



United States
Environmental Protection
Agency

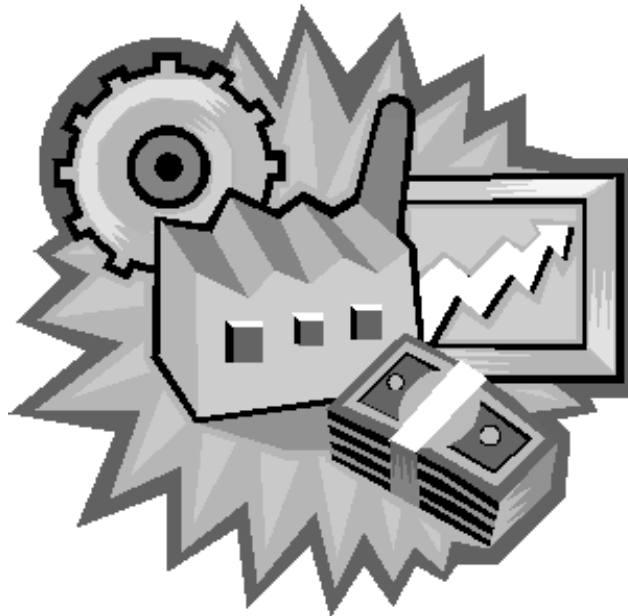
Solid Waste and
Emergency Response
(5302W)

Policy, Economics
& Innovation
(1807T)

EPA100-R-03-005
October 2003
[www.epa.gov/
innovation/lean.htm](http://www.epa.gov/innovation/lean.htm)

Lean Manufacturing and the Environment:

Research on Advanced Manufacturing Systems and the Environment and
Recommendations for Leveraging Better Environmental Performance



ACKNOWLEDGMENTS

This report was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response (OSWER) and Office of Policy, Economics, and Innovation (OPEI). Ross & Associates Environmental Consulting, Ltd. prepared this report for U.S. EPA under contract to Industrial Economics, Inc. (U.S. EPA Contract # 68-D9-9018).

DISCLAIMER

The observations articulated in this report and its appendices represent Ross & Associates' interpretation of the research, case study information, and interviews with lean experts and do not necessarily represent the opinions of the organizations or lean experts interviewed or researched as part of this effort. U.S. Environmental Protection Agency (EPA) representatives have reviewed and approved this report, but this does not necessarily constitute EPA endorsement of the observations or recommendations presented in this report.

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Executive Summary

Background

“Lean manufacturing” is a leading manufacturing paradigm being applied in many sectors of the U.S. economy, 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.

The U.S. Environmental Protection Agency (EPA) sponsored a study on lean manufacturing in 2000 that included a series of case studies with the Boeing Company to explore the relationship between lean production and environmental performance.¹ The study found that lean implementation at the Boeing Company resulted in significant resource productivity improvements with important environmental improvement implications. The Boeing case studies also found evidence that some environmentally sensitive processes, such as painting and chemical treatment, can be more difficult to lean, leaving potential resource productivity and environmental improvements unrealized. These findings led EPA’s Office of Solid Waste and Emergency Response (OSWER), in partnership with the Office of Policy, Economics, and Innovation (OPEI), to pursue new research to examine further the relationship between lean manufacturing and environmental performance and the regulatory framework. The goal of this effort is to help public environmental agencies understand ways to better leverage lean manufacturing, existing government environmental management programs and initiatives, and regulatory requirements in the hope that even greater environmental and economic benefits will result.

What is Lean Manufacturing?

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.²

Nationwide, numerous companies of varying size across multiple industry sectors, primarily in the manufacturing and service sectors, are implementing such lean production systems, and experts report that the rate of lean adoption is accelerating. Companies primarily choose to engage in lean manufacturing for three reasons: to reduce production resource requirements and costs; to increase customer responsiveness; and to improve product quality, all which combine to boost company profits and competitiveness. To help accomplish these improvements and associated waste reduction, lean involves a fundamental paradigm shift from conventional “batch and queue” mass production to product-aligned “one-piece flow” pull production. Whereas “batch and queue” involves mass production of large lots of products in advance based on potential or predicted customer demands, a “one-piece flow” system rearranges production activities in a way that processing steps of different types are conducted immediately adjacent to each other in a continuous flow.

¹ U.S. Environmental Protection Agency. *Pursuing Perfection: Case Studies Examining Lean Manufacturing Strategies, Pollution Prevention, and Environmental Regulatory Management Implications*. U.S. EPA Contract # 68-W50012 (August 20, 2000).

² Simon Caulkin. “Waste Not, Want Not,” *The Observer* (September 2002).

This shift requires highly controlled processes operated in a well maintained, ordered, and clean environment that incorporates principles of employee-involved, system-wide, continual improvement. 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.

Research Observations

Written material research, telephone interviews with “lean experts” from relevant industry, academic, and non-profit entities, and a series of brief lean case studies generated four main research observations. Key points are summarized under each of these observations below.

