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EIGHT BASIC LEAN PRODUCT DEVELOPMENT TOOLS

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Abstract

Lean manufacturing is the aggregate of many waste reduction tools and philosophies in manufacturing. Adopting a lean philosophy is a big step towards becoming a global competitor. The principles of lean manufacturing can be extended to product development to significantly decrease product development waste. Adoption of lean product development will result in better utilization of resources, decreased development time, decreased development costs, and an overall increase in the efficiency of the development organization. This paper proposes a basic toolset of eight tools for implementing lean product development. The basic tools for lean product development are proposed based on the basic tools for lean manufacturing and analogies between manufacturing and the product development process. The toolset proposed in this paper enables the implementation of the fundamental lean manufacturing principles - understanding value, identifying value, making value flow, pull, and continuous improvement in product development. Implementing the fundamental lean principles is the first and most important step in the journey to lean product development. These principles are embodied in the new lean product development tools – value stream mapping for product development, quick response product development, just in time product development, GOLCAD, load leveling, *machigaiyoke*, single minute exchange of projects, and *kaizen*.

Keywords: lean product development, lean manufacturing, product development process.

1. Lean manufacturing

Lean manufacturing has been *the* buzzword in manufacturing. The concept originated after World War II when Japanese manufacturers realized that they could not afford the massive investment required to build facilities similar to those in the U.S. The Japanese, particularly Toyota, began the long process of developing and refining manufacturing processes to minimize waste in all aspects of operations [1]. The goal of lean manufacturing is to reduce waste in manufacturing to become highly responsive to customer demand while producing world-class quality products in the most efficient and economical manner [2]. Shigeo Shingo [3] strongly advocated the elimination of waste and put forth the idea, “don’t accept waste as unavoidable.” Wasted resources can include information, time, money, space, people, machines, material, and manufacturing tools [4]. Waste uses resources, but does not add value to the product [5]. Companies that practice lean manufacturing report significant performance gains [6]; [7]; [8].

The implementation of lean manufacturing consists of five fundamental principles: understanding value; mapping the value stream, and identifying areas of waste elimination in the value stream; elimination of all stoppages to make the value stream “flow” without interruptions; creating a pull system of material control; and continuous improvement efforts to eliminate all non-value added tasks in the process [3]. In lean manufacturing, these principles are embodied in the tools defined below.

- Value stream mapping: map the existing flow of activities in the manufacturing process and identify obvious areas of waste and obstructions to the flow of value in the process.
- Pull: manufacture products to demand, ensure that the material is pulled instead of pushed through the manufacturing process.
- Just in time: identify and eliminate non-value added activities, obstructions in the flow of value; eliminate excessive inventories.
- *Kanban*: implement pull systems in manufacturing by introducing signals between manufacturing cells.
- Load leveling: level work to eliminate pile up of work in progress, create a smooth flow, and enable optimal resource utilization.
- *Pokayoke*: eliminate manufacturing errors and eliminate the need for rework.
- Single minute exchange of die (SMED): changeover machines rapidly.
- *Kaizen*: improve the process continuously.

2. Lean product development

Lean principles can be applied to the process of developing a product as well. Lean product development aims at eliminating waste in the development process. The result is better integrated development activities for quickly developing quality products in a cost effective manner. There are four differences between the design methods employed by lean designers - differences in leadership, teamwork, communication, and simultaneous development [9]. Information systems can also play a key role in supporting lean product development [10].

Toyota and Honda have found significant decreases in lead-time and costs, an increase in product quality, and an increase in organization efficiency [11]; [9]. Companies that have adopted lean product development offer a wider variety of products and replace them more frequently. Shorter development cycles also make lean companies more responsive to sudden changes in consumer demand [12]; [9]. Benefits of lean product development implementation include 50% reduction in time to market, 70% reduction in engineering effort, and 50% reduction in engineering re-work [7], while displaying dramatic improvements in profitability and customer satisfaction. Significant improvements also occur in the retention of engineering knowledge.

Researchers have been studying Toyota's product development system for over a decade [13]; [14] and have found that flexible work standards, standard skills, and design standards are very effective at waste elimination in product development [13]; [14]. Novel tools like time slicing and linked deliverables have also been proposed [13] by those outside of Toyota.

3. Objective

To sustain global competitiveness, product development companies need to decrease time to market, while maintaining product development quality and reducing the resources needed. Rapid product development tools focus on reducing product development cycle-time, whereas lean product development tools focus on eliminating wastes in any and all resources (time, space, money, people, machines, decisions, information, *etc*.). Quality of designs and products are maintained by lean product development tools since the tools focus on eliminating non value-added activities.

