3. Lean manufacturing

Lean manufacturing, **lean enterprise**, or **lean production**, often simply, "**Lean**", is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for.

Essentially, lean is centered on *preserving value with less work*. Lean manufacturing is a management philosophy derived mostly from the Toyota Production System (TPS) (hence the term Toyotism is also prevalent) and identified as "Lean" only in the 1990s. TPS is renowned for its focus on reduction of the original Toyota *seven wastes* to improve overall customer value, but there are varying perspectives on how this is best achieved. The steady growth of Toyota, from a small company to the world's largest automaker, has focused attention on how it has achieved this success.

3.1 Overview

Lean principles are derived from the Japanese manufacturing industry. The term was first coined by John Krafcik in his 1988 article, "Triumph of the Lean Production System," based on his master's thesis at the MIT Sloan School of Management. Krafcik had been a quality engineer in the Toyota-GM NUMMI joint venture in California before coming to MIT for MBA studies. Krafcik's research was continued by the International Motor Vehicle Program (IMVP) at MIT, which produced the international best-seller book co-authored by Jim Womack, Daniel Jones, and Daniel Roos called *The Machine That Changed the World*.[1] A complete historical account of the IMVP and how the term "lean" was coined is given by Holweg (2007).

For many, Lean is the set of "tools" that assist in the identification and steady elimination of waste (*muda*). As waste is eliminated quality improves while production time and cost are reduced. A non exhaustive list of such tools would include: SMED, Value Stream Mapping, Five S, *Kanban* (pull systems), *poka-yoke* (error-proofing), Total Productive Maintenance, elimination of time batching, mixed model processing, Rank Order Clustering, single point scheduling, redesigning working cells, multi-process handling and control charts (for checking mura).

There is a second approach to Lean Manufacturing, which is promoted by Toyota, in which the focus is upon improving the "flow" or smoothness of work, thereby steadily eliminating *mura* ("unevenness") through the system and not upon 'waste reduction' per se. Techniques to improve flow include production leveling, "pull" production (by means of *kanban*) and the *Heijunka box*. This is a fundamentally different approach from most improvement methodologies, which may partially account for its lack of popularity.[*citation needed*]

The difference between these two approaches is not the goal itself, but rather the prime approach to achieving it. The implementation of smooth flow exposes quality problems that already existed, and thus waste reduction naturally happens as a consequence. The advantage claimed for this approach is that it naturally takes a system-wide perspective, whereas a waste focus sometimes wrongly assumes this perspective.

Both Lean and TPS can be seen as a loosely connected set of potentially competing principles whose goal is cost reduction by the elimination of waste. These principles include: Pull processing, Perfect first-time quality, Waste minimization, Continuous improvement, Flexibility, Building and maintaining a long term relationship with suppliers, Autonomation, Load leveling and Production flow and Visual control. The disconnected nature of some of these principles perhaps springs from the fact that the TPS has grown pragmatically since 1948 as it responded to the problems it saw within its own production facilities. Thus what one sees today is the result of a 'need' driven learning to improve where each step has built on previous ideas and not something based upon a theoretical framework.

Toyota's view is that the main method of Lean is not the tools, but the reduction of three types of waste: *muda* ("non-value-adding work"), *muri* ("overburden"), and *mura* ("unevenness"), to expose problems systematically and to use the tools where the ideal cannot be achieved. From this perspective, the tools are workarounds adapted to different situations, which explains any apparent incoherence of the principles above.

3.2 Origins

Also known as the flexible mass production, the TPS has two pillar concepts: Just-in-time (JIT) or "flow", and "autonomation" (smart automation). Adherents of the Toyota approach would say that the smooth flowing delivery of value achieves all the other improvements as side-effects. If production flows perfectly (meaning it is both "pull" and with no interruptions) then there is no inventory; if customer

valued features are the only ones produced, then product design is simplified and effort is only expended on features the customer values. The other of the two TPS pillars is the very human aspect of autonomation, whereby automation is achieved with a human touch. In this instance, the "human touch" means to automate so that the machines/systems are designed to aid humans in focusing on what the humans do best. This aims, for example, to give the machines enough intelligence to recognize when they are working abnormally and flag this for human attention. Thus, in this case, humans would not have to monitor normal production and only have to focus on abnormal, or fault, conditions.

