Applicability of Lean Product Development to a company in the marine sector

E.L. Synnes[1], T. Welo[2,]
[12]Department of Mechanical and Industrial Engineering, Trondheim, Norway
(elisler@stud.ntnu.no)

Abstract – **How can a marine company best combine people, process and technology to optimize its Product Innovation system for advanced, complex products produced at low volumes? This paper discusses the possibility of using the Lean concept to improve the company's product development system. The operational context of the case company is analyzed up against the framework of Morgan and Liker's 13 Lean Product Development (LPD) principles. Our hypothesis is that although the business context of the case company is radically different from Toyota, several principles and practices will still be applicable once 'contextualized'. A workshop was held with a multidisciplinary product team to assess the practices of the company relative to LPD. The team evaluated current company practices and desired future practices. The results are summarized and discussed herein. It is concluded that the original LPD principles have a varying degree of applicability to the context of the case company.**

Keywords – **Lean Product Development, marine sector, high-value products, low-volume**

I. INTRODUCTION

The competitive pressure in the marine sector is steadily increasing due to globalization and the widespread economic crisis in the oil and gas industry. To sustain in this turmoil, companies must develop and deliver more desirable products ahead of their competitors—before technology or market changes.

However, it is not possible to sustain competitive in the market place solely by improving efficiency, reducing prices and outsourcing production. The key is to focus on value creation as a basis for successful innovation, and with this comes the need for development of novel products and manufacturing technology. In this context, the marine industry in Norway is challenged to develop more innovative products and manufacturing technology. However, the lack of investments in the marine sector during the last decades is a barrier for leveraging innovation capabilities.

In many industrial sectors—such as aerospace and automotive industry—lean has made a major contribution to manufacturing efficiency. In the long run, however, improvement in manufacturing alone will not ensure competitive advantage since the cost of a product is largely determined at the planning and design stage. For many type of products, as much as 70% of the manufacturing cost is locked-in in the design phase [1].

In the 1970s, companies experienced that the introduction of robotics, flexible manufacturing and computer integrated manufacturing did not provide the benefits expected. Many companies experienced that investing in a robot is easy compared to the challenge of successfully implementing a new product into production. In other words, successful new product introduction relies heavily on creating a strong interface between design and manufacturing, such that process and design considerations are collectively considered in order to deliver productivity improvements promised by new manufacturing technologies [2]. Design, function and implementation of advanced manufacturing technologies are directly related to the product to be produced—and vice versa.

In this paper, we ask the question: How can a company operating in the marine business (best) combine people, process and technology to optimize its Product Innovation system. We seek to answer this question by addressing Lean Product Development (LPD), discussing the applicability of Lean to the context of product development of advanced, high-value products produced at low volumes in the marine business.

The reminder of this paper is organized as follows: Section 2 present the operational context at glance. Section 3 presents relevant literature on LPD, including Morgan and Liker's 13 principles of LPD, which has been used as a basis for assessing the applicability of the Lean concept to the business context considered herein. Section 4 discusses the applicability of LPD in the operational context considered. Finally, Section 5 presents some concluding remarks.

II. OPERATIONAL CONTEXT

The applicability of Lean Product Development (LPD) principles will be investigated in connection with a large global company's marine division. This company operates in a B2B market, where the customer also typically is a marine company. Part of the marine division is located along the western coastline of Norway with local research and development, and production operations. The value chain is relatively dispersed with local responsibility for product and customer specific issues. The operational procedures and standards, on the other hand, are part of global cooperate practices where sub-functions supporting the product value stream, such as Lean production, systems thinking, etc. are rolled out. The operational practices are very much heuristic with local site standards, thus forming strong sub-cultures within the global company.

The products are mostly large, complex products with strict requirements to operating life. Here, we use the term complex to reflect the large number of (customized) components in each product (typically more than 100), the multidisciplinary skills required to deliver the product to customer (production process) and the geometry of components (and products). Each product variant is produced in limited volume, and the production process/system can be characterized as *Engineer-to-order* (ETO). The products are mainly delivering a set of functions, and the customers' main concern is that the product is working according to a set of prescribed criteria and requirements, which commonly change during the course of the product development process.

