The Integration of True Lean and Industry 4.0 to Sustain a Culture of Continuous Improvement

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Abstract. Recent advances in information and communication technology and the Internet of Things (IoT) are driving the development of Industry 4.0. Its objective is to enable real-time information exchange between people, machines, products and resources, providing new opportunities for improved safety, quality, productivity and cost factors which can be applied in all stages of Product Lifecycle Management (PLM). The application of lean principles and practices where Industry 4.0 is deployed can leverage real-time processing visibility into even greater productivity improvements if implemented correctly. To do this, companies need to go beyond the implementation of the familiar lean tools and practices such as 5S, visual management and management directed kaizen activities etc. to consider the thinking behind the tools, especially the role of the team members. An over-reliance on technology risks undervaluing the importance of human innovative capacity which can significantly impact the ability to conduct systematic problem solving, adversely effecting daily operational performance and significantly reducing continuous improvement (CI) capacity. This conceptual paper introduces the major elements and thinking of the Toyota Production System (TPS), also referred to as 'True Lean', which are often hidden or underdeveloped within the popular understanding of lean. This paper illustrates how TPS-thinking can be operationalized to support and sustain a CI environment while leveraging the improved visibility possible with Industry 4.0 to integrate all stages of PLM.

Keywords: True Lean · Toyota Production System · Industry 4.0 · Lean · Product Lifecycle Management · PLM

1 Introduction

Much of the promise of Industry 4.0 is due to the level of automation possible and the interconnectability of people, machines, products and resources through the entire value chain. The massive amounts of real-time process data generated greatly increases

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process visibility at all levels and is therefore reasonably expected to boost problem solving and improvement activities. The application of proven lean tools such as 5S, visual management and kanbans etc. to eliminate waste, improve quality and productivity while reducing cost, without requiring a significant culture shift to implement, seems obvious and is currently being explored by several authors [1–3]. While the integration of lean tools will greatly improve stability, they will not in themselves lead to systemic improvements and keep problems from recurring, which is the driving force of Toyota Production System (TPS) and the foundation of Continuous Improvement (CI).

Striving to eliminate problem reoccurrence and setting new targets are at the heart of CI but cannot happen without the full engagement of the team members (T/Ms) doing the work. Industry 4.0 may create situations where organizations become too dependent on automated processes and analytics at the expense of human involvement, which may in-turn reduce human capacity and the creativity driving problem solving and CI [4]. This is important because regardless of the level of technology and the level of automation employed in production, without effective problem solving and CI, the system will ultimately stagnate and degrade.

The University of Kentucky Lean Systems Program (LSP) is a benchmark organization initiated by Fujio Cho in 1994 while he was the president of Toyota Motor Manufacturing of Kentucky (TMMK). Its purpose is to help non-Toyota companies apply the principles and practices of TPS in any industry. The LSP is composed primarily of first generation TMMK employees who were trained and mentored directly by Fujio Cho and a select group of Japanese sensei's to replicate the TPS culture at Toyota's first fully owned manufacturing facility outside Japan. Before coming to Kentucky, Mr. Cho was mentored for many years by Kikuo Suzumura and Taiichi Ohno - often described as the "*father of the Toyota Production System*" [4]. Members of the LSP, which is led by an acting Toyota Executive serving on a rotating basis, represent over 400 years of direct TPS experience. The program coined the term "*True Lean*" as a synonym for TPS as it is practiced inside Toyota in response to the intellectual and experiential 'drift' occurring throughout the world as the popularity of lean has increased over the decades [5].

This paper introduces the two key principles ('Respect for People' and 'Continuous Improvement') and the resulting major elements and thinking of True Lean and TPS which include the importance of team member engagement in standardization and effective systematic problem solving but are often hidden or underdeveloped within the popular understanding of lean. We will use material from our current program and our member's experience to show how TPS Thinking is operationalized to support a problem-solving environment which can help utilize the full potential of Industry 4.0 for CI.

