

ENVIRONMENTAL IMPROVEMENTS VIA LEAN MANUFACTURING

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Abstract: Lean produces an cultural and operational environment that is highly conducive to pollution prevention (P2) and waste minimization. Lean methods focus on continually improving the resource productivity and production efficiency, which frequently means: less material, less capital, less energy and less waste per production unit. In addition, lean fosters a systemic, employee-involved, continual improvement culture that is similar to existing voluntary programs and initiatives, like: environmental management systems (EMS), waste minimization, pollution prevention and design for environment, among others. There is strong proof, that lean produces environmental performance improvements with very limited financial or organizational attractiveness if the business case had based primarily on conventional P2 return on investment factors associated with the projects. Examples of conventional P2 return on investment factors include: reductions in liability, compliance management costs, waste management costs, material input costs, as well as avoided pollution control equipment. This paper indicates that the lean drivers for culture change i.e. substantial improvements in profitability and competitiveness by driving down the capital and time intensity of production and service processes, are consistently much stronger than the drivers that come as “green” such as: savings from pollution prevention activities and reductions in compliance risk and liability. Also, lean implementation efforts create powerful coattails for environmental improvement. To the extent that improved environmental outcomes can ride the coattails of lean culture change, there is a win-win situation, both for business and for environmental improvement.

Key words: lean, improvement, environment, management, performance.

1. INTRODUCTION

Lean manufacturing is a leading manufacturing paradigm being applied in many sectors of the world economy (primarily in: Japan, USA, EU, ...), where improving product quality, reducing production costs, and being “first to market” and quick to respond to customer needs are critical to competitiveness and success. Lean principles and methods focus on creating a continual improvement culture that engages employees in reducing the intensity of time, materials and capital necessary for meeting a customer’s needs. While lean production’s fundamental focus is on the systematic elimination of non-value added activity and waste from the production process, the implementation of lean principles and methods also results in improved environmental performance. In its most basic form, lean manufacturing is the systematic elimination of waste from all aspects of an organization’s operations, where waste is viewed as any use or loss of resources that does not lead directly to creating the product or service a customer wants when they want it. In many industrial processes, such non-value added activity can comprise more than 90 percent of a factory’s total activity (US EPA 2000).

Companies primarily choose to engage in lean manufacturing for 3 reasons: to reduce production resource requirements and costs, to increase customer responsiveness and to improve product quality. Common methods used in lean manufacturing include: Kaizen, 5S, Total Productive Maintenance (TPM), Cellular Manufacturing, Just-in-Time Production, Six Sigma, Pre-Production Planning (3P) and Lean Enterprise Supplier Networks (US EPA 2003).

2. LEAN MANUFACTURING

2.1. What is Lean Manufacturing?

James Womack, Daniel Jones, and Daniel Roos coined the term “lean production” in their 1990 book *The Machine that Changed the World* to describe the manufacturing paradigm established by the

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Toyota Production System (Womack et al.1990). In the 1950s, the Toyota Motor Company pioneered a collection of advanced manufacturing methods that aimed to minimize the resources it takes for a single product to flow through the entire production process. Inspired by the waste elimination concepts developed by Henry Ford in the early 1900s, Toyota created an organizational culture focused on the systematic identification and elimination of all waste from the production process. In the lean context, waste was viewed as any activity that does not lead directly to creating the product or service a customer wants when they want it. In many industrial processes, such “non-value added” activity can comprise more than 90 percent of the total activity as a result of time spent waiting, unnecessary “touches” of the product, overproduction, wasted movement, and inefficient use of raw materials, energy, and other factors (Caulkin2002).

Lean production typically represents a paradigm shift from conventional “batch and queue,” functionally-aligned mass production to “one-piece flow,” product-aligned pull production. This shift requires highly controlled processes operated in a well maintained, ordered, and clean operational setting that incorporates principles of just-in-time production and employee-involved, system-wide, continual improvement. When companies implement several or all of these lean methods, several outcomes consistently result (US EPA 2003):

- Reduced *inventory* levels (raw material, work-in-progress, finished product) along with associated carrying costs and loss due to damage, spoilage, off-specification, etc;
- Decreased *material* usage (product inputs, including energy, water, metals, chemicals, etc.) by reducing material requirements and creating less material waste during manufacturing;
- Optimized *equipment* (capital equipment utilized for direct production and support purposes) using lower capital and resource-intensive machines to drive down costs;
- Reduced need for factory *facilities* (physical infrastructure primarily in the form of buildings and associated material demands) by driving down the space required for product production;
- Increased production *velocity* (the time required to process a product from initial raw material to delivery to a consumer) by eliminating process steps, movement, wait times, and downtime;
- Enhanced production *flexibility* (the ability to alter or reconfigure products and processes rapidly to adjust to customer needs and changing market circumstances) enabling the implementation of a pull production, just-in-time oriented system which lowers inventory and capital requirements;
- Reduced *complexity* (complicated products and processes that increase opportunities for variation and error) by reducing the number of parts and material types in products, and by eliminating unnecessary process steps and equipment with unneeded features.