Up until today high quality, functionality and productivity (lead-time) have been the basic elements for competitive advantage in the company. The production technology infrastructure is tailored to low-volume. For example, machining operations are largely already automated in CNC machining centers, whereas assembly operations, quality control and dimensional verification typically involve a large amount of manual labor. Due to high labor costs, it has been increasingly challenging to produce these type of products in Norway. A need has therefore been identified to extend the company's capabilities in new automation solutions for manufacturing operations. However, this type of products is not well supported by common arguments for automated assembly: Firstly, automation usually requires high volume of standardized parts. Secondly, the product size is another factor that adds complexity to automation.

The company uses a business process named Product Introduction & Lifecycle Management (PILM) to bring products and services to market, and to support the end-of-life cycle. While PILM is used for the whole product and supply chain, Manufacturing Capability Readiness Level (MCRL) and Technology Readiness Level (TRL) are internal subsystems on process and technology level, respectively. These cooperate processes are typically inherited in the marine sector from other business sectors, which operate under different terms and conditions. The interface between these processes can be difficult to manage, since competence is multidisciplinary and geographically spread in the dispersed value chain of the company.

III. LITTERATURE

A. Lean Product Development

Lean is usually associated with production of physical products, typically at high volumes. More recently, sources in the literature are discussing the application of the lean concept in the new product development (NPD) process [3-7]. *Lean product development* (LPD) is a philosophy suitable to improve efficiency in product development with basis in customer value. The Toyota Production System (TPS) is perhaps the most well-known example of successful lean processes put into action. However, the application of Lean, especially outside the manufacturing area, is not straightforward and there are only a few examples outside Toyota[5]. In 2006, Liker & Morgan [8] presents 13 management principles that—right or wrong—can be considered as a foundation for LPD, emphasizing a system's model where all the principles are mutually supportive. Hence, Lean is a highly interrelated system, in which elements interact, overlap, are interdependent, and work together as a coherent whole. One of the key insights of Liker and Morgan's [8] research is that changes made to one subsystem will always have implications for the other. Also, to succeed in putting Lean into practice, it is not enough to implement a few tools since LPD requires a cultural transformation into a learning organization [8].

According to a literature review on Lean engineering by Baines et al. [7], a successful implementation of lean requires organization-wide changes to systems, practices, and behaviors. Lean is said to be as much about creating the right culture, strategy and environment as it is about developing tools and techniques. According to McManus [9], the most important element in Lean (engineering) is to focus on understanding the customer and end-user value expectations for the product. Another important element is to choose products and architectures, which may be upgraded or improved in future product offerings—i.e. standardization and continuous improvement.

One other important element of LPD is Set-Based Concurrent Engineering (SBCE). As oppose to a point-based design strategy, SBCE is successively excluding non-viable and non-sustainable solutions by identifying limits and constraints [10-12]. The designer looks first for the weaker design solutions, using a funneling approach to reduce number of feasible design. Instead of designing from top down, the actual system configuration evolves from creative combinations of multiple solution sets [7]. SBCE imposes agreed constraints across different functions to ensure that a final sub-system solution, chosen from a set of alternatives from a particular function, will work with convergent solution from all other functions. SBCE focuses on keeping the design space open as long as possible. The paradox [5] of SBCE is that considering a broader range of concepts will delay some decisions, but in return the whole process will be faster and more efficient. During the design process each alternative is evaluated, trade-offs are made, weaker solutions are eliminated and new ones are created, often by combining components in new ways [6, 7, 12]. Haque [6], with basis in literature, argues that a set-based design is a key element of LPD. Generally, "point designs"—i.e., highly optimized and specialized solutions to specific problems—are not good lean engineering candidates. This, is according to McManus [9], due to the fact that a set-based approach is favorable to address uncertainty.

A related issue at management or system level is removing high-risk technology from the critical path of product development. For example, technology demonstrators can remove risk of unplanned delays [9].