- ***Lean produces an operational and cultural environment that is highly conducive to waste minimization and pollution prevention (P2).*** Lean methods focus on continually improving the resource productivity and production efficiency, which frequently translates into less material, less capital, less energy, and less waste per unit of production. In addition, lean fosters a systemic, employee-involved, continual improvement culture that is similar to that encouraged by public agencies’ existing voluntary programs and initiatives, such as those focused on environmental management systems (EMS), waste minimization, pollution prevention, and Design for Environment, among others. There is strong evidence that lean produces environmental performance improvements that would have had very limited financial or organizational attractiveness if the business case had rested primarily on conventional P2 return on investment factors associated with the projects.³ This research indicates that the lean drivers for culture change—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 through the “green door,” such as savings from pollution prevention activities and reductions in compliance risk and liability.

This research found that 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 for business and a win for environmental improvement. Pollution prevention may “pay,” but when associated with lean implementation efforts, the likelihood that pollution prevention will compete rises substantially.

- ***Lean can be leveraged to produce more environmental improvement, filling key “blind spots” that can arise during lean implementation.*** Although lean currently produces environmental benefits and establishes a systemic, continual improvement-based waste elimination culture, lean methods do not explicitly incorporate environmental performance considerations, leaving environmental improvement opportunities on the table. In many cases, lean methods have “blind spots” with respect to environmental risk and life-cycle impacts.

This research identified three key gaps associated with these blind spots, that, if filled, could further enhance the environmental improvements resulting from lean implementation. First, lean methods do not explicitly identify pollution and environmental risk as “wastes” to target for elimination. Second, in many organizations, environmental personnel are not well integrated into operations-

³ 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.

based lean implementation efforts, often leading environmental management activities to operate in a “parallel universe” to lean implementation efforts. Third, the wealth of information and expertise related to waste minimization and pollution prevention that environmental management agencies have assembled over the past two decades is not routinely making it into the hands of lean practitioners.

Despite these gaps, there is evidence that lean provides an excellent platform for incorporating environmental management tools such as life-cycle assessment, design-for-environment, and other tools designed to reduce environmental risk and life-cycle environmental impacts.

- ***Lean experiences regulatory “friction” around environmentally-sensitive processes.*** Where there are environmentally-sensitive manufacturing processes, the right-sized, flexible, and mobile operating environment sought under lean initiatives can be complex and difficult to implement. This research indicates that the number of environmentally sensitive processes that generate complexity and difficulty is relatively small, including:
 - Chemical point-of-use management;
 - Chemical treatment;
 - Metal finishing processes;
 - Painting and coating; and
 - Parts cleaning and degreasing.

“Friction,” in the form of uncertainty or delay, typically results where environmental regulations did not explicitly contemplate right-sized, mobile production systems or fast-paced, iterative operational change. This results in situations where either environmental performance improvements can be constrained, or the risk of potential non-compliance with environmental regulations is increased. Where companies are delayed or deterred from applying lean to environmentally-sensitive processes, not only are they less able to address competitive industry pressures, they also do not realize the waste reduction benefits around these processes that typically result from lean implementation. Alternatively, lack of regulatory precedent or clarity can cause even the most well meaning companies to misinterpret requirements and experience violations, even where environmental improvement has resulted. This research found that regulatory relief is not necessary to address these friction areas, but rather that increased clarity around acceptable compliance strategies (and regulatory interpretations) for leaning these environmentally-sensitive processes and increased government responsiveness within its administrative activities are likely to reduce this friction.

- ***Environmental agencies have a window of opportunity to enhance the environmental benefits associated with lean.*** There is a strong and growing network of companies implementing, and organizations promoting, lean across the U.S. For those companies transitioning into a lean production environment, EPA has a key opportunity to influence their lean investments and implementation strategies by helping to explicitly establish with lean methods environmental performance considerations and opportunities. Similarly, EPA can build on the educational base of lean support organizations—non-profits, publishers, and consulting firms—to ensure they incorporate environmental considerations into their efforts.

As several lean experts suggested, efforts to “paint lean green” are not likely to get far with most lean practitioners and promoters. Instead, public environmental management agencies will be better served by being at the table with practitioners and promoters, seeking opportunities to fit

environmental considerations and tools, where appropriate, into the context of operations-focused lean methods.

Recommendations

The observations gained from this research indicate three overarching recommendations and several potential actions that the EPA can take to facilitate improved environmental performance associated with lean implementation.

Recommendation 1: Work with lean experts to identify and address the environmental “blind spots” that typically arise in lean methods

By addressing the few environmental blind spots and gaps in lean manuals, publications, training, and lean implementation, environmental regulatory agencies have an opportunity to harness even greater environmental improvement from industry lean implementation efforts. To address this opportunity, EPA should consider involving “lean experts” in developing and implementing strategies for raising awareness among companies of opportunities to achieve further environmental improvements while leaning, and developing books, fact sheets, and website materials for corporate environmental managers that articulate the connection between lean endeavors and environmental improvements. Such materials would articulate the connection between lean endeavors and environmental improvements, and explain ways in which additional environmental considerations and questions can potentially be incorporated into lean manufacturing methods. For example, questions could draw on EPA’s substantial pool of waste minimization and P2 methodologies that could be considered in the context of a *kaizen* rapid process improvement event (e.g., Does the process have waste streams? If so, what are the pollutants? Can materials with lower toxicity be used? Can they be reduced or eliminated?). More specific actions the EPA can take to facilitate this process include:

- Develop an action plan for raising awareness among companies of opportunities to achieve further environmental improvements during lean implementation;
- Partner with lean promoters to develop and modify lean tools, manuals, training, and conference sessions to address environmental performance topics;
- Develop and disseminate resources and tools for environmental practitioners to help them better understand lean manufacturing techniques and benefits;
- Develop resources, fact sheets, and website materials that highlight important environmental questions and criteria that can be incorporated into lean methods; and
- Conduct explicit outreach (e.g., materials, conference presentations, workshops) to corporate environment, health, and safety (EHS) managers to raise awareness about techniques they can use to integrate environmental considerations into their companies’ lean initiatives.