At the same time, lean implementation consistently fosters changes in organizational culture that exhibit the following characteristics:

- A continual improvement culture focused on identifying and eliminating waste throughout the production process;
- Employee involvement in continual improvement and problem-solving;
- Operations-based focus of activity and involvement;
- A metrics-driven operational setting that emphasizes rapid performance feedback and leading indicators;
- Supply chain investment to improve enterprise-wide performance; and
- A whole systems view and thinking for optimizing performance.

Lean methods typically target 8 types of waste (Productivity Development Team 2000). These waste types are listed in Table 1. It is interesting to note that the “wastes” typically targeted by environmental management agencies, such as non-product output and raw material wastes, are not explicitly included in the list of manufacturing wastes that lean practitioners routinely target.

Table 1 – Eight Types of Manufacturing Waste Targeted by Lean Methods

Waste Type	Examples
Defects	Production of off-specification products, components or services that result in scrap, rework, replacement production, inspection, and/or defective materials
Waiting	Delays associated with stock-outs, lot processing delays, equipment downtime, capacity bottlenecks
Unnecessary Processing	Process steps that are not required to produce the product
Overproduction	Manufacturing items for which there are no orders
Movement	Human motions that are unnecessary or straining, and work-in-process (WIP) transporting long distances
Inventory	Excess raw material, WIP, or finished goods
Unused Employee Creativity	Failure to tap employees for process improvement suggestions
Complexity	More parts, process steps, or time than necessary to meet customer needs

2.2. Lean Implementation Methods

There are numerous methods and tools that organizations use to implement lean production systems. Eight core lean methods (Womack et al. 1990) include: Kaizen Rapid Improvement Process; 5S; Total Productive Maintenance (TPM); Cellular Manufacturing / One-piece Flow Production Systems; Just-in-time Production / Kanban; Six Sigma; Pre-Production Planning (3P) and Lean Enterprise Supplier Networks.

Kaizen Rapid Improvement Process. Lean production is founded on the idea of kaizen, or continual improvement. This philosophy implies that small, incremental changes routinely applied and sustained over a long period result in significant improvements. Kaizen focuses on eliminating waste in the targeted systems and processes of an organization, improving productivity, and achieving sustained continual improvement. The kaizen strategy aims to involve workers from multiple functions and levels in the organization in working together to address a problem or improve a particular process. The team works to rapidly implement chosen improvements (often within 72 hours of initiating the kaizen event), typically focusing on ways that do not involve large capital outlays (Masaki 2017).

5S is a system to reduce waste and optimize productivity through maintaining an orderly workplace and using visual cues to achieve more consistent operational results. The 5S pillars: *Sort* (Seiri), *Set in Order* (Seiton), *Shine* (Seiso), *Standardize* (Seiketsu), and *Sustain* (Shitsuke), provide a methodology for organizing, cleaning, developing and sustaining a productive work environment. It also would result in the organization of tools and materials into labeled and color coded storage locations (Shinde and Shende 2014).

Total Productive Maintenance (TPM). TPM seeks to engage all levels and functions to maximize the overall effectiveness of production equipment. TPM's goal is the total elimination of all losses, including breakdowns, equipment setup and adjustment losses, idling and minor stoppages, reduced speed, defects and rework, spills and process upset conditions, and startup and yield losses (Mahajan et al. 2018). TPM focuses on preventing breakdowns (preventive maintenance), "mistake-proofing" equipment (or *poka-yoke*) (Masaki 2017) to eliminate equipment malfunctions and product defects, making maintenance easier (corrective maintenance), designing and installing equipment that needs little or no maintenance (maintenance prevention), and quickly repairing equipment after breakdowns occur (breakdown maintenance).

Cellular Manufacturing/One-Piece Flow Systems. Production work stations and equipment are arranged in a product-aligned sequence that supports a smooth flow of materials and components through the production process with minimal transport or delay (Chikwendu et al. 2018). In a conventional batch and queue system, the process begins with a large batch of units from the parts

supplier. Rather than processing multiple parts before sending them on to the next machine or process step cellular manufacturing aims to move products through the manufacturing process one-piece at a time, at a rate determined by customer demand (the *pull*). This can eliminate the need for uncertain forecasting as well as the waste associated with unsuccessful forecasting. Equipment often must be modified to stop and signal when a cycle is complete or when problems occur, using a technique called autonomation (or *jidoka*) (Masaki 2017).