Compared to other Product Development theories and methods, LPD has strong focus on value and waste—and separating the two categories—compared to Lean manufacturing, becoming “Lean” is more associated with increasing value than removing waste when applied in NPD [3]. Moreover, since the lean concept in NPD is related to information and knowledge transformation—unlike the production of a physical product—it is more difficult to separate value from waste in NPD [13]. One of the key elements is important to initiate and execute value-creating activities with the correct information input. According to Browning [3], lack of value within the product development system is usually a result of having the wrong input rather than doing activities that are unnecessary. A design iteration that can be eliminated without value-loss is waste removal. Without an integrated and synchronized process to organize activities, however, doing value-added activities does not guarantee a value-adding result [3].

IV. METHODOLOGY

The operational context of the case company was analyzed up against the framework of Morgan and Liker’s [5] including 13 LPD principles presented in their earlier study of the Toyota Product Development System. A workshop was held with a multidisciplinary product team to assess the practices of the company relative to the set of LPD principles. In addition, lessons learned from an internal technology project were used as input in the discussions with the survey team. This project particularly explored automated assembly of large, complex products, see [14]. The project was selected since it was considered too well represent the contextual challenges analyzed in this article. Hence, the development of an automated production solution for the case product required concurrent development of new technology, a new product design and a new production process, leading to multiple changes in existing practices and capabilities.

The workshop included people from the following functions: Programme Management, Engineering and Manufacturing Engineering. The workshop included the following steps: First, an assessment sheet was sent to each participant for an individual scoring. The input from the participants was collected and analyzed. This was followed by a workshop where the analyzed material was assessed and discussed to ensure common understanding. After the workshop, each attendee was given the opportunity to review the result and provide additional input. The result of the assessment is presented in Table 1.

IV. RESULTS AND DISCUSSION

The variety of product development activities in the case company span from product line extensions to development of unproven technologies and processes. The team suggested that a so-called set-based approach might be favorable when the outcome is unknown and the cost of rework is high. Also, when dealing with manufacturability issues the set-based approach is advantageous, especially when the product relies on technology with limited experiences, or involves new or advanced materials and processes [11]. On the other hand, an iterative strategy—more point-based design strategy—is usually beneficial when the quality of the first guess is high, cost of re-work is low and feedback is fast.

In the case company, prototype customized products are often sold to customers, which require extensive work for preparing documentation, ensuring quality, etc. According to the survey team, this can (early) lead to a point-based design, focusing on optimization of the chosen solution rather than exploring alternative solutions. Here the use of more demonstrators upfront for rapid learning was highlighted as an important countermeasure. Such demonstrators/ “proof of concepts” can be used both at sub-system and system level. Further, this can be used as learning and early feedback for field service, a function that is involved later in the product life-cycle. Prototypes and demonstrators are important artefacts [15] to verify that results are not achieved at the cost of functional requirements, or any other compromises that degrade the final value of the product.

One of the main findings in the workshop is that although all the LPD principles are considered important in themselves, they have a varying degree of applicability in the setting of the case company. As an example, due to low-volume it is common to adapt a product to fit into a specific production process, thereby filling up the production line to achieve economies of scale. On the other hand, there are major trade-offs to be made between what the customer wants (ETO), and standardization of products and components. Another element regarding standardization and modularization emphasized by the survey team is the need for interface control for adding changes to design during ETO or later sub-optimization during sustained engineering.

In the case project considered, it appeared that a small team was doing “skunk work” outside business-as-usual working outside the existing boundaries of their departments to develop the new capabilities necessary. This turned out to be an efficient way of resolving specific technology challenges. Moreover, introducing “new-to-the-company” type technology in product realization projects is a major challenge since it enforces the company`s existing capabilities to change[14].

TABLE 1 ASSESSMENT OF LPD PRINCIPLES IN THE COMPANY.