Recommendation 2: Develop a pilot/demonstration program to encourage companies who are implementing lean to achieve more waste reduction and P2 by explicitly incorporating environmental considerations and tools into their lean initiatives.

EPA can help build the bridge between lean manufacturing initiatives and environmental management by assisting companies who are implementing lean to achieve more waste reduction and P2 through the explicit incorporation of environmental considerations and tools into their lean initiatives. Beginning a pilot/demonstration program with specific companies could open avenues for putting the wealth of pollution prevention expertise, techniques, and technologies developed in recent decades for driving waste and risk out of these processes into the hands of lean practitioners who are engaged in process innovation. By

building such a “bridge,” environmental agencies will be better positioned to understand lean implementation processes and to realize greater environmental improvement result from lean initiatives. Specific pilot/demonstration activities could include:

- Work with companies to document and disseminate case study examples of companies that have successfully integrated environmental activities into lean. In addition, EPA could explore and highlight case study examples that illustrate how companies have effectively used lean as a platform for implementing environmentally sustainable tools (e.g., life-cycle analyses, Design for Environment);
- Partner with selected industry sectors and associated organizations in which there is large amount of lean activity to improve the environmental benefits associated with lean. For example, EPA could explore partnership opportunities with the Lean Aerospace Initiative or the Society for Automotive Engineers to bridge lean and the environment in these sectors; and
- Expand individual EPA initiatives, such as OSWER’s “Greening Hospitals” initiative, by integrating waste reduction and product stewardship techniques into the organizations’ lean initiatives. This effort could include conducting a pilot project with a hospital implementing lean, designed to integrate waste reduction and product stewardship techniques into its lean initiatives. The resulting lessons could then be publicized for the benefit of other hospitals.

Recommendation 3: Use pilot projects and resulting documentation to clarify specific areas of environmental regulatory uncertainty associated with lean implementation and improve regulatory responsiveness to lean implementation.

This research suggests that public environmental management agencies have an important opportunity to align the environmental regulatory system to address key business competitiveness needs in a manner that improves environmental performance. Lack of regulatory precedent associated with mobile, “right-sized” equipment begs the need for environmental agencies to articulate acceptable compliance strategies for addressing applicable requirements in the lean operating environment. At the same time, regulatory “friction”—cost, delay, uncertainty—can often arise when regulatory “lead times” (e.g., time to secure applicability determinations, permits, and approval) slow the fast-paced, iterative operational change that is typically associated with lean implementation.

Using pilot projects with specific companies, EPA can address specific areas of environmental regulatory uncertainty associated with lean implementation as well as improve regulatory responsiveness to lean implementation. EPA can then communicate the results of such endeavors through guidance documents for companies implementing advanced manufacturing methods that clarify the appropriate regulatory procedures for leaning environmentally-sensitive processes, and replicable models for reducing the lead times associated with certain regulatory processes. More specific actions EPA can take to facilitate this process include:

- Developing guidance on acceptable compliance strategies for implementing lean techniques around environmentally sensitive processes (for example, clarifying acceptable approaches for addressing RCRA satellite hazardous waste accumulation requirements in the context of implementing chemical point-of-use management systems);
- Developing acceptable compliance strategies and permitting tools that can accommodate the implementation of mobile, right-sized equipment around environmentally sensitive processes; and
- Identifying and documenting guidance regarding acceptable strategies for applying lean to other environmentally sensitive processes, including painting and metal finishing.

I. Introduction

A. Purpose

The U.S. Environmental Protection Agency (EPA) through work in various innovation initiatives with regulated industries over the past decade has recognized an emerging and very real transformation of the economic landscape. Largely, this change has arisen in the context of today's competitive global market, increasing the pressure on U.S. companies to conceive and deliver products faster, at lower cost, and of better quality than their competitors. Pioneered by the Toyota Motor Company in Japan in the 1950s, a variety of advanced manufacturing techniques are increasingly being implemented by U.S. companies across a broad range of manufacturing and service industry sectors in response to these competitive pressures. "Lean manufacturing," which focuses on the systematic elimination of waste, is a leading manufacturing paradigm of this new economy and competitive landscape.

In 2000, the U.S. EPA sponsored a study on lean manufacturing that included a series of case studies with the Boeing Company.⁴ The study found that lean implementation at the Boeing Company resulted in significant resource productivity improvements with important environmental improvement implications. Moreover, the continual improvement, waste elimination organizational culture engendered by lean methods at Boeing closely resembled the organizational culture that environmental agencies have been working successfully to encourage through the development and promotion of environmental management systems (EMS), pollution prevention, waste minimization, Design for Environment, and other voluntary initiatives. At the same time, the Boeing case studies found that certain environmentally sensitive processes, such as painting and chemical treatment, can be difficult to lean, leaving potential resource productivity and environmental improvements unrealized.

