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A New Set of Principles for Pursuing the Lean Ideal in Engineer-to-Order Manufacturers

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Abstract

For many years, lean production has been successfully applied in large companies producing high volumes of standardized products. However, companies which operate in dissimilar environments have yet to expose a suitable model for pursuing the lean ideal, adapted and fine-tuned to the diverse characteristics demonstrated by producers of, for example, highly customized, engineer-to-order products. The aim of this paper is to examine the evolution of lean principles with the primary goal of converging towards a new set of principles that are more clearly aligned for the deployment of lean in engineer-to-order manufacturers. We take insight in lean production, lean project management, and lean product development in order to develop a set of principles which we suggest is more clearly suited for the deployment of lean thinking in engineer-to-order manufacturers. Firstly, we use literature review in order to examine the most prevalent lean principles in the extant literature, and we apply qualitative content analysis in order to propose a new set of principles. We then adopt a multiple-case study approach in order to validate the derivation of the new principles in the context of two, distinct engineer-to-order environments. Our findings highlight a transition from the traditional lean production model to a more contemporary, innovative approach for pursuing the lean ideal in the context of ETO manufacturers.

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1. Introduction

Lean production can be described as both a philosophy and a set of tools and techniques that aims to identify and eliminate all waste in manufacturing operations. Though it was never intended for Lean to be the antithesis of mass production, it certainly is the antithesis of large-lot production [1]. Thus, at least in the traditional sense, Lean can be thought of as an alternative way of organizing mass production. As such, [2] defines Lean as a term given to a family of related methodologies that seek to streamline production processes. It is generally agreed amongst researchers and practitioners that Lean was developed from the methods and working practices of the Toyota Production System (TPS), with its roots in the continuous flow thinking and moving assembly line concept of Henry Ford. Due to the fact that Lean has indeed emerged from the high volume production environments of global automotive OEMs, for example, it is no surprise that there have been difficulties in applying such methods in environments that demonstrate much higher levels of variation in both products and processes, and experience demand for much lower volumes, such as one-of-a-kind products. Indeed, if we consider the basic principles of mass and flow production [3], it becomes clearer for us to identify the need to reconsider Lean in the context of low volume, high variety manufacturing: (a) Mass production demands mass consumption, and (b) Flow production

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requires continuity of demand. Low volume, high variety (e.g. ETO) producers exhibit neither *mass consumption* nor *continuity of demand*, thus, in order to develop "Lean" working practices that are much better suited to this type of production environment, we assert that the fundamental lean principles be re-examined in the context of such low-volume, high variety producers. To summarize, Lean has been variously understood over time, first as a new and better way to make things, then as a way to design and make things, and more recently as a fundamental management philosophy defined by the ideal pursued. The lean ideal can be stated thusly: *providing customers (both internal and external) with exactly what they need to accomplish their purposes, with no waste*; where we define waste as *anything that incurs a cost of any kind, the elimination of which does not reduce the value delivered* [4]. Therefore, in this paper, we attempt to develop a new set of principles in order to answer the general question: *How to pursue the lean ideal in the ETO context?*

2. The Customer order decoupling point

In order to distinctively define what we interpret as ETO, we shall first consider the concept known as customer order decoupling point (CODP). CODP is a concept that is used to distinguish between different market interaction strategies in manufacturing [5, 6]. The CODP separates the part of the material and information flow that is based on firm customer orders from the part that is based on forecasts and speculation [5]. In general, four different strategies are distinguished based on different CODP positions [7]: ***Make-to-stock (MTS); Assemble-to-order (ATO); Make-to-order (MTO);*** and ***Engineer-to-order (ETO).***

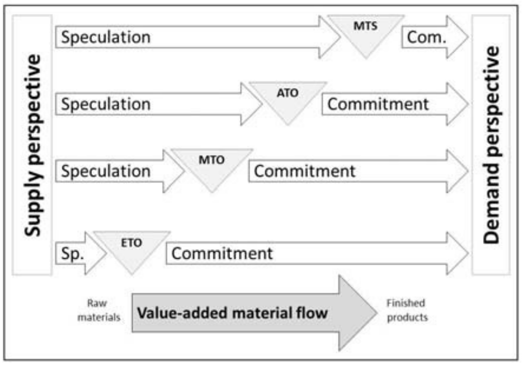

Fig. 1. The Customer Order Decoupling Point Concept [8].