	Principle	Current state case company	Desired future state	Gap between current and future state	Difficulty to change	Bottleneck/critical action
Process	Establish **customer-defined value** to separate value from waste.	Considered very important.	Develop resources and competence to fully understand and define customer value.	Low	Low	Sub-optimization. Ship owner and ship operator have different needs.
	Front load the product development process.	The mentality of making things work creates a risk of operating in "start-up" mode, being impatient in the concept phase, and focusing on one solution.	Seamless integration of product and process. Demonstrators for rapid learning to optimize the solution both at sub-systems and systems level.	Medium	Medium	Allocate sufficient resources (funding) early on in the project, competing with short term tasks.
	Create a leveled Product Development process flow.	To some extent leveled today. Resources that are not fully dedicated to the project are more difficult to utilize. Main challenge is prioritization of daily production over PD in case of urgency.	Dedicated resources (human and machines) for PD.	Medium	Medium	Difficult to plan. How to ensure that temporary/less dedicated resources get ownership to the project.
	Utilize Rigorous Standardization to reduce variation.	Process level: good Product level: needs to be improved. Challenging due to differentiated product portfolio and limited volume.	Enforce product modularization and standardization; e.g., design for common tool and equipment.	High	Medium	Prevent trade-off customer value and standardization. Clarify what is assumption, what is verified, what is re-use of knowledge and what needs to be validated to ensure that standardization does not make the company reactive.
People	Develop a "Chief Engineer System".	Project leader (PL) that has several roles in a project. Generally high technical expertise. However, sometimes lack capacity to manage project. Today, rigid processes to ensure control.	PL of a dedicated team with clear responsibilities. Ensure seamless integration between functions. Strong network and understanding of life cycle.	High	Medium	Finding persons with the right skills. Management of TRL and MCRL processes. Difficult to have overview of the entire process.
	Organize to balance Functional Expertise and Cross-functional integration.	Interface between functions is not clear. For example, Design Engineer doing Manufacturing Engineer work and vice versa.	Provide equal authority of all disciplines. Early involvement from all functions.	High	High	Ensure access to resources. Understanding the mechanisms that are resulting in successful projects.
	Develop towering technical competence in all Engineers.	Experts and special competence are satisfying. The need for more T-shaped people is highlighted..	A mix between T-shaped and expert competence. More system competence. Utilize learning from previous projects.	Medium	Medium	Ideas often stem from Gemba. Key to follow these ideas to the project table without losing the original intention and drive.
	Fully integrate suppliers into the PD system.	To some extent existing today. However, there is lack of a formal process.	Suppliers to deliver a product with the correct cost and design.	Low	Medium	Early supplier involvement. However, many design changes result in changing premises during the project.
	Build in learning and continuous improvement.	Global company with local sub-cultures. Need to encourage knowledge sharing and cooperation (trust). Works on individual level.	Utilize learning in projects to develop more T-shaped people.	Medium	Medium	Strong sub-cultures.
	Build a culture to support excellence and relentless improvement.	Continuous improvement important to company	Cultural change to create additional awareness.	Medium	Low	Must "choose the right battles".
Tools	Adapt Technology to fit your people and process.	A tendency to favor technology over people and processes.	Manage technology and competence in a more digitalized world. Competence to read out results from new technology.	High	Medium	Need to systematize competence.
	Align your organization through simple, visual communication.	3D models.	Early simulation for common understanding.	Low	Low	
	Use powerful tools for standardization and organizational learning.	A3 has recently been introduced in the Research and Technology department.	Solve problem with Gemba and at the root cause.	High	Low	Problem solving can be too complicated.

V. CONCLUDING REMARKS

The LPD principles proposed by Morgan and Liker [5] have a varying degree of applicability to the context of the case company studied herein. In practice, the principles need to be contextualized since they are of guiding nature. As an example, standardization is key, especially in low-volume production due to cost. However, the assessment made emphasized major trade-off between standardization and flexibility to create value for the customer.

