A Primer: Lean Manufacturing Applications for the Semiconductor Industry

By
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Abstract

Much has been written about the topic of lean manufacturing. It has proven itself in the automotive industry. However, these methodologies and associated technologies are only emerging within the semiconductor manufacturing industry. The following paper, specifically addressed to the Maricopa Advanced Technological Education Center and the Technician Performance Improvement Council at SAME-TEC 2005, contends that "lean" models, rules, principles and applications have a place within the semiconductor industry; as a matter of fact, the industry may already be using some of the methodologies without actually realizing it. The goal of the paper is to invigorate curiosity about the concept, rules and principles of "lean", give the reader additional learning resources, and prompt future discussions so that the semiconductor industry can consider embracing what is clearly much more then just a fad.

Introduction

When addressing audiences found within the MATEC/TPIC community, whether community college professors and leadership, capital equipment suppliers, semiconductor manufacturers, or governing bodies such as SEMI/SEMATECH, finding something we can all learn from is paramount. Lean manufacturing is the umbrella under which we all have something to learn and gain! The following paper will give a very broad overview of what lean manufacturing is and demonstrate that it has a place within the semiconductor industry. The goal of the paper is to invigorate curiosity about the concept, rules and principles of "lean", give the reader additional learning resources, and prompt future discussions so that the semiconductor industry can consider embracing what is clearly much more then just a fad.

Does your organization need to:

- Eliminate wasted time and resources?
- Build quality into workplace systems?
- Find low cost, reliable alternatives to expensive/new technologies?
- Streamline the creation of business processes that need to be "perfect"?
- Build a learning culture centered on continuous improvement?

All organizations can relate to these concepts; the semiconductor industry isn't any different. Adopting lean thinking methods provides a roadmap by which to address all of these needs.

According to Womack, Jones & Roos (1991), lean production vs. mass production requires,

- ½ the human effort in the factory
- ½ the manufacturing space
- ½ the investment tools
- ½ the engineering hours
- ½ the time to develop new products (introduction page)

What if this was the achievable case within the semiconductor industry? What kind of savings/profit would that equate to? Would this sustain the drumbeat of Moore's Law for years to come? Lean methods of thinking, although not perfect in and of themselves, provide a basis to build upon. Flinchbaugh (n.d.) says,

> Principles, rules, theory and concepts are all examples of models. Models are by definition simplifications of reality. Because they are a simplification, there is no one model, no one theory, that is all encompassing and failsafe to use. Models should not be trusted. At the same time, we need them to guide us in action and decision-making. Without models such as principles and rules, life would just be a long series of random experiments without any ability to learn from one day to the next. For that reason, we have articulated a set of principles – a model – of what we think best describes lean systems. These principles can guide us as we learn, experiment and transform our organizations. These principles are not an attempt at completeness, but instead are crafted so that they are useful and effective principles to learn and internalize. (p. 7)