Lean implementation is therefore focused on getting the right things to the right place at the right time in the right quantity to achieve perfect work flow, while minimizing waste and being flexible and able to change. These concepts of flexibility and change are principally required to allow production leveling (Heijunka), using tools like SMED, but have their analogues in other processes such as research and development (R&D). The flexibility and ability to change are within bounds and not open-ended, and therefore often not expensive capability requirements. More importantly, all of these concepts have to be understood, appreciated, and embraced by the actual employees who build the products and therefore own the processes that deliver the value. The cultural and managerial aspects of Lean are possibly more important than the actual tools or methodologies of production itself. There are many examples of Lean tool implementation without sustained benefit, and these are often blamed on weak understanding of Lean throughout the whole organization.

Lean aims to make the work simple enough to understand, do and manage. To achieve these three goals at once there is a belief held by some that Toyota's mentoring process,(loosely called *Senpai* and *Kohai*, which is Japanese for senior and junior), is one of the best ways to foster Lean Thinking up and down the organizational structure. This is the process undertaken by Toyota as it helps its suppliers improve their own production. The closest equivalent to Toyota's mentoring process is the concept of "*Lean Sensei*," which encourages companies, organizations, and teams to seek outside, third-party experts, who can provide unbiased advice and coaching, (see Womack et al., *Lean Thinking*, 1998).

In 1999, Spear and Bowen identified four rules which characterize the "Toyota DNA":

Rule 1: All work shall be highly specified as to content, sequence, timing, and outcome.

Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes or no way to send requests and receive responses.

Rule 3: The pathway for every product and service must be simple and direct.

Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

There have been recent attempts to link Lean to Service Management, perhaps one of the most recent and spectacular of which was London Heathrow Airport's Terminal 5. This particular case provides a graphic example of how care should be taken in translating successful practices from one context (production) to another (services), expecting the same results. In this case the public perception is more of a spectacular failure, than a spectacular success, resulting in potentially an unfair tainting of the lean manufacturing philosophies.

3.3 A brief history of waste reduction thinking

The avoidance of waste has a long history. In fact many of the concepts now seen as key to lean have been discovered and rediscovered over the years by others in their search to reduce waste. Lean manufacturing builds on their experiences, including learning from their mistakes.

3.4 Pre-20th century

Most of the basic goals of lean manufacturing are common sense, and documented examples can be seen as early as Benjamin Franklin. *Poor Richard's Almanac* says of wasted time, "He that idly loses 5s. worth of time, loses 5s., and might as prudently throw 5s. into the river." He added that avoiding unnecessary costs could be more profitable than increasing sales: "A penny saved is two pence clear. A pin a-day is a groat a-year. Save and have."

Again Franklin's *The Way to Wealth* says the following about carrying unnecessary inventory. "You call them goods; but, if you do not take care, they will prove evils to some of you. You expect they will be sold cheap, and, perhaps, they may [be bought] for less than they cost; but, if you have no occasion for them, they must be dear to you. Remember what Poor Richard says, 'Buy what thou hast no need of, and ere long thou shalt sell thy necessaries.' In another place he says, 'Many have been ruined by buying good penny worths'." Henry Ford cited Franklin as a major influence on his own business practices, which included Just-in-time manufacturing.

The concept of waste being built into jobs and then taken for granted was noticed by motion efficiency expert Frank Gilbreth, who saw that masons bent over to pick up bricks from the ground. The bricklayer was therefore lowering and raising his entire upper body to pick up a 2.3 kg (5 lb.) brick, and this inefficiency had been built into the job through long practice. Introduction of a non-stooping scaffold, which delivered the bricks at waist level, allowed masons to work about three times as quickly, and with less effort.

3.4 20th century

Frederick Winslow Taylor, the father of scientific management, introduced what are now called standardization and best practice deployment. In his *Principles of Scientific Management*, (1911), Taylor said: "And whenever a workman proposes an improvement, it should be the policy of the management to make a careful analysis of the new method, and if necessary conduct a series of experiments to determine accurately the relative merit of the new suggestion and of the old standard. And whenever the new method is found to be markedly superior to the old, it should be adopted as the standard for the whole establishment."

Taylor also warned explicitly against cutting piece rates (or, by implication, cutting wages or discharging workers) when efficiency improvements reduce the need for raw labor: "…after a workman has had the price per piece of the work he is doing lowered two or three times as a result of his having worked harder and increased his output, he is likely entirely to lose sight of his employer's side of the case and become imbued with a grim determination to have no more cuts if soldiering [marking time, just doing what he is told] can prevent it."

Shigeo Shingo, the best-known exponent of single minute exchange of die and error-proofing or poka-yoke, cites *Principles of Scientific Management* as his inspiration.