2 Literature Review

2.1 Industry 4.0

Industry 4.0 is seen as the next generation of industry, leveraging the advancements of information and communication technology (ICT) to the manufacturing sphere to integrate the systems involved and facilitate automation. While the term Industry 4.0 was popularized by the German Government in 2011, there is no universally accepted definition for this term. Liao et al. reviews a large number of recent publications and shows the continuing increase of publications in this area [6]. Previous work of Hermann et al. [7] summarizes the three major components of Industry 4.0: (i) Internet of Things (IoT) – this includes the inanimate objects (sensors and other smart components) that connect through internet to communicate between themselves. (ii) Cyber Physical Systems (CPS) – integrated computational and physical processes with feedback loops. (iii) Smart Factories – context-aware factories which assist the people and machines in the execution of their work [7]. This work also identifies four design principles involved in implementing Industry 4.0. These include: (i) Interconnection – of machines, devices and people over technologies such as IoT. (ii) Information transparency – to all objects and people involved in the system, especially by methods such as virtual models of the plants. (iii) Decentralized decisions – made by involved parties utilizing local and global information available for increased productivity. (iv) Technical assistance – as the main role of humans, contrasting the role as 'operators' in conventional manufacturing systems to the 'strategic decision-maker' in smart factories. While other literature [8, 9] suggests slightly different principles, the underlying concepts are variations of these. There are also works available in literature which study what is involved in the transition to the Industry 4.0, and what can be learnt from past technological shifts [10]. Kopp et al. published a critical look at the application of Industry 4.0 from a German perspective and illustrated the importance of ongoing human innovation in advanced technical systems [11].

The common thread running between all these components and principles of Industry 4.0 can be identified as information. Thus, collecting, communicating, analyzing and using information can be expected to be among the most important aspects to ensuring the optimal use of Industry 4.0.

2.2 Conventional Lean and True Lean (TPS)

While lean manufacturing [12, 13] was originally based on TPS [14], previous literature [15] discusses how the term lean has been used in different contexts and with varying definitions (even within academic research). TPS was conceived as a method to fulfill customer expectations for high quality products while eliminating waste and reducing cost within the entire manufacturing system by fully utilizing each T/M's capabilities. As the previous work [15] detailed, most of the available literature focuses on the individual technical tools of lean. The technical tools of lean are just one of the three integral elements required to create and sustain a TPS or lean culture, the other two being the managerial role and the philosophy [16]. TPS Philosophy is the integral element that is the main concern of this paper with respect to the implementation of PLM and IoT. TPS Philosophy includes: *1. Customer First; 2. People are the Most Valuable Resource; 3. Shop Floor Focus (a focus on the workplace); 4. Kaizen (continuous improvement).* Our concern is that the second component of the philosophy, "P*eople are the Most Valuable Resource"*, is in danger of being be overlooked in the implementation of Industry 4.0. Focus on *"Respect for People"* and *"People are the Most Valuable Resource"* are the most common yet critical missing considerations in most conventional lean initiatives. [15, 17]. Not utilizing each T/M's full capability is a form of disrespect by not developing their God-given ability (Chie) for innovation [4]. In TPS, a Key Principle of Respect for

People at every level is practiced by developing all T/M's in an environment designed to fully utilize their capability [18]. CI is the other Key Principle embodied in TPS, focusing on reducing cost and improving quality through waste elimination [14, 18] which would not be possible without the Key Principle of Respect for People.

Due to the use in differing contexts, the term 'lean' itself has no standard definition. As a result, organizations attempting to apply lean are subjected to significant variations in what it actually means to be lean and therefore how to create and sustain it. To help overcome this problem, the LSP trademarked the term "True Lean" to describe the basic operational condition of TPS as it is practiced inside Toyota. True Lean is defined as; "*the group by themselves, using systematic problem solving to improve the work they do, towards the achievement of the company's targets and goals, when and only when the company culture is the reason the improvement occurs*" [5]. Similarly, but slightly different, TPS is defined by Toyota as: *"An organization culture of highly engaged people solving problems (or innovating) to drive performance that is created and sustained by a system of philosophy, technical tools and practices and a managerial role."* [19].