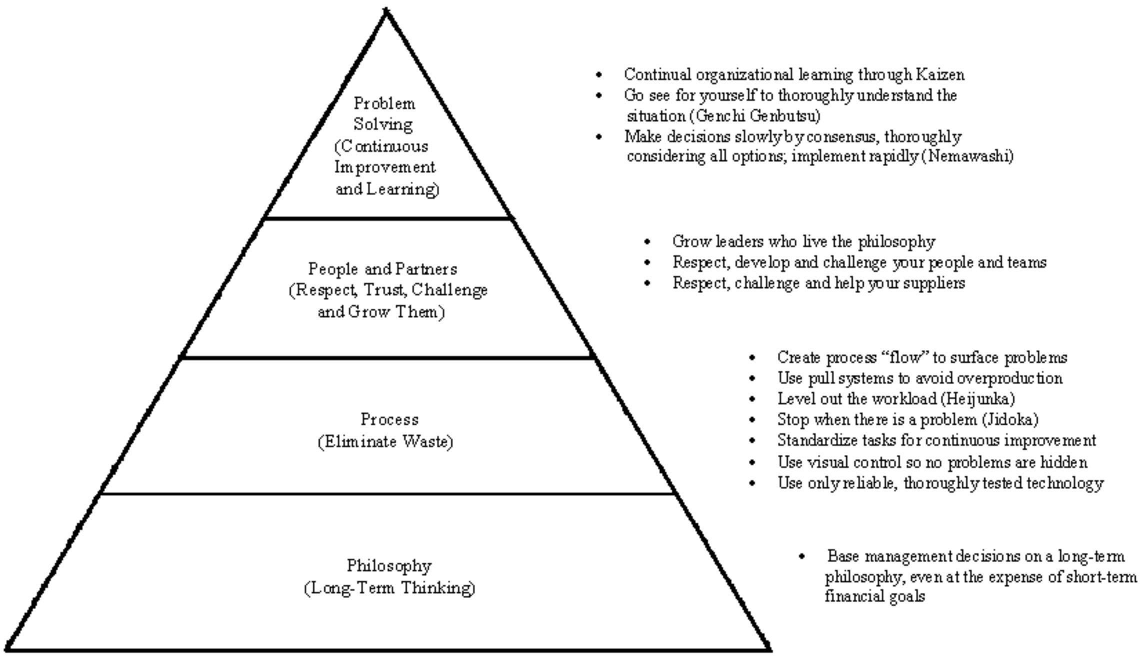
He later goes on to share that,

> Using principles as a method to organize and align your organization for lean transformation will bring standardized thinking to your organization. Through that standardized thinking, people can work on making progress with a shared understanding of how the world works, or at least how the company will work. This will create both shared mental models and shared vision among those engaged in the effort. Without shared mental models, the team responsible for lean transformation will have works with different meanings, tools with different purposes and projects heading towards different visions. That is not a recipe for success. It may not be imperative that the team members' mental models are identical with ours, but it is absolutely critical that their thinking is consistent with each other. (p. 7)

Models, Rules, Principles, and the Application of Each

No discussion on lean is appropriate without mentioning the Toyota Production System (TPS). For all intents and purpose, Toyota created the Toyota Production System and thus the concept of Lean Production (oftentimes referred to as Lean Manufacturing) (Ohno, 1988; Womack, Jones & Roos, 1991; Monden, 1993; Rother & Shook, 1999; Fujimoto, 1999; Liker, 2004). Perhaps the most concise representation of the TPS, and its 14 principles, is the "4P" model Liker (2004) presents (see Figure 1 and refer to Liker, Chapter 4 for an "Executive Summary of the 14 Toyota Way Principles").

Figure 1. The "4P" Model



Adapted from Jeffrey K. Liker. The Toyota Way (2004).

Many have adopted this model to their principles of lean in order to build additional rules and principles to be used more generically (away from the automotive industry in general and Toyota in particular). "One fundamental difference between Toyota and others is the significant involvement of everyone in the improvement process…if we operate as a lean system, we can have everyone in the organization focused real-time on solving problems and driving waste out of the organization" (Flinchbaugh, n.d., p. 2). Principles of lean production include (Womack, Jones & Roos, 1991):

- Teamwork
- Communication
- Efficient use of resources
- Continuous improvement

Flinchbaugh elaborates on these citing Spears and Bowen (1999). He says, "(A) standardized way of thinking at Toyota…starts with four rules that have formed the foundation of all of its innovative tools and concepts. The four rules are:

- Structure every activity

- Clearly connect every customer/supplier
- Specify and simplify every flow
- Improve through experimentation at the lowest level possible towards the ideal state (Flinchbaugh, n.d., p. 3)

After one has built the "base" on the rules, the following principles apply (and thus collectively build a lean "house"). These five principles are (Flinchbaugh, n.d.):

1. Directly observe work as activities, connections and flows (p. 8)

    - Structure, operate and improve your activities, connections and flows (p. 9)
    - Understand current reality requires deep observation (p. 9-10)

2. Systematic waste (overproduction, transportation, motion, inventory, waiting, over-processing, product/process defects) elimination (p. 10)

    - Connect to your customer and always add value (p. 10-11)
    - Relentlessly pursue systematic waste elimination (p. 11)

3. Establish high agreement of both What and How (p. 11)

    - Standardization is the foundation of continuous improvement; create high agreement and no ambiguity (p. 12)
    - Sustainable change happens only at the systems level – lean is rules, not tools (p. 13)

4. Systematic problem solving (p. 13)

    - Seek every problem as an opportunity to focus on the ideal state (p. 14)
    - Decision-making at the point of activity (p. 14-15)

5. Create a Learning Organization (p. 15)

    - Create frequent points of reflection – be a learning organization (p. 15-16)
    - Leaders must be learners and teachers (p. 16)

People

Central to the success of lean concepts are the people in general, but relationships among groups in particular. Flinchbaugh (2001 – A) says,

> If we learn that lean is about the development of people systems, where there is a shared way of thinking and shared vision that all people can engage in, that aligns problem solving and improvement activities, and that gives people a framework for observing, discussing and changing the way work is done. Under those conditions, we can see that lean can apply

