottom line. LCA can also be an important input in the overall assessment of the value of the new product that additionally needs to consider environmental and societal factors such as public health. As a result, similar to LPD, green engineering is an approach based on concurrent engineering that supports designers to achieve multiple objectives without sacrificing any important values.

## 6 Green engineering principles versus lean principles

To further deepen our understanding of the relationship between green engineering and LPD, the next section categorizes the essential principles of green engineering based on the five basic principles of lean. Two different seminal sources were considered for selecting the main green engineering principles: the nine guidelines defined by Abraham and Nguyen (2003) as an outcome of the Sandestin Conference, and the twelve principles promoted by the American Chemical Society (Anastas & Zimmerman, 2003). Table 3 illustrates the results of the projection of green engineering principles on the traditional lean principles.

Whereas the arguments behind this classification are not included in this paper due to page limitations, Table 4 summarizes the insights that emerge from this, including the parallels between LPD and green engineering that were identified before.

## 7 Insights and conclusions

The innovation and design of products are critical

**Table 3**

*Green Principles in Support of Lean Principles*

| | Sandestin Conference | Americal Chemical Society |
|---|---|---|
| Value | 1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools<br>2. Conserve and improve natural ecosystems while protecting human health and well-being | 1. Inherent Rather Than Circumstantial—Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible<br>7. Durability Rather Than Immortality—Targeted durability, not immortality, should be a design goal<br>6. Conserve Complexity—Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition |
| Value stream | 3. Use life cycle thinking in all engineering activities | 11. Design for Commercial "Afterlife"—Products, processes, and systems should be designed for performance in a commercial "afterlife"<br>2. Prevention Instead of Treatment—It is better to prevent waste than to treat or clean up waste after it is formed<br>10. Integrate Material and Energy Flows—Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows |
| Flow | 4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible<br>5. Minimize depletion of natural resources<br>6. Strive to prevent waste | 4. Maximize Efficiency—Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency<br>3. Design for Separation—Separation and purification operations should be designed to minimize energy consumption and materials use<br>9. Minimize Material Diversity—Material diversity in multi-component products should be minimized to promote disassembly and value retention<br>12. Renewable Rather Than Depleting—Material and energy inputs should be renewable rather than depleting |
| Pull | 7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures | 5. Output-Pulled Versus Input-Pushed—Products, processes, and systems should be "output-pulled" rather than "input-pushed" through the use of energy and materials<br>8. Meet Need, Minimize Excess—Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw |
| Perfection | 8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability<br>9. Actively engage communities and stakeholders in development of engineering solutions | Nihil |

**Table 4**

*Similarities and Differences between LPD and Sustainability Engineering*

| Principles | LPD | Sustainability engineering |
|---|---|---|
| Value | • Identifying customers and their requirements<br>• Understanding product and performance tradeoffs<br>• Value assessment and risk-based decision making, seeking to optimize, product and service characteristics at a minimal cost; in the shortest schedule possible | • Identify environmental stakeholders and legal requirements<br>• Understanding business versus social and environmental tradeoffs<br>• Environmental impact assessment and risk-based decision making, seeking to optimize product and service characteristics over the life cycle of the product at a minimal life cycle cost of the supporting ecosystem, in the shortest schedule possible |
| Value stream | • Consider all elements of the value chain (product and process)<br>• Assess the impact of rework<br>• Strong initial focus on knowledge development activities | • Consider the whole product and process life cycle in the context of the overall eco-system<br>• Assess the impact of material and energy consumption, and of backflows<br>• Identify environmental waste (energy, materials) |
| Flow | • Cadence of value adding activities and risk reducing decisions<br>• Optimal product and information flow to minimize interruptions and rework<br>• Concurrent engineering | • Idem, including (legal) environmental approvals<br>• Minimize backflow<br>• Eliminate and minimize environmental waste<br>• Concurrent engineering<br>• Stakeholder involvement |
| Pull | • Customer involvement<br>• Set based design (deep understanding of tradeoffs)<br>• Modular design and reuse<br>• Robust design<br>• Pulling lean atoms of value (LAVA)<br>• Deliver when needed<br>• Cross-functional and cross-disciplinary integration events | • Eco-alternative evaluation<br>• Reuse and recycle<br>• Minimal resource consumption<br>• Pulling natural resources for the LAVAs<br>• Operating when needed<br>• Cross-disciplinary ecosystem integration events |
| Perfection | • Of engineering and other processes<br>• Visualization of imperfections in flow | • Of engineering and the overall ecosystem<br>• Visualization of flow and eco-waste |

instruments in support of the transformation of society toward sustainability. The overuse of resources and the socio-ecological impacts of production, distribution, use and disposal are evidence that current methods of decision making for innovation and design are insufficient (Byggeth, Ny, Wall, Broman, & Robèrt, 2007). Developing an approach that integrates the best of LPD and green engineering may provide a solution to this problem. Whereas LPD clearly has a strong emphasis on optimizing strong economical benefits, and green engineering focuses primarily on minimizing the impact on the environment, the combination of both approaches should help us to find a better balance between at least two elements of the triple bottom line.

However, the integration of both product development approaches could be a challenging route. Insights from Table 4 testify of the mutual benefits and common elements in both approaches, but also highlight clear differences that add to the complexity of optimizing the goals of triple bottom line for a sustainable future. Some tools and techniques are different as they serve different goals, align with different value constructs, and support the analysis of different value streams. So if the primary concern of LPD is to develop profitable new products and to bring them to the market as fast as possible, adding a green engineering perspective to LPD implies considering a larger set of requirements and design constraints that are essential to assure the development of sustainable solutions. This may seem overwhelming and even in conflict with a strict economic perspective at first, but it actually only further emphasizes the importance of various LPD practices that have been developed to accelerate product development under the conditions of stringent constraints and extreme uncertainty. In their book *Cradle to Cradle: Remaking the Way We Make Things*, McDonough and Braungart (2002) emphasized that design is a signal of intent. To make sure designers have the best intention when designing new products from a lean and sustainability perspective, they have to develop a holistic view of the problem at hand, in order to fully understand the design space constrained by all tradeoffs, and to pull the atoms of value that supports making value optimizing and risk reducing decisions with the best intention for all social, environmental, and economic stakeholders involved.

## 8 Limitations and opportunities for future research

There are several limitations to this conceptual work and as such, as a first priority, it seems essential to repeat this reflection process using a more rigorous research methodology. Still the insights can be considered as encouraging. They clearly highlight valuable avenues for future research, be it to obtain a more articulated view of the integrated approach, to list specific practices of mutual interest, or to investigate factors that would support the implementation of an integrated approach in organizations and societies with different cultural backgrounds. Findings of such research efforts would not only support developing things right, but would also enable developing the right things for a sustainable future of life and business.

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