The tools of lean manufacturing can be applied to the product development process to drastically eliminate waste. A structured toolset for lean product development will enable companies to implement lean product development in a structured manner and achieve impressive savings and benefits. As with the genesis of lean manufacturing, lean product development must begin with Shigeo Shingo's five fundamental lean principles [3] as applied to product development [10]. The objective of this paper is to put forth a basic toolset for lean product development, which will act as a starting point for companies to implement lean product development. We proceeded by mapping the eight basic tools of lean manufacturing to a set of analogous lean product development tools.

4. Eight basic tools for lean product development

The eight basic tools for lean manufacturing are – value stream mapping, just in time, pull system, *kanban*, load leveling, *pokayoke*, single minute exchange of die, and *kaizen* [3]. Depending mostly upon their reliance on a mass manufacturing environment, the tools vary in their applicability to lean product development. We developed the eight analogous lean product development tools (Figure 1) based on their implementation in a low volume, high variety that is the product development process. Each tool is described in the following sections.

Lean manufacturing tool	**Analogous lean product development tool**
Value stream mapping	Product development value stream mapping
Just in time	Just in time product development
Pull system	Quick response product development
Kanban	GOLCAD
Load leveling	Design task *heijunka*
Pokayoke	*Machigaiyoke*
Single minute exchange of die	Single minute exchange of projects
Kaizen	*Kaizen*

Figure 1. Basic lean manufacturing and corresponding lean product development tools.

4.1 Value stream mapping → Product development value stream mapping

Value stream mapping is a graphical tool that portrays the tasks (both value-added and non value-added) required to produce a product. A value stream map provides a clear view of the current flow of the product and the information flow in the production environment considered. This view is then used in the improvement of an existing manufacturing environment. Central to a value stream map is the standard icons it uses to represent process elements [15]; [16].

The product development value stream consists of tasks that create and transform information and allow for the convergence of dispersed, segmented, or diverse information to define a final design [17]. Value stream mapping can be easily adapted to the product development environment by devising an analogous set of icons similar to those used in value stream mapping for manufacturing [18]. The implementation in product development is exactly as in manufacturing. It consists of four steps: select a product family; draw the current state map; draw the future state map; and propose a work plan for improvement and implement it. Figure 2 illustrates how a value stream map could be drawn for a small part of an example product development process. In practice, each design task should be mapped.

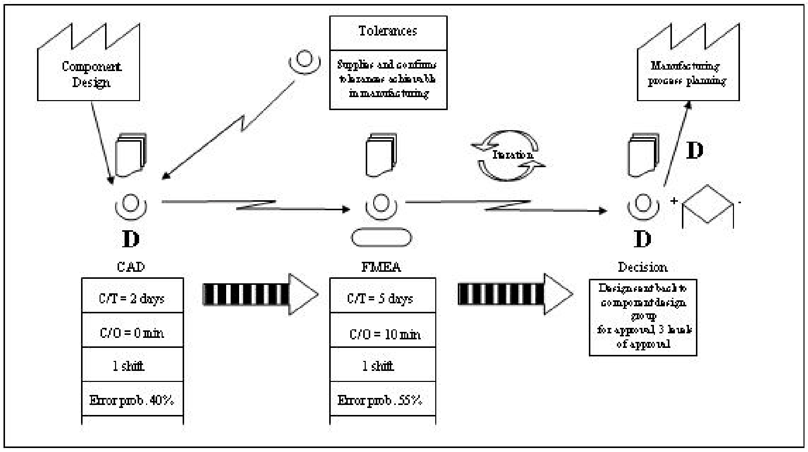

Figure 2. Value stream map of a part of a product development process.

4.2 Just in time → Just in time product development

Just in time (JIT) in manufacturing is a system in which each process is supplied with the required items, in the required quantity, at required time [19]. JIT strives to eliminate sources of manufacturing waste by producing the right part, at the right place, at the right time. JIT applies primarily to repetitive manufacturing processes. The goal is to establish flow processes by linking work centers so that there is a continuous flow of materials throughout the entire production process. To accomplish this, an attempt is made to drive all queues and inventories toward zero and achieve an ideal lot size of one unit [20]. The difficulty of adapting JIT to product development is that JIT manufacturing is applicable to cases of repetitive production where the same products are being produced continuously [20]. Product development, however, is usually a highly customized process wherein designs are processed to greatly differing specifications and processing times are highly variable.