EPA's Office of Solid Waste and Emergency Response (OSWER), in partnership with the Office of Policy, Economics, and Innovation (OPEI), initiated this project to examine further the relationship between lean manufacturing, environmental performance, and the environmental regulatory framework. The goal of this effort was to help public environmental agencies better understand the environmental implications of lean manufacturing and to help them adjust environmental management and regulatory initiatives to boost the environmental and economic benefits of lean initiatives. Through this effort, EPA aimed specifically to:

- Better understand the transformation occurring in the U.S. economy as companies shift to lean production systems as well as the environmental benefits associated with this change;
- Identify opportunities to better align existing public agency pollution prevention and sustainability promotion initiatives, programs, and tools to encourage improved environmental performance through increased integration with lean production techniques and tools;
- Understand the potential areas where environmental regulations and requirements, including those associated with the Resource Conservation and Recovery Act (RCRA), may impede and/or help companies' abilities to implement and optimize lean production systems; and
- Identify opportunities to improve public agencies' responsiveness to needs associated with organizations' implementation of lean production systems, while improving environmental performance.

⁴ U.S. Environmental Protection Agency. *Pursuing Perfection: Case Studies Examining Lean Manufacturing Strategies, Pollution Prevention, and Environmental Regulatory Management Implications*. U.S. EPA Contract # 68-W50012 (August 20, 2000).

B. Project Activities

This project sought to address the objectives listed above through a multi-pronged research approach. Key research activities are summarized below.

- The research included extensive review and analysis of academic, business, news, and internet publications addressing lean manufacturing trends, methods, case studies, and results.
- A series of telephone interviews with “lean experts” from both industry and non-profit entities actively involved in promoting, implementing, and studying advanced manufacturing methods were conducted to collect information and opinions related to the above-mentioned objectives (see Appendix B for a list of interviews conducted). These interviews provided numerous examples and mini-case studies that highlight the relationship between lean implementation and environmental performance. Several of these examples are woven through this report.
- A series of brief case studies were completed to document four organizations’ experience with implementing lean production systems, and the implications for environmental management and performance. The case studies typically included analyses of publically available information, supplemented in most cases by telephone interviews with company representatives or others responsible for or familiar with the detailed aspects of lean manufacturing implementation at their facilities.⁵ A site visit was also performed in the case of Goodrich Corporation. Case study organizations were selected based on information obtained in the review of lean literature and recommendations obtained during lean expert interviews, with an attempt to cover a variety of different business sectors. The case studies include: Apollo Hardwoods Company; General Motors Corporation; Goodrich Corporation; and Warner Robins Air Force Base (see Appendix C for summaries of the case studies).
- The results of this research has been compiled into this report and its attachments. Section II provides background information on lean manufacturing, section III documents four key observations on the relationship between lean manufacturing and environmental management, and section IV discusses recommendations for EPA and other public environmental management agencies based on the observations from this research.

⁵ The Warner Robins Air Force Base case study was assembled based on published interviews with Air Force officials and articles documenting the base’s lean implementation efforts and results. See Appendix C for information on the specific information sources.

II. Introduction to Lean Manufacturing

A. 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 Toyota Production System.⁶ 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.⁷ Toyota’s success from implementing advanced manufacturing methods has led hundreds of other companies across numerous industry sectors to tailor these advanced production methods to address their operations. Throughout this report, the term “lean” is used to describe broadly the implementation of several advanced manufacturing methods.

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. To accomplish this, companies employ a variety of advanced manufacturing tools (see profiles of core lean methods later in this section) to lower the time intensity, material intensity, and capital intensity of production. When companies implement several or all of these lean methods, several outcomes consistently result:

- 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; and

⁶ James Womack, Daniel Jones, and Daniel Roos. *The Machine That Changed the World* (New York: Simon & Schuster, 1990).

⁷ Simon Caulkin. “Waste Not, Want Not,” *The Observer* (September 2002).

- 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 eight types of waste.⁸ 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

⁸ Productivity Development Team, *Just-in-Time for Operators* (Portland, Oregon: Productivity Press, 2000) 3.

B. What Methods Are Organizations Using to Implement Lean?

There are numerous methods and tools that organizations use to implement lean production systems. Eight core lean methods are described briefly below. The methods include:

1. Kaizen Rapid Improvement Process
2. 5S
3. Total Productive Maintenance (TPM)
4. Cellular Manufacturing / One-piece Flow Production Systems
5. Just-in-time Production / Kanban
6. Six Sigma
7. Pre-Production Planning (3P)
8. Lean Enterprise Supplier Networks

While most of these lean methods are interrelated and can occur concurrently, their implementation is often sequenced in the order they are presented below. Most organizations begin by implementing lean techniques in a particular production area or at a “pilot” facility, and then expand use of the methods over time. Companies typically tailor these methods to address their own unique needs and circumstances, although the methods generally remain similar. In doing so, they may develop their own terminology around the various methods. Appendix A includes a glossary of common lean manufacturing terms.