Based on our assessment of LPD practices, and with support from the selected case project, we have identified several areas that have potential to strengthen the PD process in the case company once contextualized to the marine sector at glance. The most apparent areas are:

1. Use a set-based approach in combination with demonstrators to leverage rapid learning and optimized solutions.
2. Seamless integration between functional areas, especially integration of manufacturing early in the PD process to prevent waste later in the process; e.g., design loopbacks. Avoid formal, gate-type hand-overs and an "over the wall approach" that can be a hindrance to pace in the project.
3. Enforce equal authority of all functions in the project team.

This research supports insights of Liker and Morgan's [8] research reflecting that changes made to one subsystem will always have implications for the other. Hence, it is not enough to implement a few lean tools, as achieving leanness in PD requires transformation into a learning organization. Based on continuous learning from projects, following a set-based design strategy, the company can build T-shaped people [16] and improve integration between functions and phases in the PD process.

ACKNOWLEDGMENT

Rolls-Royce Marine AS and the Research Council Norway's Industrial Ph.D. programme project 241103,who are both gratefully acknowledged, funded this work. Also, we express our special thanks to the workshop participants.

REFERENCES

1. Boothroyd, G., P. Dewhurst, and W.A. Knight, *Product Design for Manufacture and Assembly*. 3rd ed, ed. G. Boothroyd. 2011, Boca Raton: CRC Press Tylor & Francis Group.
2. Stoll, H.W., *Design for manufacture: An overview* Applied Mechanics Reviews, 1986. **39**(9): p. 1356-1364.
3. Browning, T., *On Customer Value and Improvement in Product Development Processes* Systems Engineering, 2003. **6**(1): p. 49-61.
4. Schipper, T. and M. Swets, *Innovative Lean Development How to Create, Implement and Maintain a Learning Culture Using Fast Learning Cycles*. 2010, New York: CRC Press Taylor & Francis Group A Productivity Press Book.
5. Morgan, J.M. and J.K. Liker, *The Toyota Product Development System*. 2006, New York: Productivity Press.
6. Haque, B., *Lean engineering in the aerospace industry.* Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 2003. **217**(10): p. 1409-1420.
7. Baines, T., et al., *State-of-the-art in lean design engineering: a literature review on white collar lean*, in *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*. 2006. p. 1539-1547.
8. Liker, J.K. and J.M. Morgan, *The Toyota Way in Services: The Case of Lean Product Development.* Academy of Mangement Perspectives, 2006. **20**(2): p. 5-20.
9. McManus, H., A. Haggerty, and E. Murman, *Lean Engineering: Doing the Right Thing Right*, in *1st International Conference on Innovation and Integration in Aerospace Sciences*. 2005, CEIAT, Queen`s University Belfast: Queen`s University Belfast, Northern Ireland, UK.
10. Smith, P.G., *Flexible Product Development: Building Agility for Changing Markets*. 1st ed. 2007, San Francisco CA: Jossey-Bass John Wiley & Sons, Inc. .
11. Vallhagen, J., et al., *An approach for producibility and DFM methodlogy in aerospace engine component development.* Procedia CIRP, 2013. **11**: p. 151-156.
12. Sobek, D.K., A.C. Ward, and J.K. Liker, *Toyota`s Principles of Set-Based Concurrent Engineering.* MITSloan, 1999. **40**(2): p. 67-83.
13. Welo, T. and G. Ringen, *Investigating Lean development practices in SE companies: A comparative study between sectors*, in *Procedia Computer Science*. 2015.
14. Synnes, E.L. and T. Welo. *Bridging the Gap Between High and Low-Volume Production through Enhancement of Integrative Capabilities*. in *44th Proceedings of the North American Manufacturing Research Institution of SME*. 2016. Procedia Manufacturing.
15. Elverum, C.W. and T. Welo, *Leveraging prototypes to generate value in the concept-to-production process: a qualitative study of the automotive industry* International Journal of Production Research 2016. **54**(10): p. 3006-3018.
16. Kelley, T. and J. Littman, *The Ten Faces of Innovation: IDEO`s Strategies for Defeating the Devil`s Advocate and Driving Creativity Throughout Your Organization*. 2005, United States of America: Doubleday Random House Inc.