Fig. 1. illustrates the positioning of the CODP in each of the four main strategies, relative to each other. As we see it, there are in fact two conflicting interests when deciding where to position the CODP. Firstly, a company may desire to become less reliant upon the use of forecasts, thus there is a desire to shift the CODP from right to left in the figure. On the other hand, a company may want to reduce lead times, which would often require a shift of the CODP from left to right, in order to move the decoupling point closer to the market and ultimately closer to the customer. This is certainly true of MTO/ETO companies. For example, [9] clearly states that a competitive priority in the MTO/ETO sector is often shorter lead times. However, though there is no doubt that the majority of successful applications of lean manufacturing have occurred at companies that produce high volumes of standardized products in fairly low varieties (these types of company have often been able to combine lead time reduction through the application of lean flow techniques with a lower emphasis on the use of forecasts by moving from MTS to ATO), there does remain a recognizable distinction between such high volume, low variety MTS/ATO environments and the more challenging low volume, high variety environments present in make-to-order (MTO) and engineer-to-order (ETO) producers. As customers are nowadays demanding more and more customized products with shorter life cycles, we choose to focus our investigation only on ETO manufacturers that represent those companies at the extreme left of the scale, offering the most bespoke, customer-specific products on the market - see Fig. 1. Furthermore, we consider ETO manufacturers that either adapt existing designs, or develop completely new designs from scratch, in response of a confirmed customer order. We do not consider MTO producers that use standardized, existing designs, as these companies already benefit from reduced lead times due to the fact that the design and engineering phase is not required in response of customer orders. As such, it is fair to assume applicability of some traditional lean concepts in the context of MTO companies, as the very existence of standardized designs assumes some constancy of mass consumption and continuity of demand.

3. A classification scheme for ETO manufacturers: Characteristics and challenges

ETO refers to the strategy by which design, engineering and production do not commence until after a customer order is confirmed. In terms of the product-process characteristics of this type of environment [e.g. 10], the products are customer specific, highly customized items produced in low volumes (often one-of-a-kind), and processes are typically non-repetitive yet labor intensive, often demanding highly skilled labor. As such, ETO companies cannot accurately forecast demand, order materials and produce in advance, or effectively apply batch production methods [11].

The earlier CODP means that a greater degree of customization can be offered in an ETO setting, albeit at the cost of longer lead times and increased uncertainty. In fact, ETO manufacturers endure uncertainty across a number of dimensions, including uncertainty in product specification and mix; process specification uncertainty; and volume uncertainty [12, 13]. Because of the extent of uncertainty experienced by ETO manufacturers, planning and control becomes more complex and difficult for these companies, as does the pursuit of the lean ideal. This is particularly true when we further consider the concept of uncertainty in terms of Lean, where the success of Lean in the traditional sense has been built on the elimination of uncertainty and variation through demand- and production leveling. It is in fact this focus on leveling (also referred to as Heijunka – the Japanese term for "smooth wave") that has been criticized as making Lean too inflexible and not applicable in more volatile markets [14].

4. The evolution of lean principles

4.1. *Lean production and the five lean principles*

The term lean production was first coined by [15] and was later popularized in the book *The Machine that Changed the World* [16]. As such, during the 1990s there was wide acceptance by manufacturing companies of this new approach to organizing mass-production, which, although was not the anti-thesis of mass-production, certainly offered a very effective alternative set of methods that were to allow many companies to thrive in an increasingly competitive global marketplace. Womack and Jones later renewed their lean message for applications outside of the automotive arena when they defined Lean Thinking in terms of five lean principles: "precisely specify *value* by specific product; identify the *value stream* for each product; make value *flow* without interruptions; let the customer *pull* value from the producer; and pursue *perfection*" [17]. Though in their most basic and fundamental state the majority of these principles are indeed applicable within high variety, low volume production environments; the very formulation of them from the context of high volume, low variety producers leaves much to be desired for their deployment in, for example, engineer-to-order (ETO) manufacturers, particularly during the design and engineering phase. This is because, by definition, "Lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability" [18]. Thus, the relevance of many of the so-called lean practices could in fact appear detrimental to the success of a company that prioritizes the ability to offer product variety as an order winner, or indeed an order qualifier.