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, or rapid improvement processes, often are considered to be the “building block” of all lean production methods, as it is a key method used to foster a culture of continual improvement and waste elimination. 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 uses analytical techniques, such as Value Stream Mapping, to quickly identify opportunities to eliminate waste in a targeted 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. Periodic follow-up events aim to ensure that the improvements from the kaizen “blitz” are sustained over time. Kaizen can be used as an implementation tool for most of the other lean methods.

5S. 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. It derives from the belief that, in the daily work of a company, routines that maintain organization and orderliness are essential to a smooth and efficient flow of activities. Implementation of this method “cleans up” and organizes the workplace basically in its existing configuration, and it is typically the starting point for shop-floor transformation. 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. 5S encourages workers to improve the physical setting of their work and teaches them to reduce waste, unplanned downtime, and in-process inventory. A typical 5S implementation would result in significant reductions in the square footage of space needed for existing operations. It also would result in the organization of tools and materials into labeled and color coded storage locations, as well as “kits” that contain just what is needed to perform a task. 5S provides the foundation on which other lean methods, such as TPM, cellular manufacturing, just-in-time production, and six sigma, can be introduced effectively.

Total Productive Maintenance (TPM). Total Productive Maintenance (TPM) seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment. This method further tunes up existing processes and equipment by reducing mistakes and accidents. Whereas maintenance departments are the traditional center of preventive maintenance programs, TPM seeks to involve workers in all departments and levels, from the plant-floor to senior executives, to ensure effective equipment operation. Autonomous maintenance, a key aspect of TPM, trains and focuses workers to take care of the equipment and machines with which they work. TPM addresses the entire production system lifecycle and builds a solid, plant-floor based system to prevent accidents, defects, and breakdowns. TPM focuses on preventing breakdowns (preventive maintenance), “mistake-proofing” equipment (or *poka-yoke*) 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). 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. The ultimate goals of TPM are zero equipment breakdowns and zero product defects, which lead to improved utilization of production assets and plant capacity.

Cellular Manufacturing/One-Piece Flow Systems. In cellular manufacturing, 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. Implementation of this lean method often represents the first major shift in production activity and shop floor configuration, and it is the key enabler of increased production velocity and flexibility, as well as the reduction of capital requirements, in the form of excess inventories, facilities, and large production equipment. Figure A illustrates the production flow in a conventional batch and queue system, where the process begins with a large batch of units from the parts supplier. The parts make their way through the various functional departments in large “lots,” until the assembled products eventually are shipped to the customer.

Rather than processing multiple parts before sending them on to the next machine or process step (as is the case in batch-and-queue, or large-lot production), cellular manufacturing aims to move products through the

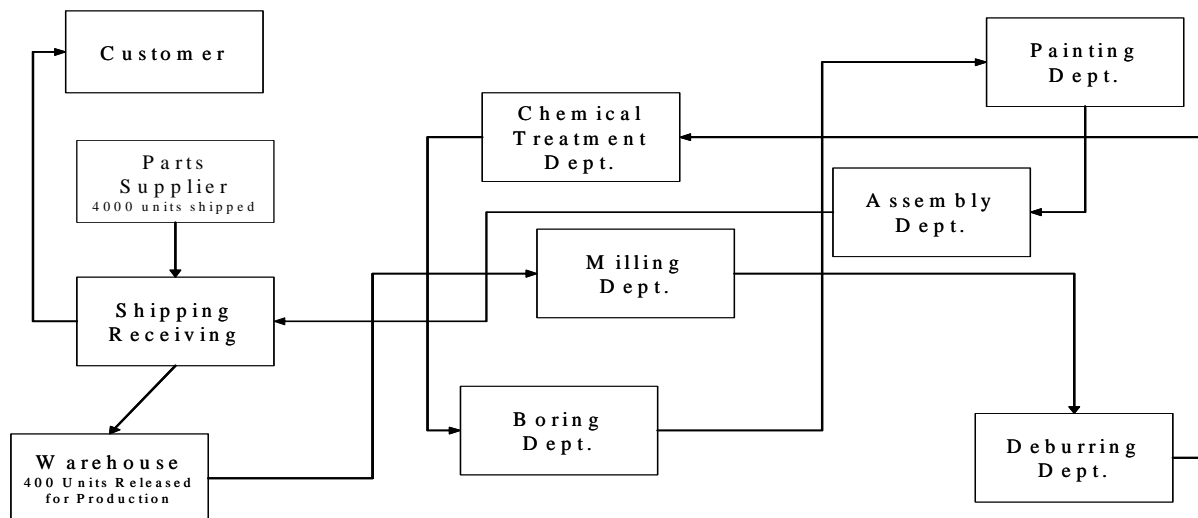


Figure A: Functionally-Aligned, Batch and Queue, Mass Production

manufacturing process one-piece at a time, at a rate determined by customer demand (the *pull*). Cellular manufacturing can also provide companies with the flexibility to make quick “changeovers” to vary product type or features on the production line in response to specific customer demands. This can eliminate the need

for uncertain forecasting as well as the waste associated with unsuccessful forecasting. Figure B illustrates production in this product-aligned, one-piece flow, pull production approach.