JIT product development (JIT-PD) is a system where each design task is supplied with the required information, knowledge, or decisions, in the required form, at the required time. JIT-PD eliminates sources of product development waste by producing the right decisions, at the right place, at the right time. In a traditional process, design decisions related to product features are decided beforehand, at the start of the product development process. In JIT-PD, design decisions related to product features are not made until the product enters, say the detail design phase, which contains tasks that need those decisions as inputs. JIT-PD should improve profits and return on investment by reducing designs in progress (DIP) levels, reducing unnecessary information, improving product quality, reducing design lead times, and reducing product development costs such as the holding and storage costs of information, costs incurred due to lost or misplaced information or decisions, *etc*. The JIT-PD philosophy is enabled by a pull system (QRPD) of design control, which in turn, is enabled by a *kanban* system (GOLCAD).

4.3 Pull system for material control → Quick response product development

A pull system in manufacturing enables the "release" for moving material within the plant or from suppliers only when the next process needs the material. Done for every task in the process, pull eliminates product wait time. A pull production system produces only what is needed and when it is needed since it relies on customer requests [6]. For job shops, as well as product development, a traditional pull system has problems. Traditional pull systems focus on product control between successive tasks. This is possible in mass manufacturing or large quantity production environments. On the other hand, in a job shop each product is highly customized, demanding a different set of operations to manufacture each product. This would result in the creation of numerous small pull systems within a larger system, making it hard to manage and leading to confusion.

Quick response manufacturing (QRM) combines the best features of "push" and "pull" without their drawbacks [21]. QRM, or the quick response product development (QRPD) we introduce, are process pulls rather than product pulls. This makes the pull system independent of product features and thus, can be easily managed. In QRPD, the customer pushes the specifications to the beginning of the product development process and then the specifications are pulled towards the end of the process as needed by each design tasks. Figure 3 shows a generalized view of QRPD with four development tasks - N_{i} are the number of concepts / projects passing through each design task and the takt times for each design task are denoted by t_i. Note that $N_{i+1} - N_i$ projects are unsuccessful at each task, much like scrap in a manufacturing process. The *takt* times for each of the design tasks upstream and downstream are calculated to match the *takt* time of the pace process. Thus, each design task downstream will pull a design from the tasks upstream as soon as it is free for processing ensuring a smooth flow of DIP through the process, including the pace process.

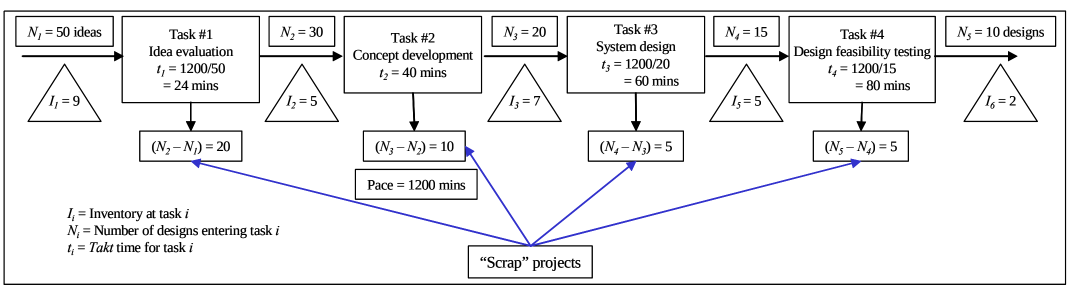

Figure 3. Pull in product development.

4.4 Kanban → Grouped Overlapping Loops of Cards with Authorization for Development (GOLCAD)

A pull production system in manufacturing can use a *kanban* system for signaling what to produce and when to produce it. A *kanban* is a card containing vital information such as part number, a brief description, type of container, and unit load. The *kanbans* maintain the discipline of pull production by authorizing the production and movement of materials as they move between stations [3]. A high customization, high variety, and low volume environment will result in the generation of hundreds of *kanban* cards, making them impossible to handle and manage. Paired-cell overlapping loops of cards with authorization (POLCA) system is based on the same principle as *kanban*, but used in high variety manufacturing operations [21]. POLCA cards rotate between a pair of cells rather than a longer succession of manufacturing operations.