2.3 Industry 4.0 and Lean

Previous literature has different views on how Lean and Industry 4.0 are related. Some literature [8] argues Industry 4.0 as an enabler for Lean, by correlating the 'ten dimensions of lean' to the concepts in Industry 4.0. Other work has focused on "the new level of visibility and access to real-time performance data across global operations" provided by Industry 4.0 which will lead to increased productivity, lower costs and shorter lead time [2]. This same source states the opportunities inherent with the increased interconnectedness of devices, systems and even plants create huge increases in complexity, which seems contrary to Lean's traditionally understood focus on process simplification but adds that the proper lean processes and infrastructure could unleash the potential of IoT, resulting in 'Lean on steroids' [2]. This work concludes that for lean to achieve this new level of capability, fully integrated software management systems to generate real-time, actionable information will be required. Other researchers [3] have extended 'Lean Automation' as the combination of Lean and Industry 4.0, providing e-Kanban systems and robot-supported Chaku-Chaku (fully automated) lines as examples of initial Industry 4.0 applications within Lean environments. Unfortunately, all these works seem to rely heavily, if not exclusively, on automation to provide solutions and tend to understate the core aspect of 'people' to implement and sustain effective continuous improvement.

It's important to note that Toyota itself, which lean was based upon, takes a more cautionary stance on combining TPS and Industry 4.0 (and its related technologies). Toyota IT manager, Satoshi Kuroiwa [20] repeated the philosophy of "*first people, then the machines*", explaining Toyota will invest in ICT only after applying Kaizen to improve the process, and only when there are no other options. However, Satoshi also acknowledges the use of digital systems in certain areas such as product development where there are opportunities in doing so. Toyota Motor North America executives on the other hand have acknowledged [21] the possibility of using technologies such as 'Big data' for predictive analytics and using information systems that are based on Industry 4.0 to capture conditions in real-time to support the decision-making process of T/Ms [21]. Examples from Toyota North America includes IoT sensor-enabled equipment capturing data in paint departments, which enabled faster problem identification and resolution by the T/M [21]. Industry 4.0 applications are used to reduce time spent on data gathering and analysis, enabling T/Ms to focus on problem solving [21]. Their response is to remain focused on the decision-making capabilities of their people, using Industry 4.0 and its related technologies as a resource.

3 Discussion

3.1 The Challenges of Industry 4.0 and PLM, and the True Lean Advantage

The integration of True Lean and PLM along with sustainable manufacturing was discussed in a previous paper [14]. In that paper, the concept of the Benevolent Production System was also introduced to illustrate the integration of True Lean (TPS) principles and practices at all stages of PLM and production within the circular economy.

Figure 1 illustrates the conceptual relationship between Industry 4.0 and True Lean.

According to the model, a company implements Industry 4.0 through the use of ICT. Which greatly enhance process visibility, enabling companies to significantly improve performance. This condition is dependent on technology for performance and includes common lean tools as needed. Real-time process visibility can speed up problem identification and reaction but cannot prevent problem reoccurrence. It may be effective to keep the process running and initial costs down, but as unresolved problems accumulate, costs will increase and performance decrease. Changing this condition can be very difficult as T/Ms and management develop a level of comfort and confidence in their ability to address familiar problems quickly.

The addition of True Lean in the model illustrates fundamental TPS thinking, especially the drive to keep problems from coming back, which makes standardization critical. But strict adherence to following standardized work means there must be a system to respond when T/Ms are unable to perform their standardized work and feel safe to let someone know they have a problem. Therefore, they must trust there will be no recriminations as a result.

