

Lean Implementation in Integrated Design and Manufacturing

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ABSTRACT

Lean applications in product development usually start with manufacturing due to the relative experience of measuring improvements and identifying wastes in physical settings. The full potential of lean implementation in any product development, however, can only be realized when applied throughout the process, starting with early process. Considering that the first and most essential principle in lean implementation is the characterization of value from the customer's perspective, it is imperative that the proper definition of value is realized at the beginning of the process. In addition, streaming and flowing of this customer's specified value should be realized throughout the process from start to finish.

This paper discusses the application of lean principles to integrated design and manufacturing phases of the Product Development Process. The importance of introducing lean principles at the beginning of the product development phases for successful lean implementation is demonstrated. Two case studies are presented to demonstrate the lean application of integrated design and manufacturing phases from inception to a validated concept.

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INTRODUCTION

Lean manufacturing has provided a sustained proven and effective approach to process development and maintenance. By focusing on Value, this process-based thinking has created a systematic approach to continuous improvement. TOYOTA Lean Production System has demonstrated how lean thinking has propelled the movement of Auto Industry from mass production to lean production [1, 2]. With the success in manufacturing, Lean thinking has spread to many practices in other industries such as software development, health care, construction industries, financial services, and others [3,4,5,6].

In the area of product design there have been some few lean application efforts [7,8,9,10]. Some of these efforts are focused on directing the design activities to enable lean manufacturing, cost reduction, or managing the traditional product development process [7, 8]. Other research efforts have been directed towards the development of a lean design process by applying the lean principles and tools to different process phases [9, 10].

In the following, the implementation of lean principles in integrated design and manufacturing phases of the Product Development Process are discussed. To demonstrate the application of the lean integrated processes phases from inception to a validated concept two case studies are considered.

THE FIVE PRINCIPLES OF LEAN

Most of lean applications focus on the lean tools. The real success of lean applications, however, can only be achieved when the lean principles, shown in Figure 1, are applied and lean tools are used to realize these principles.

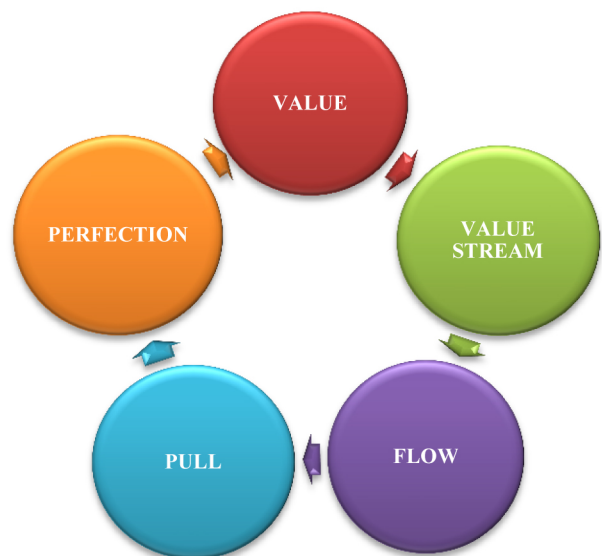


Figure 1. The Five Lean Principles.

The basic five principles of lean thinking, shown in [Figure 1](#), can be summarized as:

- Value -Specified from the voice of the customer.
- Value stream -Streaming value along the process.
- Flow -Facilitating the value process flow.
- Pull -Executing what is needed by the customer.
- Perfection -Striving for perfection through continuous improvement of process and product.

One of the main outcomes of applying these five principles is the identification of waste. Through the focus on value and by identifying the activities/resources needed to create it, any process steps or efforts that do not add value are considered waste. Therefore, in addition to striving for perfection, the essence of any successful lean process is to add nothing but value and eliminate all possible forms of waste.

PRODUCT DEVELOPMENT PROCESS

Traditional Product Development processes are usually established with several identifiable sequential steps. Some of the most common product development models follow the Ulrich and Eppinger development process [11], shown in [Figure 2](#).

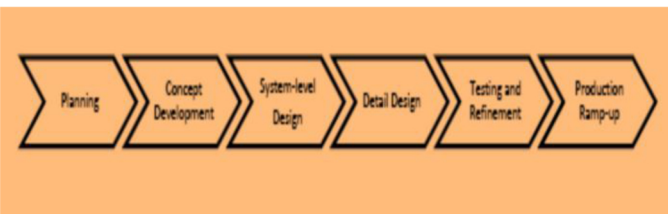


Figure 2. Ulrich and Eppinger development process.