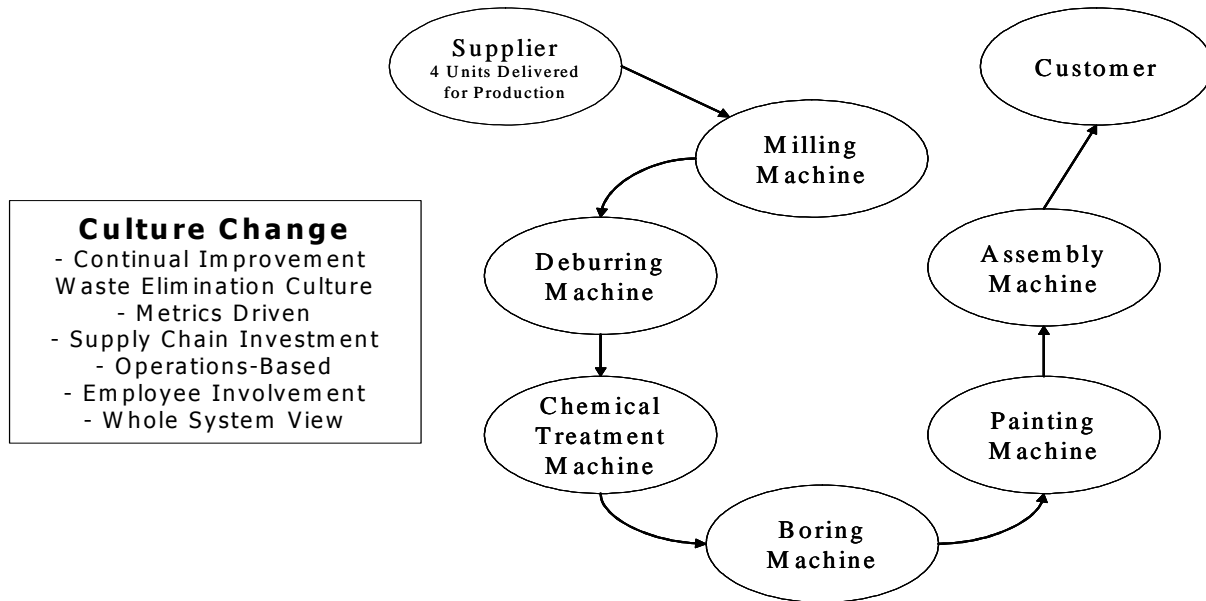


Figure B: Product-Aligned, One-Piece Flow, Pull Production

Cellular manufacturing methods include specific analytical techniques for assessing current operations and designing a new cell-based manufacturing layout that will shorten cycle times and changeover times. To enhance the productivity of the cellular design, an organization must often replace large, high volume production machines with small, mobile, flexible, “right-sized” machines to fit well in the cell. Equipment often must be modified to stop and signal when a cycle is complete or when problems occur, using a technique called automation (or *jidoka*). This transformation often shifts worker responsibilities from watching a single machine, to managing multiple machines in a production cell. While plant-floor workers may need to feed or unload pieces at the beginning or end of the process sequence, they are generally freed to focus on implementing TPM and process improvements. Using this technique, production capacity can be incrementally increased or decreased by adding or removing production cells.

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. Varying the mix of products produced on a single line, often referred to as shish-kebab production, provides an effective means for producing the desired production mix in a smooth manner. JIT frequently relies on the use of physical inventory control cues (or *kanban*), often in the form of reusable containers, to signal the need to move or produce new raw materials or components from the previous process. Many companies implementing lean production systems are also requiring suppliers to deliver components using JIT. The company signals its suppliers, using computers or delivery of empty containers, to supply more of a particular component when they are needed. The end result is typically a significant reduction in waste associated with unnecessary inventory, WIP, packaging, and overproduction.

Six Sigma. Six Sigma was developed by Motorola in the 1990s, drawing on well-established statistical quality control techniques and data analysis methods. The term *sigma* is a Greek alphabet letter used to describe variability. A sigma quality level serves as an indicator of how often defects are likely to occur in processes, parts, or products. A Six Sigma quality level equates to approximately 3.4 defects per million opportunities, representing high quality and minimal process variability. 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. Not all companies using Six Sigma methods, however, are implementing lean manufacturing systems or using other lean methods. Six Sigma has evolved among some companies to include methods for implementing and maintaining performance of process improvements. The statistical tools of the Six Sigma system are designed to help an organization correctly diagnose the root causes of performance gaps and variability, and apply the most appropriate tools and solutions to address those gaps.

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. 3P represents a key pivot point, as organizations move beyond a focus on *efficiency* to incorporate *effectiveness* in meeting customer needs. Lean experts typically view 3P as one of the most powerful and transformative advanced manufacturing tools, and it is typically only used by organizations that have experience implementing other lean methods. 3P seeks to meet customer requirements by starting with a clean product development slate to rapidly create and test potential product and process designs that require the least time, material, and capital resources. This method typically engages a diverse group of employees (and at times product customers) in a week-long creative process to identify several alternative ways to meet the customer's needs using different product or process designs. Participants seek to identify the key activities required to produce a product (e.g., shaving wood for veneer, attaching an airplane engine to the wing), and then look for examples of how these activities are performed in nature. Promising designs are quickly "mocked up" to test their feasibility, and are evaluated on their ability to satisfy criteria along several dimensions (e.g., capital cost, production cost, quality, time). 3P typically results in products that are less complex, easier to manufacture (often referred to as "design for manufacturability"), and easier to use and maintain. 3P can also design production processes that eliminate multiple process steps and that utilize homemade, right-sized equipment that better meet production needs.