Just-in-time Production Systems/Kanban. Just-in-time production, or JIT, and cellular manufacturing are closely related, as a cellular production layout is typically a prerequisite for achieving just-in-time production. JIT leverages the cellular manufacturing layout to reduce significantly inventory and work-in-process (WIP). JIT enables a company to produce the products its customers want, when they want them, in the amount they want. JIT techniques work to level production, spreading production evenly over time to foster a smooth flow between processes. The end result is typically a significant reduction in waste associated with unnecessary inventory, WIP, packaging, and overproduction (Masaki 2017).

Six Sigma. Six Sigma was developed by Motorola in the 1990s, drawing on well-established statistical quality control techniques and data analysis methods. Six Sigma consists of a set of structured, data-driven methods for systemically analyzing processes to reduce process variation, which are sometimes used to support and guide organizational continual improvement activities. Six Sigma's toolbox of statistical process control and analytical techniques are being used by some companies to assess process quality and waste areas to which other lean methods can be applied as solutions. Six Sigma is also being used to further drive productivity and quality improvements in lean operations (US EPA 2003).

Pre-Production Planning (3P). Whereas other lean methods take a product and its core production process steps and techniques as given, the Pre-Production Planning (3P) focuses on eliminating waste through "greenfield" product and process redesign (US EPA 2003).

Lean Enterprise Supplier Networks. To fully realize the benefits of implementing advanced manufacturing systems, many companies are working more aggressively with other companies in their supply chain to encourage and facilitate broader adoption of lean methods. Lean enterprise supplier networks aim to deliver products of the right design and quantity at the right place and time, resulting in shared cost, quality, and waste reduction benefits. It is estimated that many companies can only lean operations by 25 to 30 percent if suppliers and customer firms are not similarly leaned (Womack et al. 1990).

3. ENVIRONMENTAL IMPROVEMENTS

At the heart of successful lean implementation efforts lies an operations-based, employee-involved, continual improvement-focused waste elimination culture. While environmental wastes (e.g., solid waste, hazardous wastes, air emissions, wastewater discharges) are seldom the explicit targets of or drivers for lean implementation efforts, case studies show that the environmental benefits resulting from lean initiatives are typically substantial. Environmental benefits are embedded in creating this smooth and rapid flow of products through the production process with minimal defects, inventory, downtime, and wasted movement. For example, reducing defects eliminates the environmental impacts associated with the materials and processing used to create the defective product, as well as the waste and emissions stemming from reworking or disposing of the defective products. Similarly, reducing inventory and converting to a cellular manufacturing layout lessen the facility space requirements, along with water, energy, and material use associated with heating, cooling, lighting, and maintaining the building. The cumulative effect makes lean manufacturing a powerful vehicle for reducing the overall environmental footprint of manufacturing and business operations, while creating an engine for sustained and continual environmental improvement (US EPA 2003).

3.1. Promotion of Continual Improvement and Waste Elimination Culture

Over the past 20 years, public environmental regulatory agencies have worked to promote wasteminimization, pollution prevention, and sustainability through environmental management systems (EMS),voluntary partnerships, technical assistance, tools and guidance, and pollution prevention planningrequirements. A common theme emerges when one looks across such federal, state, and local initiatives: tomake sustained environmental improvement progress that moves beyond the “low-hanging fruit,” anorganization must create a continual improvement-focused waste elimination culture. Common elements ofthis organizational culture, as identified by public agency EMS and pollution prevention guidance, include:

- A systemic approach to continual improvement;
- A systemic and on-going effort to identify, evaluate and eliminate waste and environmental impactsthat is embraced and implemented by operations personnel;
- Environmental and pollution prevention metrics that provide performance feedback and
- Engagement with the supply chain to improve enterprise-wide performance.

The organizational culture engendered by lean methods, is remarkably similar to the organizational culturebeing promoted by environmental management agencies. Standard workestablishes clear proceduresfor the proper performance of jobs and tasks, and visual controlsreinforce desired procedures and practices;Kaizenevents involve employees from the shop floor in rapid process improvement events to identify andeliminate waste; 3Ptaps worker creativity to develop innovative process and product designs that improveefficiency and effectiveness and total productive maintenanceempowers workers to maintain and improveoperations and equipment in their work areas, preventing breakdowns, malfunctions, and accidents(US EPA 2003).