For product development, we introduce a similar system of information control called grouped-cell overlapping loops of cards with authorization for development (GOLCAD). GOLCAD uses cards to signal when each design cell may begin work on a particular design or project. The cards are assigned to a group of cells rather than a specific design or concept. A group can be any number of cells (two or more) depending on the size of the development process, size of the organization, and the degree of customization of the development process. Forming GOLCAD loops encompassing a group of cells makes it possible to absorb variation in processing time and the number of tasks required for each design or project depending upon the complexity and degree of customization of the design or project. Figure 4 shows the use of GOLCAD cards in a sample product development organization. When the design enters cell S1, an S1/D1 card is attached to the design concept. This card takes the design from cell S1 to cell D1 after it has finished processing in cell S1. After completing the processing in cell D1, the S1/D1 card is returned to cell S1 indicating that cell D1 is free for more processing. The cell S1 cannot start processing a new design or project unless the S1/D1 card is returned to it from cell D1. At cell D1, a D1/P1 card takes the design from cell D1 to cell P1 for further processing.

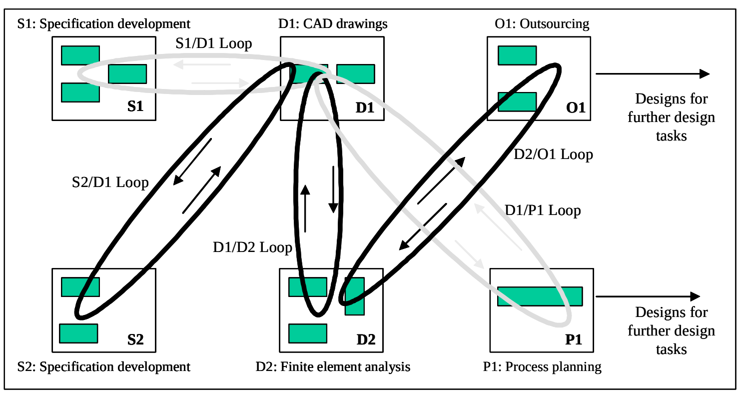

Figure 4. GOLCAD system of information and decision control for lean product development.

4.5 Heijunka → Design task heijunka

Load leveling in manufacturing (*heijunka*) involves balancing throughput for each operation in the production sequence such that the production rate of any one operation in the sequence is balanced with each of the other operations in sequence. To achieve this balance, work should be distributed so that each worker is 100% occupied; surplus time should be concentrated in one worker. Load leveling is achieved by combining or splitting of tasks between personnel, sharing tasks, eliminating redundancy, *etc.* Again, this is in a high volume environment. In a job shop environment, the focus of leveling is better utilization of resources by proper scheduling.

Product development has significant variability in processing time much like a job shop. This variability necessitates process-based leveling methods that are updated for each product at each step in the process. Load leveling in product development (design task *heijunka*) balances the throughput of each task in the product development sequence so that the processing time of any design task is balanced with the processing time of other design tasks in the sequence. We propose the use of three simple scheduling methods for leveling tasks. For scheduling the entire project, we suggest the use of PERT [22]. For prioritizing two or more tasks, we recommend the use of critical ratio [23]; [24]. For scheduling different tasks between two stations, or designers we suggest the use of Johnson's rule [23]; [24]. These tools can be first used to identify bottlenecks and then to level the loads at these bottlenecks.

4.6 Pokayoke → Machigaiyoke

Pokayoke, mistake-proofing, prevents wastes due to error in manufacturing. An error in counting part batches, misalignment of a job on the machine, or skipping a part during assembly. would be some examples of errors in manufacturing. *Pokayoke* devices check and prevent any abnormalities in the manufacturing process from occurring thereby eliminating defects [3]. The general idea of *pokayoke* is to study the system and identify where there is a high probability of errors either by observation or by using tools like failure modes and effects analysis and then establish devices, procedures, or methods that prevent errors from occurring. *Pokayoke* devices may include sensors, alarms, signal lights, counters, circuit breakers, *etc*.

Pokayoke in product development (*machigaiyoke*) enables an error free design process. Product development errors may be improper conversions, use of wrong information, processing of wrong information, *etc*. Mistake proofing will eliminate costly changes to the design and project overruns in time, money, and other resources. *Machigaiyoke* devices must compare the state of the DIP to the desired state and report to the designer any abnormalities. Error proofing devices for product development should check the design for three things: form – the desired state of design; fit – the interactions between components; and function – the ability of the design to produce components that will serve the intended function. As an example, we suggest one *machigaiyoke* for product development – standard design information sheets - standard A4 sized forms containing design process information in a standard format. Such standard forms have been put into practice at Toyota but are unavailable outside their organization. Figure 5 shows a simplified format of an information sheet for the design of a can opener handle during detail design. Another example of *machigaiyoke* is design process failure modes and effects analysis or design process FMEA (DPFMEA). DPFMEA aids in identifying and assessing ways in which the design could fail and the possible causes [25]; [26]; [27].