Toyota's people-friendly philosophy captured in their Key Principle of Respect for People is not there just because it's the right thing to do. It is based on "*economic rationality*" [4] since it helps promote trust and enables Toyota to sustain a standard-based culture maintained by a workforce with the strong belief that problem reoccurrence is not acceptable. This enables problem solving activities that identify and eliminate underlying causes (root cause analysis). Since eliminating the cause of a problem involves changing someone's work, it results in a change in standardized work that keeps the problem from coming back, which as mentioned before, is the foundation of TPS and True Lean. This is the genesis of the central features of the operational side of TPS, which are; 8-Step Problem Solving, also called Toyota Business Practices (TBP) [18], and Standardized Work. These are the engines that drive sustainable productivity and quality [22].

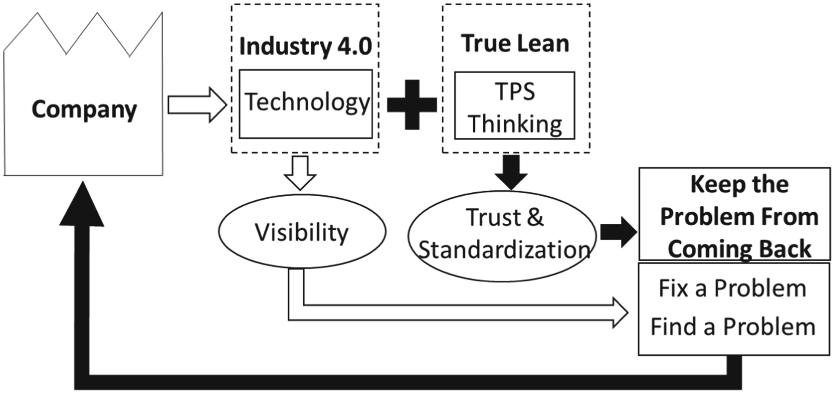

Fig. 1. Conceptual model illustrating the relationship between Industry 4.0 & True Lean

Toyota's key principles of Continuous Improvement and Respect for People are fundamental to T/M engagement. As illustrated in the model above, it is TPS thinking along with Trust and Standardization that provides the ability to eliminate problem recurrence and True Lean defines the operational conditions necessary to accomplish that.

3.2 Operational True Lean (TPS)

Team members in a True Lean system practice problem solving with the objective of eliminating waste, reducing processes and re-aligning T/Ms in production and non-production areas.

A model depicting the True Lean operations environment is presented in Fig. 2. The model illustrates seven conditions which must be met in a True Lean environment. It is most easily explained starting at the customer and working backwards through the annotated conditions as follows. The goal for most organizations is to achieve the Highest Customer Satisfaction using a series of processes to create a product or deliver a service. To do that, there must be a way to eliminate problems which adversely impact the customer. In True Lean, this is 8-Step Problem Solving or TBP. Effective problem-solving practice and thinking is critical for Abnormality Management in which both implementing temporary (fighting fires) and permanent countermeasures are essential activities. These activities require Standard Processes (standardized work) so T/Ms can distinguish normal from abnormal and identify problems. Notice in the model that standard processes, i.e. standardization, is essential for improvement. The primary conditions for the operating system (illustrated in the top half of Fig. 1) is to have stable processes where problems can be quickly identified and a systematic problem-solving methodology capable of permanently eliminating problems. Technologies associated with Industry 4.0 can increase the amount and quality of information and appropriate analytics can assist in finding problems and in some instances even self-correcting them, but without a systematic problem-solving methodology, cannot keep them from recurring. To create and maintain this system requires Engaged Staff. This may be the most essential element of all since they are the ones doing the work and are the most knowledgeable of how the work is performed. They are in the best position to see problems and to contribute meaningful ideas for improvement. Since the T/Ms doing the work are the only ones who are doing value-added work (i.e. providing products or services the customer is willing to pay for), it is important for them to react quickly to all abnormalities so they can continue normal work. This is accomplished in a True Lean system, through the use of Roles, especially the Team Leader role, who is responsible for managing abnormalities at the shop floor level. Finally, for all the above conditions to be sustained, a strong Management Support Culture is required.