4.2. *The Toyota Way principles*

As Lean is proclaimed to have its roots in the Toyota Production System (TPS), it is also insightful to consider the work of [19], who describes TPS and the Toyota Way as a set of 14 principles. Though Womack and Jones' five lean principles can perhaps be interpreted as manufacturing-centric (for example due to the implicit supposition that customer value is fully expressed in the customer order); the Toyota Way principles extend toward a more general management philosophy where organizational purpose is understood in terms of the concepts and principles of production, and production is understood as the integration of designing and making useful things:

1. *Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals;*
2. *Create a continuous process flow to bring problems to the surface;*
3. *Use 'pull' systems to avoid overproduction;*
4. *Level out the workload (work like the tortoise, not the hare);*
5. *Build a culture of stopping to fix problems, to get quality right the first time;*
6. *Standardized tasks and processes are the foundation for continuous improvement and employee empowerment;*
7. *Use visual controls so no problems are hidden;*
8. *Use only reliable, thoroughly tested technology that serves your people and process;*
9. *Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others;*
10. *Develop exceptional people and teams who follow your company's philosophy;*
11. *Respect your extended network of partners and suppliers by challenging them and helping them improve;*
12. *Go and see for yourself to thoroughly understand the situation*
13. *Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly;*
14. *Become a learning organization through relentless reflection and continuous improvement.*

We consider these principles to be more operationalized than the previous five lean principles, thus the Toyota Way offers a deeper understanding of how such principles should be applied in order to develop and deploy a set of lean and efficient operations.

4.3. *Lean enterprise principles*

While the two previous sets of lean principles were developed with insight from the automotive industry, a long-term effort to apply lean in the aerospace industry resulted in a further set of five principles: *Create lean value by doing the right job and by doing the job right; deliver value only after identifying stakeholder value and constructing robust value propositions; fully realize lean value only by adopting an enterprise perspective; address the interdependencies across enterprise levels to increase lean value;* and *people, not just processes, effectuate lean value* [20]. These lean enterprise principles take an even stronger standpoint on value, which broadens the focus of lean to value creation rather than waste elimination exclusively [21]. They also state more explicitly the importance of addressing value from the perspective of all stakeholders rather than simply from the customer viewpoint.

4.4. *Enterprise transformation principles*

[21] makes an additional contribution to the field by moving further away from the manufacturing sector and redefining lean principles in the context of enterprise

transformation in general. They suggest a set of seven principles: *adopt a holistic approach to enterprise transformation; secure leadership commitment to drive and institutionalize enterprise behaviors; identify relevant stakeholders and determine their value propositions; focus on enterprise effectiveness before efficiency; address internal and external enterprise interdependencies; ensure stability and flow within and across the enterprise;* and *emphasize organizational learning*. Such a holistic, systems approach to transformation highlights enterprise interconnections, identifies enterprise waste and creates strategies to translate waste into opportunities for value creation [21].

4.5. *Lean Construction principles*

Also shifting the focus away from "pure" manufacturing environments, [22] defines a set of principles for lean construction: *reduce the share of non-value adding activities; increase output value through systematic consideration of customer requirements; reduce process variability; reduce cycle times; simplify by minimizing the number of steps, parts, and linkages; increase output flexibility; increase process transparency; focus on complete process; build continuous improvement into the process; balance flow improvement with conversion improvement;* and *benchmark*.

4.6. *Lean Product Development System principles* [23]

Finally, [23] develops a further set of lean principles in the context of product development, which is very relevant in the case of ETO manufacturing that has a high degree of customer specific design and engineering activity.

1. Establish customer-defined value to separate value-added from waste.
2. Front-load the product development process to explore thoroughly alternative solutions while there is maximum design space.
3. Create a level product development process flow.
4. Utilize rigorous standardization to reduce variation, and create flexibility and predictable outcomes.
5. Develop a chief engineer system to integrate development from start to finish.
6. Organize to balance functional expertise and cross-functional integration.
7. Develop towering competence in all engineers.
8. Fully integrate suppliers into the product development system.
9. Build in learning and continuous improvement.
10. Build a culture to support excellence and relentless improvement.
11. Adapt technologies to fit your people and process.
12. Align your organization through simple visual communication.
13. Use powerful tools for standardization and organizational learning.