> (to any organization)…but lean instead is about learning a development process that integrates into everything you do. (p. 4-5)

Customers and suppliers are also key. Flinchbaugh (2001 – B) says,

> By applying the principles and rules of lean to the customer-supplier relationship, we can drive out waste without taking short cuts on the all-important product. Suppliers are neither friends nor foes, but they are part of the overall system that delivers value to our own customers. If we weaken our supply chain we will eventually weaken ourselves. Look hard at the structure of how you deal with that supply base…(p. 5)

Semiconductor Applications/Adoption

The remainder of the paper will provide two specific examples of work that are, whether intended to be or not, premises for lean thought within the semiconductor industry. One need not look very hard to find the above mentioned rules and principles applied in the struggles to reduce cycle time and increase availability (to reduce effective variability). Both examples demonstrate how the semiconductor industry thrives to achieve a process that addresses waste reduction while requiring long term thinking, investing in people and partners and emphasizing continuous improvement/learning – based methods of problem solving.

Load Adjusted Effective Cycle Time – LACTE

Intel's Fab 11X Factory Manager, at a recent open forum regarding his work with a Cycle Time improvement study, projects $5-50M/day for every day that the factory's cycle time is reduced depending on the multitude of variables that need to be considered ("information turns", response to market conditions, availability, excursion prevention, ect.). Central to being able to measure cycle time improvements is the primary indicator of effective cycle time adjusted for the capacity that the factory can run (Load Adjusted Effective Cycle Time – LACTE).

$$\text{LACTE} = \rho \times \text{RPT}/\text{CT}$$

ρ = Load Adjustment (Actual Starts/Actual Capacity)

- Starts and capacity are averaged over the most recent planned cycle time of the factory
- Capacity: lowest wafer starts achievable of most constrained (Goldratt, 1992) tool as defined by model of record (MOR) and actual product/tool mix.

RPT = Raw Process Time

- Sum of Raw Process Times for a 25 wafer lot processed through each individual step

- Does not include material handling
- Sampling based on actual process requirements
- Theoretically, all fabs would have the same RPT

CT = Sum of individual steps actual cycle time (move-out to move-out)

On average, using this formula, today's best manufacturing fabs are achieving approximately 20% LACTE. According to lean thinking, that equates to 80 percent waste. "World class" is pictured to be 30%. Imagine increasing effective capacity to 30%; this would obtain much more then the previously considered one day of cycle time reduction.

Mathematical-based Impact of Availability

Variability is anything that causes the system to depart from regular, predictable behavior (Hopp & Spearman, 2001). Unpredictable, or inconsistent equipment downtime, creates variability.

Process variability is measured by the following variables:

t_e = mean process time of a job.

σ_e = standard deviation of process time.

c_e = coefficient of variation, CV (in factory physics calculations, the term SCV or "squared coefficient of variation" is commonly used.

Therefore,

$$c_e = \frac{\sigma_e}{t_e}$$

Equipment downtime results in mean effects. These mean effects are measured by the following variables:

t_0 = base process time

c_e = base process time coefficient of variability

r_0 = base capacity (rate or parts/hour) $1/t_0$

m_f = mean time to failure

m_r = mean time to repair (also referred to as green to green or G2G)

c_r = coefficient of variability of repair times

Therefore, availability (the fraction of time equipment is up) is expressed as,

$$A = \frac{m_f}{m_f + m_r}$$

and the effective processing time and rate is expressed as,

$$r_e = A r_0 \qquad\qquad t_e = t_0 / A$$

therefore, Effective Variability is represented by:

$$t_e = t_0 / A$$

$$\sigma_e^2 = \left(\frac{\sigma_0}{A}\right)^2 + \frac{(m_r + \sigma_r^2)(1 - A)\, t_0}{A m_r}$$

$$c_e^2 = \frac{\sigma_e^2}{t_e^2} = c_0^2 + (1 + c_r^2) A (1 - A) \frac{m_r}{t_0}$$

Variability depends on repair times in addition to availability

Having technicians that can positively impact/improve Mean Time to Failure and Mean Time to Repair by being the best trained/educated will reduce the time tools are down, thus increasing availability and reducing variability. Equipment repair is quickly becoming the next big "lever" for influencing manufacturing and operational excellence. The more automated the semiconductor manufacturing factories become, the more important the technicians equipment troubleshooting/repair competencies become.