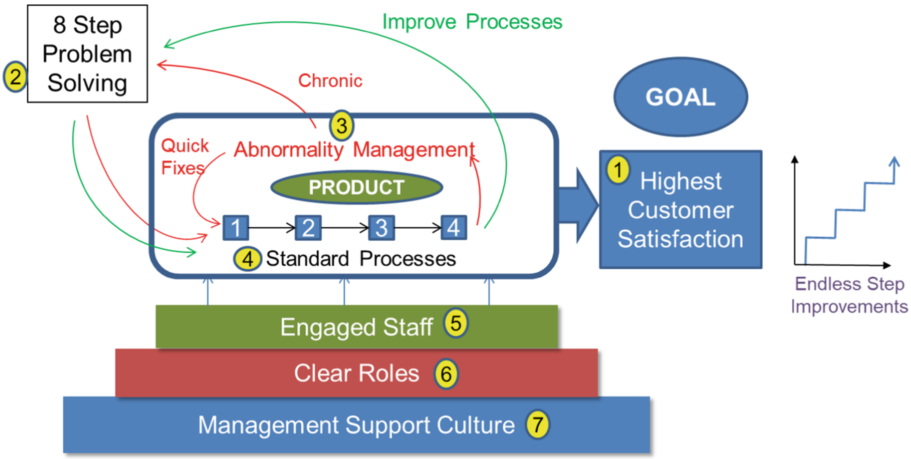

Fig. 2. True Lean Operating Environment model [23]

Meeting the conditions described above often requires an adjustment in how work is performed. The shift (illustrated in Fig. 3) is from the simultaneous performance of normal and abnormal work by T/Ms to one where their primary role is to only perform 'normal' work which is defined as the T/M's repeatable work elements. This contrasts with abnormal work, which disrupts the T/M's ability to perform their repeatable work elements, reducing the amount of value-added work being performed. The role of the Team Leader (T/L) is to eliminate abnormality so the T/Ms can complete their normal work.

When T/Ms are expected to perform both normal and abnormal work, the abnormal eventually becomes normal. This adds variation in processing time, making it impossible to predict the overall lead time for delivering the product or service to the customer and hides problems. In short, problems become normal and will never be eliminated.

As seen in the right-side Fig. 3, introducing the role of T/L helps remove abnormal work which allows the T/M to concentrate on performing normal or value-added work. This provides operational stability and enables processes to be standardized making abnormalities more visible and allows for more effective problem solving and leads to CI. In Industry 4.0 the T/M-T/L roles may be even more critical because with increased visibility will come increased abnormality detection and therefore even more pressure to respond effectively.