The core idea of those principles is to reduce variation in product development while preserving creativity. For example, Toyota creates a higher level of flexibility by standardizing lower-level tasks. [23] suggests that there are three broad categories of standardization at Toyota:

- Design standardization: use of common architecture, modularity and reusable or shared components;
- Process standardization: in order to reduce variability found in having many non-standard low levels tasks;
- Engineering skill set standardization: to make easier knowledge modeling and knowledge representation.

In terms of design standardization and component modularity, [24] suggests that successful modularization provides a company with three benefits:

- It allows a company to economically increase product variety that can be offered to customers;
- It increases a company's ability to respond to various demands from dynamic competitive environments, thereby creating strategic flexibility;
- It allows reduced task complexity and enhances the ability to complete tasks in parallel.

As such, we identify modularization as a key element for success in pursuing the lean ideal in ETO manufacturing companies.

5. A new set of Principles for Operational Excellence in ETO manufacturers

By analyzing and reflecting on the existing principles for lean production, lean construction, and lean product development, we aimed to propose a new set of principles that shall enable ETO manufacturers to pursue the lean ideal. We applied a method of qualitative content analysis in order to code and group the lean principles evaluated within this research paper. This resulted in the categorization of ten fundamental principles which we further defined in the context of ETO manufacturers:

1. ***Defining Stakeholder Value***
2. ***Leadership, People and Learning***
3. ***Flexibility***
4. ***Modularization***
5. ***Continuous Process Flow***
6. ***Demand Pull***
7. ***Stakeholder- and Systems Integration***
8. ***Transparency***
9. ***Technology***
10. ***Continuous Improvement***

Firstly, within the context of ETO manufacturers, we maintain a strong emphasis on value. However, due to the project-based nature of this type of production, we suggest that value should be defined from the perspective of all major stakeholders, rather than purely the customer (end-user). Because the end product often tends to be complex, successful ETO companies need to engage with customers throughout the entire design, engineering and production process in order to ensure specifications are met. This is in line with the work conducted at the Lean Aerospace Initiative [20], which suggests that defining stakeholder value is an enabler of constructing robust value propositions. Adopting the perspective of all major stakeholders is also reinforced in our definition of the lean ideal (providing customers - *both internal and external* - with exactly what they need to accomplish their purposes, with no waste). Principle 2 focuses on the softer side of lean, and includes leadership, people and learning. In fact these three principles are accountable for many of the failed attempts at lean implementations, as they are often over-looked in favor of the "tool-head" approach. These elements were also seemingly overlooked in the original five lean principles. Flexibility is a principle which we add from lean construction and lean product development, as with traditional lean production the emphasis seems to lie in the application of standardization and repetition to achieve efficiency. Though it can be argued that the application of tools such as single minute exchange of dies (SMED) could contribute towards greater flexibility to some extent, the primary reason for developing such an approach in TPS was to reduce lot-sizes due to the high costs associated with storing vehicles [25], rather than to enable rapid product innovation. We introduce modularization as the next principle, as a modular design allows an organization to combine the advantages of standardization (e.g. lower costs associated with higher volumes) with those of customization (e.g. greater variety of product / service offerings). Improved flow is enabled as a result of greater flexibility and the standardization created from the use of a modular approach, thus we suggest that, where possible, production should take place in response of actual customer demand, hence principle number six, demand pull. Demand pull implies that products be processed more in a "just-in-time" fashion rather than the typical push approach A further enabler of continuous process flow and demand pull is stakeholder- and systems integration, which means adopting a systems view of the entire supply network, with systematic cross-functional and inter-organizational integration that includes all of the major stakeholders (these were considered in the very first principle). For such integration to be successful, the entire network must be transparent, thus there is an emphasis on the use of visual controls and sharing of key indicators amongst stakeholders (principle eight). It is apparent that the design, engineering and production of such highly customized products requires a greater level of technology deployment than more standardized environments, therefore technology is also considered as a major enabler of operational excellence in ETO manufacturers and as such is listed in our set of principles. Finally, continuous improvement is an essential part of the application of lean in any setting; therefore we include it as principle number ten.

6. Case studies

We now validate the new set of principles for lean in ETO by evaluating them against two case studies.