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. As companies move to just-in-time production, the implications of supply disruptions due to poor quality, poor planning, or unplanned downtime become more acute. Some suppliers may increase their own inventories to meet their customer's just-in-time needs, merely shifting inventory carrying costs upstream in the supply chain. At the same time, some lean companies are finding value in tapping supplier knowledge and experience by collaborating with key suppliers to design components, instead of sending out specifications and procuring from the low bidder. It is estimated that many companies can only lean operations by 25 to 30 percent if suppliers and customer firms are not similarly leaned.⁹ Some larger companies have initiated lean enterprise supply chain activities to support the implementation of lean

⁹ Womack, Jones, and Roos, 1990, 266.

methods throughout their supply chain. Specific techniques can include training, technical assistance, annual supply chain meetings, site visits, employee exchanges, and joint projects (e.g., product or component design).

C. *Why Do Companies Engage in Lean Manufacturing?*

Fundamentally, organizations implement lean to achieve the highest quality product or service at the lowest possible cost with maximum customer responsiveness. To accomplish this, they typically focus on three key goals:

- Reducing product or service production resource requirements in the form of capital and materials;
- Increasing manufacturing velocity and flexibility; and
- Improving first time product quality.

Economic and competitiveness factors related to customer responsiveness, product quality, and cost are increasingly driving U.S. companies to implement lean production systems. Global competition is intensifying across nearly every business sector. The integration of financial markets, reductions in trade barriers, and increased industrial development in Asia and other regions where production costs are often lower are eroding barriers to competition.¹⁰ In this context, being “first to market” and quick to respond to customer needs, improving product quality, and reducing production costs (to help maintain or lower prices) are critical to success. Lean production, with its fundamental focus on the systematic elimination of waste, has quickly emerged as a prominent strategy for meeting these objectives and maintaining business competitiveness.

C.1 Production Resource Requirements and Costs. Advanced manufacturing methods can improve a company’s profitability by reducing production costs in a variety of ways.¹¹

Lean reduces the amount of cash tied up in inventory and “work in process” (WIP) and shortens the time between when a company purchases inputs and receives payment for product or service delivery.

¹⁰ Numerous books written in recent years document the competitive pressures arising from globalization and other factors. See: Thomas Friedman., *The Lexus and the Olive Tree: Understanding Globalization* (Thorndike, ME: Thorndike Press, 1999); and Gary Hamel and C.K. Prahalad. *Competing for the Future* (Boston: Harvard Business Review Press, 1996).

¹¹ Most of the available evidence on the benefits of lean production systems comes in the form of case studies and anecdotes assembled by various companies, organizations, academics, and authors investigating lean. Looking across multiple sources, there appears to be robust patterns in the levels of performance improvements that are typically possible through lean implementation (e.g., resource productivity improvements ranging from 30 to 70 percent). The few empirical studies that have been conducted on the economic benefits of lean appear to support the case study evidence. For example, a study of 249 small automotive part suppliers used statistical techniques to test the relationship between lean manufacturing and production performance outcomes. The study, based on a 1992 survey by the Midwest Manufacturing Technology Center, found that key facets of lean production (i.e., a lean supplier system; a high involvement, team-based organization; a built-in quality system; and just-in-time production systems) are each associated with production performance improvements, as measured by shopfloor efficiency, product quality, and machine uptime. The study also found that firms implementing a combination of just-in-time production, total productive maintenance, and kaizen-type, team-based continual improvement systems experienced a multiplier effect, achieving even higher levels of production performance improvement. See Steven F. Rasch. “Lean Manufacturing Practices at Small and Medium-Sized U.S. Parts Suppliers-Does It Work?” *Becoming Lean: Inside Stories of U.S. Manufacturers* (Portland, Oregon: Productivity Press, 1998).

Conventional large-lot mass production methods use a functionally-aligned,¹² “batch and queue” approach where large quantities of parts are produced in batches and wait “in queue” until the lot moves to the next process step. This results in the need to hold significant stocks of inventory that in turn takes up floor space and increases energy requirements and costs. Lean manufacturing realigns the production process to focus on products, grouping all of the machines and conducting all of the process steps in a compact “cell” that “flows” one part through the process as it is needed. This realignment substantially reduces inventory requirements and associated factory floor and energy needs with the result that the capital intensity of production has been substantially reduced. As one company representative quipped, “We suddenly realized we’re working in a factory, not a warehouse!” Lean implementation also increases “inventory turns” (the number of times per year a facility’s inventory turns over), reducing the probability of product deterioration or damage, minimizing the potential for overproduction and obsolescence, releasing cash for other productive uses, further driving down inventory stock requirements, and reducing the overall time intensity of product production or service delivery.