Product name: **Component:**	Can opener Handle
Design tasks carried out	Design of the handle and rivets for assembly to main body of can opener
Design entry criteria	• Design of can opener halves with detail specifications • List of customer requirements influencing design of handle (see attached QFD) • System level sketches of the product (attached)
Standard information required to complete the design tasks	• Steel cannot be plated • A surface finish of 0.07 µm results in finish pleasing to users • Target value for surface finish 0.09 µm • Do not use Plastic for handle • Handle will be manufactured by stamping • Aluminum rivets lack required durability
Design exit criteria	Detailed design of handle and related components depending on design of handle with drawings, tolerances, manufacturing processes, in a state ready for release
Contact information of personnel for assistance or need of more information	Ms. Smith: Customer requirements smith@abc.com Mr. Jones: System design jones@abc.com Mr. Franco: Manufacturing franco@abc.com

Figure 5. Standard information sheet for a can opener handle during detail design.

4.7 Single Minute Exchange of Die (SMED) → Single Minute Exchange of Projects (SMEP)

Single Minute Exchange of Die (SMED) is a systematic approach to reducing manufacturing downtime due to changeovers that involves identifying, separating, and modifying the internal and external setup elements [3]. The goal of SMED is to make internal and external setup elements independent, then coordinate and reduce the time for both, especially the internal elements. The focus is on internal setup elements, those requiring down time, since the external set up elements can be performed as a parallel task when the machine is in operation.

In product development, a changeover might be considered as switching between projects for a particular design task. We therefore define single minute exchange of projects (SMEP). With high variability and volumes of near one, changeover occurs frequently and the change can be significant. The goal of SMEP is to allow designers working on multiple projects, switch between projects, and tune themselves for the requirements of different projects in minimum time. The waste of time, personnel, a station, machinery, and the possible loss of information is analogous to waste from an internal setup element during changeover. The project or the processing on the design must wait until the designer is prepared to begin processing. A strategy we suggest to reduce the changeover time is to maintain standard information forms as discussed in error proofing. The implementation of SMEP in product development should run on parallel lines to that of SMED in manufacturing. SMEP, like SMED, is a three step process: clearly identify between internal and external elements of changeover; convert internal setup elements to external setup elements; and streamline all setup activities.

4.8 Kaizen → Kaizen

Kaizen for product development is implemented in the same way as in manufacturing. *Kaizen* is a highly focused improvement process aimed at waste elimination in narrowly targeted areas. *Kaizen* activities focus on each process and every operation to add value and eliminate waste [28]. A *kaizen* activity is team driven and aimed at the rapid use of lean thinking to eliminate production waste in particular areas of the shop floor. It is well planned and highly structured to enable the quick, focused discovery of root causes and the implementation of solutions [28]. Value stream mapping is often used to identify the focus of *kaizen* events. Once the root causes or sources of waste are determined and understood, then participants develop ways to eliminate non-value added activities. In the *kaizen* philosophy, improvements in all business areas - cost, meeting delivery schedules, employee safety and skills development, supplier relations, new product development, or productivity - serve to enhance the quality of the organization. Some simple examples of *kaizen* events in product development would be implementing 5S to a design station or work area to make it organized, or devising cellular layout for product development organization, smoothing the design flow through the process, and achieving a "one design flow" through the product development organization.

5. Conclusions

The eight tools discussed above - product development value stream mapping, just in time product development, quick response product development, GOLCAD, design task *heijunka*, *machigaiyoke*, single minute exchange of projects, and *kaizen* - constitute a basic toolset for lean product development. These eight basic tools implement the fundamental principles of lean and are the starting point for companies trying to implement lean product development. These eight basic tools were adapted from lean manufacturing by beginning with the underlying lean principles on which the tools are built. The big change in tools was to make them viable in the low volume, high variety environment of product development. It is well understood by the authors that it is necessary to validate the tools as well as the fundamental idea of lean product development. That work is ongoing. This paper was intended to jumpstart the conversation of applying lean to the design process.

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