Planning, in Ulrich and Eppinger model, is the phase where the project gets approved and the product development process starts. The output of this phase specifies the target market, business goals, key assumptions, and constraints. In the second phase, concept development, the target market needs and customer requirements are identified. One or more concepts are then selected from several alternatives for further development and testing. During the system-level design phase the focus is directed towards the products definition and architecture. The product's individual components and its final assembly process are defined. During the detail design phase, the complete specification of the geometry, materials, and tolerances of all the components as well as the identification of all the supplied parts are completed. The establishment of a production system process plan is made and tools are designed for each part to be produced. During the testing and refinement phase multiple preproduction types of the product are constructed and

evaluated. The prototypes can be divided into alpha or beta prototypes. Alpha prototypes are not necessarily fabricated by means of the actual processes to be used in production. Beta prototypes are usually built with parts supplied by the intended production process. Testing makes it possible to refine the product before the start of production. The last phase production ramp up consists of training the work force and resolving all remaining production problems.

INTEGRATED LEAN PROCESS

One of the main drives of lean thinking is to simplify the process. Therefore, a lean design process should have the minimum number of steps. These steps should sufficiently define the process, eliminating overlaps and transitional wastes. To identify the basic steps of a lean and integrated development process, the simplest and most natural form of this process can be illustrated as shown in [Figure 3](#).

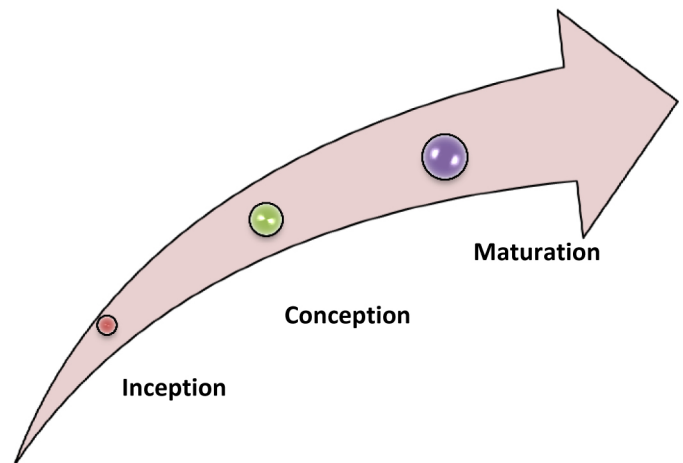


Figure 3. Lean Product Development Process Phases.

The process phases flow from inception to production through conception and maturation. The process activities flow through the three main domains perceptual, virtual and physical for achieving the desired product attributes [12]. As shown in [Figure 4](#), the three activities are integrated and span the product development process with the perceptual activity as the foundation, virtual activity or design as the bridge and the physical activity or manufacturing as the process peak.

In comparison with the traditional product development processes, the perceptual domain activities include the planning and conceptualization phases. The virtual activities, during the development phase, correspond to the traditional design activities. All physical activities starting from concept development to production signify traditional manufacturing.

In the lean Product Development model, shown in [figure 3](#) and detailed in [fig. 4](#), planning is the initial sub-phase of inception. The inception phase, which is missing in Ulrich and Eppinger model, represents the Fuzzy Front End (FFE) process phase for innovation, linking idea generation, opportunity evaluation, and key decision making [13, 14].

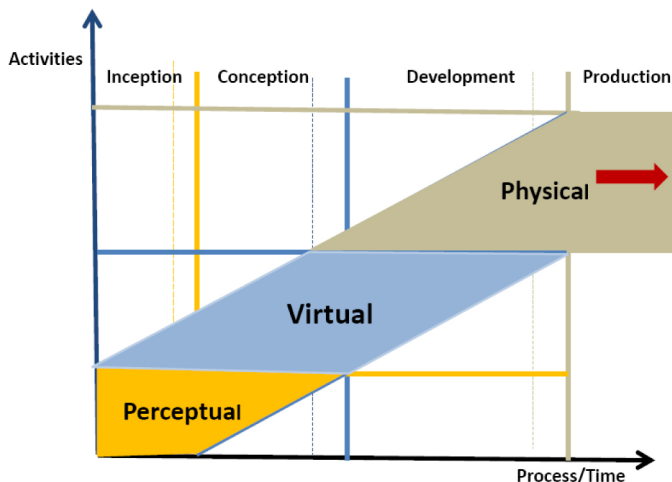


Figure 4. Steps of Integrated Lean Development process.