Moving Forward

Some success is often found in and through the application and adoption of lean tools, but two results seem to be inevitable when it is just the tools being applied. Flinchbaugh suggests two problematic results (n.d.). He says,

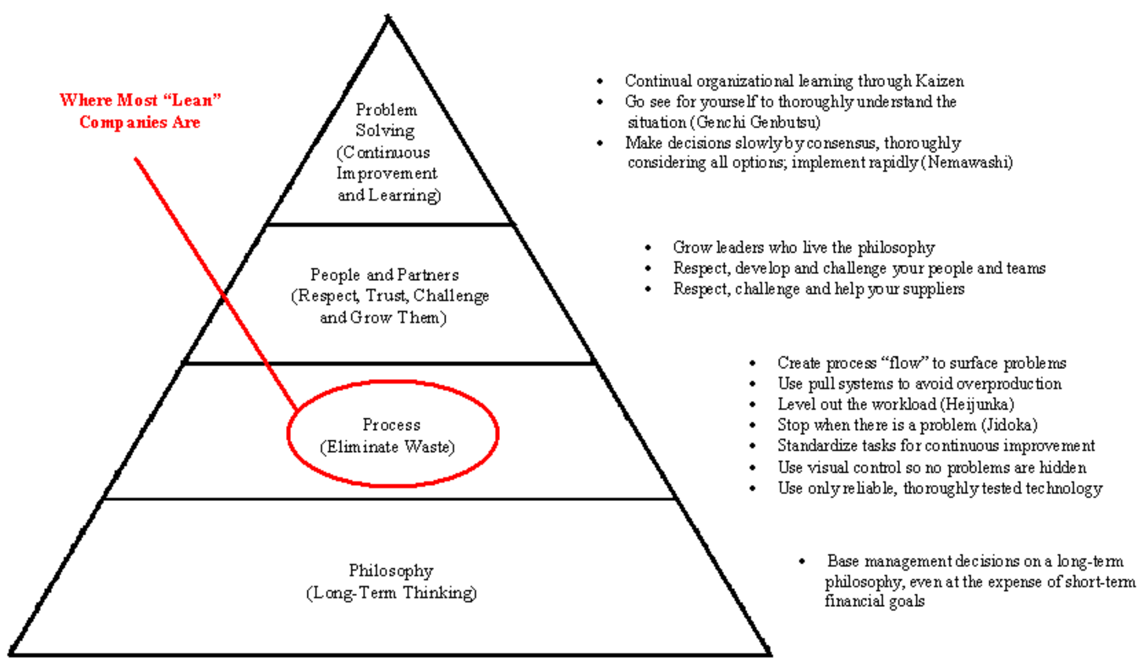
> First, companies do not reach nearly the level of success desired or come close to Toyota's success. This leads people to either abandon their lean efforts or to search aimlessly for new ideas or programs to adopt. Second, companies do not find their lean improvements sustainable. This leads many people to conclude that lean simply doesn't work in their industry or even conclude that it doesn't work outside Japan. Both of these results can be avoided by recognizing lean not as a collection of tools but as a way of thinking across your company. (p. 5-6)

Flinchbaugh (n.d.) notes that the whole argument of "it doesn't work outside Japan" is defeated by the success at NUMMI (New United Motor Manufacturing Inc.) and the Toyota factory at Georgetown, KY (Womack, Jones & Roos, 1991).

The fact of the matter is, although the concepts within the Toyota Production System triangle all sound familiar, they are not being *utilized as a system* within the semiconductor industry. Liker (2004) says,

> The U.S. has been exposed to TPS for at least two decades. The basic concepts and tools are not new. The problem, I believe, is that the U.S. companies have embraced lean tools but do not understand what makes them work together in a system. Typically, management adopts a few of these technical tools and even struggles to go beyond the amateurish application of them to create a technical system. But they do not understand the power behind true TPS: the continuous improvement culture needed to sustain the principles of the Toyota Way. Within the 4P model…most companies are dabbling at one level – the process level (See Figure 2). Without adopting the other 3Ps, they will do little more then dabble because the improvements they make will not have the heart and the intelligence behind them to make them sustainable throughout the company. Their performance will continue to lag behind those companies that adopt a true culture of continuous improvement. (p. 12-13)

Figure 2. Where Most "Lean" (as they perceive themselves to be) Companies Are



Adapted from Jeffrey K. Liker. The Toyota Way (2004).

Conclusion

The semiconductor industry already strives for sustainability and growth. The above paper contends that lean thinking, and its models, rules, principles, and application of each have a place at the industry's table. All of the participants who attend SAME-TEC 2005 can benefit from these concepts (as well as their organizations). Hopefully the above paper will prime the pump for further discussions so that lean ideas may flow throughout the MATEC, TPIC, and SEMI/SEMATECH consortium.

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Bibliography

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