6.1. ConXtech, USA

ConXtech is a construction technology company based in Hayward, California. The company has developed "ConX", a mass-customizable, modular, prefabricated structural steel building system based upon a limited set of machined steel connections which are robotically welded to beams and columns. As such, ConXtech is a prime exemplar of the principle *modularization* through the development and deployment of the company's patented modular approach, such that structural steel components can be manufactured in highly automated factories and shipped to the building site, rather than constructed on the building site. Such a simplified and standardized, modular approach results in both a huge cost-saving and time-saving, as well as a significant reduction of labor in the field. Through the application of advanced CAD/CAM, product configurators, and Building Information Modelling (BIM) systems, ConXtech have also been able to show how *technology* is a key enabler of Lean in ETO. *Defining stakeholder value* and *stakeholder- and systems integration* are also demonstrated at ConXtech, where the ConX system allows the company to offer construction solutions to a diverse range of customers, from hospitals and governmental premises to military applications and parking structures. Value for stakeholders is also realized in that "factory manufactured" enables the construction labor force to locate their homes and families near to their place of employment. ConXtech is also collaborating with outside subcontractors and design teams in order to offer additional value through a systemized, integrated approach. *Demand pull* is also exhibited by ConXtech, as through streamlining the process from manufacture to the field (by establishing *continuous process flow*); ConX structures are manufactured in the order in which the building will be assembled on a just-in-time, just-in-sequence basis. This minimizes the need for storage of finished goods and lay-down on site. The company also uses go/no-go fixturing to ensure proper fit-up and to eliminate costly rework in the field. Finally, *leadership, people and learning* has been an essential part of the success of ConXtech's lean journey, particularly due to the passion and flair of the company's founder, who had long envisioned a concept that would streamline traditional building processes. His aim was to create a building system that would enable mass customization of high quality buildings that would be faster and more cost effective than conventional wood, concrete or steel framed methods. As such, ConXtech leaders see continuous learning and the involvement of everybody as key enablers in the pursuit of the lean ideal.

6.2. Kongsberg Maritime Subsea, Norway

Kongsberg Maritime Subsea (KMS), based in Horten, is part of the KONGSBERG Group, and delivers a number of customized high-tech products, including systems for under water navigation. One such product is the "cNODE", which a newly developed family of transponders for underwater acoustic positioning. The cNODE has a modular construction such that the transducer, transponder electronics, and battery pack, as well as any optional add-ons, can be replaced individually. This also highlights the importance of *modularization* in order to gain benefits from the combination of standardization and customization, which leads to increased process *flexibility* and also allows for *continuous process flow* within the product assembly process. *Transparency* will be exemplified by KMS through the deployment of modern *technology* in the form of a manufacturing execution system (MES). For many of the products offered by KMS there are a large amount of process steps which occur in various locations throughout the plant, and the application of MES will visualize the progress of the operations and make the entire process more transparent. Finally, KMS is committed to *continuous improvement* and encourages all employees to participate in improvement activities by making suggestions and carrying out small, team-based improvements.

7. Discussion, Conclusion and further work

[26] suggests that a headlong rush into becoming lean has resulted in many misapplications of lean tools, often due to inadequate understanding of the purpose of them. We advocate that such tools were created in order to apply principles that were initially developed to pursue the lean ideal within a given context, e.g. the Toyota Production System. Thus, as principles vary from more or less widely applicable to a variety of contexts, we set out to examine the evolution of lean principles in order to develop a new set of principles for pursuing the lean ideal in the context of ETO manufacturers. We analyzed the evolution of lean principles across a range of application areas (lean production, lean construction, lean product development), and restructured various elements through the use of a qualitative content analysis technique in order to propose a new set of principles for pursuing the lean ideal in ETO manufacturers. We validated the new principles through the use of a multiple case study approach, and suggest that the new principles can be applied by producers of low volume, high variety products in order to *provide customers (both internal and external) with exactly what they need to accomplish their purposes, with no waste.* Our findings indicate a strong trend toward *modularization*, which allows ETO manufacturers to economically increase product variety. This was apparent in the literature survey and was highly prominent in both case studies. Further work should apply and assess the new principles in other ETO environments, as well as focus on the development of new tools and technologies to support companies of this type in deploying the new principles in pursuit of the lean ideal.

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