The conception phase in the lean integrated process is different than the second phase of concept development in the Ulrich and Eppinger model. Since target market needs and customer requirements are identified in the inception phase, full concept development, including concept validation, are completed during this phase.

During the maturation phase architectural integration of components, subsystems, and systems for mass production are completed. Simultaneously, performance integration including testing and validation of all components and subsystems are performed, tested, and validated. Concurrently, manufacturing processes, tooling, assembly process for mass production, and supply chain are shaped and finalized. For product development testing, preproduction Alpha prototypes constructed from non-production tools are evaluated. For product validation testing, Beta prototypes built with parts supplied from the intended production process are validated. Production ramp up and work force training are finalized during final product validation and issues resolution.

As shown in [fig. 5](#), while the lean principles of [figure. 1](#) are applicable during implementation of each development phase of [figure 4](#) such as design and manufacturing, each principle is more dominantly aligned with a specific phase of the full development process.

Value is determined from the voice of the customer at early phases of product inception, as a result of customers' surveys, market research, and bench marking etc. Value streaming, flow, and, pull dominate the core development phases to assure that the voice of the customer is the main drive and guide from inception to production. Strive for perfection should be continual at a micro level during each sub-phase and Macro-level over each phase and the entire process [15].

There are many lean tools such as the Kano Model and House of Quality that can be used during the inception phase and Design for Six Sigma that can be used during the development and phase. To enable the application of the lean

principles during the integrated lean development process other well developed lean tools can be adopted for each phase [10].

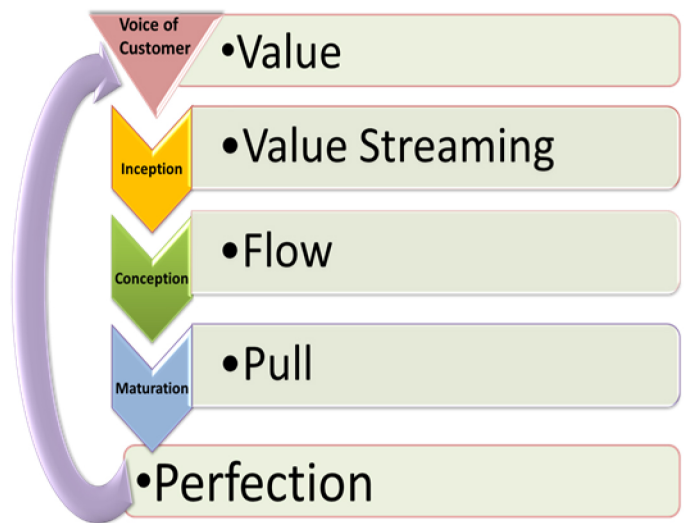


Figure 5. Dominant principles at different process phases.

DEFINING VALUE AT INCEPTION

The main reason for demonstrated success in lean manufacturing is the ability to measure quality improvement, cost saving, and time reduction in the physical domain. It is difficult to demonstrate success in the virtual domain and more difficult in the perceptual domain. However, the most gains for lean applications can be achieved by starting at the perceptual domain. For a truly lean product development process Value, Value Stream Mapping, and Flow must start at the inception phase of the product.

Customer requirements, in general, are expressed in terms of desired product attributes. These desired attributes define the product value from the customer's perspective and should be the main source of the key product characteristics and specifications as shown in [Table 1](#).

Table 1. Product Specification Based on Customer's Value.

Attribute 1	▪ Criteria 11 ▪ Criteria 12	• Target 111 • Target112 • Target 121
Attribute 2	▪ Criteria 21 ▪ Criteria 22	• Target 211 • Target 212 • Target 211
Attribute I	▪ Criteria IJ	• Target IJK

Customer's desired attributes should also be the main driver for the development of all components and subsystems