Lean experts and implementers consistently pointed to culture change as the mostdifficult aspect of lean implementation. Overcoming the inertia, skepticism, and even fear that can inhibitbehavior change is typically the greatest hurdle to creating and sustaining an organizational culture conducive to lean production and waste elimination. These findings are consistent with the challenge often identified by environmental experts ofincorporating pollution prevention and waste minimization into an organization’s culture in a sustainedmanner(Natural Resources 2000). Similarly, many organizations wrestle with the challenge of “breathing life” into their EMS andintegrating EMS elements and procedures into organizational operations and activities, to avoid the EMSbecoming just a paper pushing exercise(Brown and Larson 1998).

Several researches indicate that the lean drivers for culture change—substantial improvements in profitability andcompetitiveness by driving down the capital and time intensity of production and service processes, areconsistently much stronger than the drivers that come through the “green door,” such as savings frompollution prevention activities and reductions in compliance risk and liability. To the extent that improvedenvironmental outcomes can ride the coattails of lean culture change, there is a win for business and a win for environmental improvement.

3.2. Lean and Environmental Improvement Link

Environmental performance is almost never the objective of lean initiatives and that the financial contribution to the lean business case of environmental performance improvements (e.g., less material loss, lower waste management costs, lower liability, reduced regulatory burden) are often trivial. The benefits associated with driving capital and time out of the production process are so potent, that other potential benefits such as environmental improvement are rarely necessary to justify action or even worth quantifying to make the business case. And yet, lean implementation produces very real environmental benefits(US EPA 2003).

Several lean manufacturing experts and company representatives (Florida 1996, Hart 1997, Pojasek 1999, Soltero and Waldrip 2002)indicated that the environmental benefits associated with

implementation of lean systems are frequently not calculated or reported by companies. The lean experts cited three reasons to explain the relatively limited availability of specific company information on environmental benefits resulting from lean initiatives. First, there are relatively few forums available for publicly sharing information on the environmental results of lean implementation. While some companies include environmental benefits from lean initiatives in their overall voluntary pollution prevention reporting, many other companies do not publicly share such information to protect competitive advantages or because they do not see value in voluntarily disclosing it. Second, environmental benefits such as solid and hazardous waste reduction are seldom used to make the business case for investing in lean systems. As a result, estimating or tracking environmental improvement associated with lean implementation often does not occur. The business case is instead generally based on factors with greater impact on profitability, such as reductions in product flow time, inventory carrying costs, and defect rates, as well as increases in productivity. Essentially, environmental benefits are often ancillary, although nonetheless environmentally important. Third, in many companies, personnel engaged in implementing lean systems (e.g., operations, engineering, R&D) often operate in a "parallel universe" to environmental personnel. While both seek to drive waste out of the organization, environmental personnel are not always aware of a company's lean initiatives or at the table during discussion and assessment of them. Lean experts suggest that operations personnel are less likely to focus on environmental benefits or that they are more likely to consider them under the umbrella of resource productivity improvements. In the cases where companies do calculate and communicate environmental benefits associated with lean implementation, lean experts indicated that they typically include only direct benefits (e.g., reductions in material use, water use, energy use, and waste generation).

Other less direct environmental benefits, including those experienced throughout the product life cycle, are rarely considered: reduced demand for raw materials avoids environmental impacts from their extraction, processing, and transport; higher quality products often have greater longevity, decreasing the frequency of product repair and replacement and the associated environmental impacts and lean design for manufacturability can reduce the number of parts and materials in a product, and therefore may make it easier to recycle products or product components (US EPA 2003). Despite the findings that organizations rarely undertake lean initiatives for environmental performance improvement reasons and that the specific environmental benefits are not frequently tracked, there is significant and expanding evidence that enhanced environmental performance is resulting from lean implementation. Since the mid-1990s, several environmental experts and researchers have identified a strong relationship between lean manufacturing and environmental improvement, with most basing this finding on a combination of an analysis of lean principles and case study experience (Florida 1996, Hart 1997, Pojasek 1999, Soltero and Waldrip 2002).