American industrialists recognized the threat of cheap offshore labor to American workers during the 1910s, and explicitly stated the goal of what is now called lean manufacturing as a countermeasure. Henry Towne, past President of the American Society of Mechanical Engineers, wrote in the Foreword to Frederick Winslow Taylor's *Shop Management* (1911), "We are justly proud of the high wage rates which prevail throughout our country, and jealous of any interference with them by the products of the cheaper labor of other countries. To maintain this condition, to strengthen our control of home markets, and, above all, to broaden our opportunities in foreign markets where we must compete with the products of other

industrial nations, we should welcome and encourage every influence tending to increase the efficiency of our productive processes."

3.5 Types of waste

While the elimination of waste may seem like a simple and clear subject it is noticeable that waste is often very conservatively identified. This then hugely reduces the potential of such an aim. The elimination of waste is the goal of Lean, and Toyota defined three broad types of waste: *muda*, *muri* and *mura*; it should be noted that for many Lean implementations this list shrinks to the first waste type only with corresponding benefits decrease. To illustrate the state of this thinking Shigeo Shingo observed that only the last turn of a bolt tightens it—the rest is just movement. This ever finer clarification of waste is key to establishing distinctions between value-adding activity, waste and non-value-adding work. Non-value adding work is waste that must be done under the present work conditions. One key is to measure, or estimate, the size of these wastes, to demonstrate the effect of the changes achieved and therefore the movement toward the goal.

The "flow" (or smoothness) based approach aims to achieve JIT, by removing the variation caused by work scheduling and thereby provide a driver, rationale or target and priorities for implementation, using a variety of techniques. The effort to achieve JIT exposes many quality problems that are hidden by buffer stocks; by forcing smooth flow of only value-adding steps, these problems become visible and must be dealt with explicitly.

Muri is all the unreasonable work that management imposes on workers and machines because of poor organization, such as carrying heavy weights, moving things around, dangerous tasks, even working significantly faster than usual. It is pushing a person or a machine beyond its natural limits. This may simply be asking a greater level of performance from a process than it can handle without taking shortcuts and informally modifying decision criteria. Unreasonable work is almost always a cause of multiple variations.

To link these three concepts is simple in TPS and thus Lean. Firstly, *muri* focuses on the preparation and planning of the process, or what work can be avoided proactively by design. Next, *mura* then focuses on how the work design is implemented and the elimination of fluctuation at the scheduling or operations level, such as quality and volume. *Muda* is then discovered after the process is in place and is dealt with reactively. It is seen through variation in output. It is the role of management to examine the *muda*, in the processes and eliminate the

deeper causes by considering the connections to the *muri* and *mura* of the system. The *muda* and *mura* inconsistencies must be fed back to the *muri*, or planning, stage for the next project.

A typical example of the interplay of these wastes is the corporate behaviour of "making the numbers" as the end of a reporting period approaches. Demand is raised to 'make plan,' increasing (*mura*), when the "numbers" are low, which causes production to try to squeeze extra capacity from the process, which causes routines and standards to be modified or stretched. This stretch and improvisation leads to *muri*-style waste, which leads to downtime, mistakes and back flows, and waiting, thus the muda of waiting, correction and movement.

The original seven *muda* are:

- Transport (moving products that are not actually required to perform the processing)
- Inventory (all components, work in process and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step)
- Overproduction (production ahead of demand)
- Over Processing (resulting from poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects)

Later an eighth waste was defined by Womack et al. (2003); it was described as manufacturing goods or services that do not meet customer demand or specifications. Many others have added the "waste of unused human talent" to the original seven wastes. These wastes were not originally a part of the seven deadly wastes defined by Taiichi Ohno in TPS, but were found to be useful additions in practice. In 1999 Geoffrey Mika in his book, "Kaizen Event Implementation Manual" added three more forms of waste that are now universally accepted; The waste associated with working to the wrong metrics or no metrics, the waste associated with not utilizing a complete worker by not allowing them to contribute ideas and suggestions and be part of Participative Management, and lastly the waste attributable to improper use of computers; not having the proper software, training on use and time spent surfing, playing games or just wasting time.For a complete listing of the "old" and "new" wastes see Bicheno and Holweg (2009)

Some of these definitions may seem rather idealistic, but this tough definition is seen as important and they drove the success of TPS. The clear identification of non-value-adding work, as distinct from wasted work, is critical to identifying the assumptions behind the current work process and to challenging them in due course. Breakthroughs in SMED and other process changing techniques rely upon clear identification of where untapped opportunities may lie if the processing assumptions are challenged.