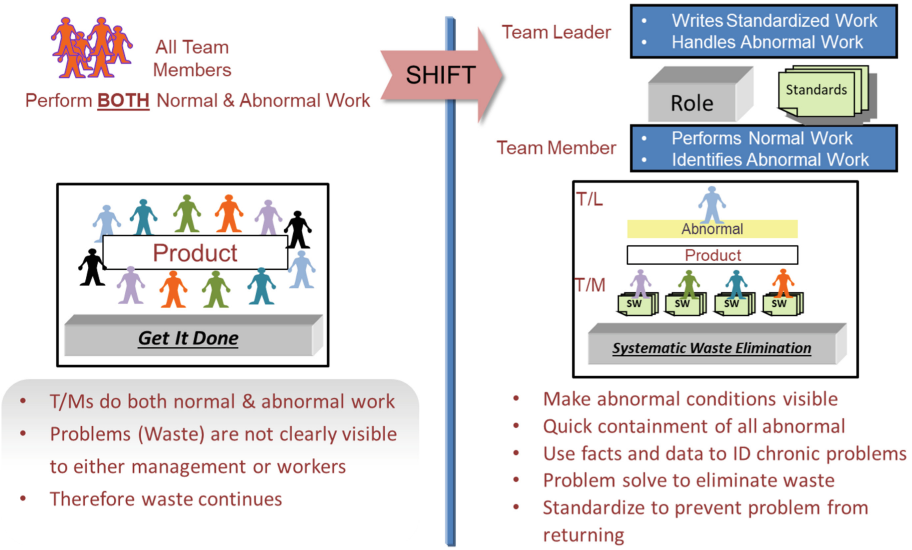

Fig. 3. True Lean Operations Environment shift model [23]

Once the processes are standardized and abnormalities become visible, systematic problem solving can be performed. Adherence to following standardized work is important for two reasons. The first is to provide an environment where problems (abnormalities) can be quickly seen and defined. The second is to provide a foundation on which problem-solving countermeasures can be implemented. Knowing the root cause and implementing the solution to a problem will not ensure CI unless the standardized work is adjusted to accommodate the new work and is adhered to consistently. The importance of this and the T/M-T/L relationship cannot be overstated.

The people side of lean is the most important and most overlooked part of lean transformations. As discussed earlier, engaging T/Ms to participate in systematic problem solving is critical to successfully keep problems from coming back and the key to that is trust. This will be even more difficult to achieve in mostly automated systems such as Industry 4.0 as more problems may be missed as the relationship of workers to the system becomes more impersonal. Therefore, from the outset it is important to promote T/M engagement by not disrespecting them by just relegating them to mindless monitoring status [4, 18].

Toyota believes firmly in the value of people and the importance of providing development opportunities for all their T/Ms, not just because it's the right thing to do morally but because it makes economic sense [4]. Workers must feel safe to call attention to problems, if not, meaningful CI cannot take place. Establishing trust in True Lean requires creating a balanced system that meets the expectations of both the company and the workers through two-way communication. Creating policies to help meet and advocate on behalf of both the T/M's and company's expectations is the role of HR. Often HR policies affecting work and management performance need to be adjusted to support

True Lean operation requirements such as ensuring a safe work environment, supporting training activities and aligning job performance evaluations to reflect their actions supporting both process and results.

4 Conclusions

This paper acknowledges the advantages of utilizing lean tools and concepts in conjunction with Industry 4.0 to leverage the improvements possible with increased process visibility as the result of access to real-time performance and other data. However, to be most effective, lean must be implemented in Industry 4.0 organizations with the intent to build a culture that supports standardization and problem solving with the goal of keeping problems from coming back. The system required to support this condition is called True Lean, which is a product of benchmarking TPS – a fundamentally people-oriented system. The Toyota perspective is that machines and systems cannot improve themselves, therefore an engaged workforce capable of creative and innovative problem solving is critical for sustained CI. Unfortunately, current and accurate Toyota thinking is generally not explicitly available in the lean literature, especially with respect to how fundamental concepts are operationalized. This paper's contribution is to introduce some basic operational models developed by the University of Kentucky Lean Systems Program to help explain TPS critical thinking behind the common tools in an understandable manner, especially in the context of automated manufacturing environments such as I4.0. To promote this outcome, operational models were introduced to illustrate the operating environment and the required environment shift to prevent problem reoccurrence. The Operating Environment model shows the relationship of both temporary countermeasures (quick fix) and permanent countermeasures to standardization. It also illustrates the importance of T/M engagement, clear roles and a strong management support structure to succeed. The Operations Environment Shift model highlights the importance of separating normal (standardized work) from abnormal work to perform effective problem solving and CI.

In highlighting the importance of T/M development this paper exposes the potential risk of developing an over-reliance on data and technology while under-valuing the role of T/Ms to conduct systematic problem solving and sustain CI within Industry 4.0. Undervaluing their importance may alienate people in the system, limiting their engagement and ultimately undermine the system's ability to achieve the full potential of Industry 4.0 and its application within PLM.

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