Joseph Romm in his book (Romm 1994), recognized the environmental benefits inherent in the waste elimination philosophies and tools espoused by Henry Ford and, later, the Toyota Production System. Paul Hawken, Amory Lovins, and L. Hunter Lovins in their book (Hawken et al. 2010), advocate lean manufacturing as a strategy that can not only improve substantially the resource productivity of companies, but also reduce the ecological footprint of economic activity overall. In 1999, the National Institute of Standards and Technology's Manufacturing Extension Partnership in collaboration with the National Environmental Policy Institute, launched "Lean & Clean" initiative (US EPA 2000) focused primarily on SMEs in the USA, encouraging the integration of environmental management principles with lean manufacturing approaches. This white paper with brief case study examples of the environmental benefits associated with lean implementation was released with recommendations for improving the environmental performance of SMEs. Key recommendations included: (1) increase investment in pollution prevention technical assistance and compliance assistance programs, (2) develop partnerships between environmental agencies and manufacturing extension programs, (3) supply chain relationships can be leveraged to encourage behavior change, and (4) the financial services sector should be engaged to increase incentives and/or responsiveness to

good environmental performance. Although they may not directly reference lean manufacturing or other advanced manufacturing trends, some recent studies have both examined the reasons why companies are increasingly viewing proactive environmental management as good business practice and discussed the public policy implications of this occurrence (Rondinelli 2000). Most of evidences to support the links between lean production systems and environmental benefit evidence come in the form of case examples that have been collected by researchers, published directly by companies or assembled for lean manufacturing award competitions such as the Shingo Prize for Manufacturing Excellence (Shingo Prize 2002).

3.3. Environmental Improvement Mechanisms through Lean Implementation

Conceptually, the link between lean production and environmental improvement is strong. The fundamental objective of lean systems is the systematic elimination of waste by focusing on production costs, product quality and delivery, and worker involvement. Organizations implementing lean methods continually seek to reduce the materials, energy, water, space, and equipment needed per unit of production. Even though environmental endpoints, such as hazardous waste, air emissions, and wastewater discharges, are frequently not directly identified in the types of manufacturing wastes targeted by lean initiatives, improvements in these areas are deeply embedded in the other types of manufacturing wastes. Table 2. lists 7 common types of waste that lean works to eliminate, along with the environmental impacts that are often associated with each of them (Soltero and Waldrup 2002, US EPA 2003, 2000).

Table 2–Environmental Impacts Linked with Manufacturing Waste

Waste Type	Examples	Environmental Impacts
Defects	Scrap, rework, replacement production, inspection	<ul style="list-style-type: none"> • Raw materials consumed in making defective products • Defective components require recycling or disposal • More space required for rework and repair, increasing energy use for heating, cooling and lighting
Waiting	Stock-outs, lot processing delays, equipment downtime, capacity bottlenecks	<ul style="list-style-type: none"> • Potential material spoilage or component damage causing waste • Wasted energy from heating, cooling, and lighting during production downtime
Overproduction	Manufacturing items for which there are no orders	<ul style="list-style-type: none"> • More raw materials consumed in making the unneeded products • Extra products may spoil or become obsolete requiring disposal
Movement	Human motions that are unnecessary or straining, carrying work in process (WIP) long distances, transport	<ul style="list-style-type: none"> • More energy use for transport • Emissions from transport • More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption • More packaging required to protect components during movement
Inventory	Excess raw material, WIP, or finished goods	<ul style="list-style-type: none"> • More packaging to store work-in-process • Waste from deterioration or damage to stored WIP • More materials needed to replace damaged WIP • More energy used to heat, cool, and light inventory space
Complexity	More parts, process steps, or time than necessary to meet customer needs	<ul style="list-style-type: none"> • More parts and raw materials consumed per unit of production • Unnecessary processing increases wastes, energy use, and emissions
Unused Employee Creativity	Lost time, ideas, skills, improvements, and suggestions from employees	<ul style="list-style-type: none"> • Fewer suggestions of P2 and waste minimization opportunities

4. CONCLUSIONS

Each of the lean methods examined for this analysis have multiple ways in which they can produce environmental benefits. While there are a few cases where lean methods have potential to result in increased environmental risks or impacts, most of these situations can be mitigated or eliminated

through the incorporation of environmental considerations during method. In many cases, it appears that the environmental improvements resulting from lean implementation are improvements for which there would not likely have been a strong business case in the absence of the lean initiative. Improving “flow and linkage” in the production process, and reducing the capital and time intensity of production, overshadowed other benefits, creating a compelling case for the conversion to a right-sized, cellular manufacturing environment. Savings in operational costs, such as reduced chemical or material use and reduced waste disposal costs, may be significant, but they are significantly smaller than business benefits achieved from reduced capital and time intensity of production. Even in cases where “pollution prevention pays,” such projects often have difficulty competing effectively for limited organization attention and investment resources. The lean operational environment can fundamentally alter the business case for waste minimization and P2, insofar as they follow on the hefty coattails of improving flow and linkage, and of reducing the eight types of manufacturing wastes. If the operational change is already being made, then pollution prevention can “pay” even more, and, at times, pollution prevention that does not “pay” can be adopted because it contributes to overall lower systems cost. In effect, lean can help pollution prevention to better compete.

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