For example, implementation of lean methods at Warner Robins U.S. Air Force Base in Georgia has reduced the number of days it takes to overhaul a C-5 transport plane from approximately 360 to 260. This has major resource requirement implications for the Air Force, since the 25 to 30 percent reduction in maintenance time means that the Air Force needs to procure fewer total planes (i.e., maintain a lower inventory of planes) to maintain a target number of planes in service. According to one Air Force official, “If we can achieve even half of the typical lean results, we would expect to be able to cut the programmed depot maintenance time of our systems [e.g., planes] in half. This would put up to 10 percent more of our aircraft in flying status at any given time.”¹³ As a result, the total cost of maintaining a given in-service aircraft target level is substantially reduced.

As another example of WIP reductions and competitiveness, advanced manufacturing systems have enabled Maytag Corporation’s higher-priced, water-saving washing machines to compete against lower-priced competitors. Maytag’s Jackson, Tennessee dishwasher plant cut work in process by 60 percent, reduced space needs by 43,000 square feet, and improved quality by 55 percent, while increasing capacity by 50 percent and enabling the plant to quickly switch the production mix to respond to department store demand for various models.¹⁴

Lean lowers the capital equipment requirements of production, and makes it less costly to increase or decrease production levels or to alter the mix of products produced. Under the conventional mass production approach, companies often purchased large pieces of equipment with sufficient capacity to meet peak forecasted demand levels, plus some. Large machines could then be used to perform the same function (e.g., milling) on different part types, using (often complicated and time consuming) tooling changes. Functional departments established in this manner then look to minimize marginal cost by processing large lots of identical parts over longer time frames. This can fully utilize the capacity of the machines and minimizes tooling changes, but comes at the expense of requiring large inventories, substantial added overall production time, limited flexibility, and the need to predict demand accurately or bear the expense of overproduction.

¹² “Functionally-aligned” refers to the conventional production approach which establishes processing departments such as milling, heat treating, etc. that requires parts to move from department to department.

¹³ Interview with Gary Waggoner, Director of Lean Programs, Air Force Research Laboratory’s Materials and Manufacturing Directorate, as published in “Lean Becomes a Basic Pillar In Air Force Manufacturing Technology Program,” *Manufacturing News* (January 15, 2002).

¹⁴ *The Economist*, July 14, 2001, 65.

Lean methods, on the other hand, focus on developing smaller, “right-sized” equipment specifically tailored to a particular product or product line that meet current needs in a manner that is significantly less capital intensive and more flexible.

For example, Apollo Hardwoods, a veneer manufacturing start-up company, is using lean methods to create “right-sized” equipment that is approximately one half of the capital intensity of the typical large-scale equipment used in the industry today. Companies such as the Boeing Company, Goodrich Aerospace, and Hon Industries have developed small, mobile equipment (e.g., parts washers, paint booths, presses, drying ovens) that cost a fraction of the cost of conventional large equipment, and that can be readily duplicated to meet increases in demand. Under a conventional mass production approach with large equipment, it is typically not possible to add new capacity in small increments and without major new investment in capital equipment.

Lean substantially reduces the facility footprint of production. The realignment of production around products and into cells using right-sized equipment—which in turn drives inventory requirements and movement out of the production system—has allowed companies to reduce by as much as 50 percent their floor space requirements. This can significantly reduce facility capital costs (e.g., property, buildings), as well as facility operating expenses (e.g., maintenance, utilities). For example, Goodrich Aerostructures consolidated the manufacturing operations at its Chula Vista, California facility into two buildings from five while doubling output as a result of implementing lean methods. This decreased overall facility space needs by 50 percent, enabling the facility to sell property to the city for waterfront redevelopment.¹⁵

Lean reduces operating costs associated with material use, movement, equipment downtime, rework, and other factors. Lean tools and methods seek the optimization of any given manufacturing, service, or administrative process, enabling companies to drive down operating costs and time requirements. Material use reductions result from lean methods that address inventory control, point-of-use material management, and workplace organization; movement reductions result from production process realignment; equipment downtime reductions result from the implementation of Total Productive Maintenance (TPM) activities that prevent errors and malfunctions; and defects and rework reductions result from “mistake-proofing” equipment and processes. These individual tools and methods are embedded in “whole systems thinking” that can allow paying higher prices—for materials, for example—if it reduces overall system costs due to efficiency gains in other areas such as time, mistakes, and material loss. For example, this thinking may lead a company to pay more to have smaller amounts of chemicals delivered in “right-sized” containers rather than buying bulk chemicals at cheaper prices. Optimizing processes and reducing operating costs can occur both before major conversion to product-aligned, cellular manufacturing or after. The combined impact of reducing various operating costs using lean tools and continual improvement efforts can produce large dividends. For example, applying lean methods to a small number of maintenance operations at Robins Air Force Base has saved the Air Force about \$8 million.¹⁶

C.2 Velocity and Flexibility. Lean enables companies to increase substantially the velocity and flexibility of the manufacturing or service process. These outcomes produce two critical benefits: reducing the cash requirements of the process by shortening the time frames between material acquisition expenses and customer payments; and increasing customer and marketplace responsiveness. Responsiveness to

¹⁵ Case study interviews with Goodrich Aerostructures Group representatives on October 3, 2002 and “Aerospace Industry Mimics Toyota,” *Financial Post*, Canada (March 10, 1999).

¹⁶ George Cahlink. “Air Support,” *Government Executive Magazine*. (<http://www.govexec.com>) (June 2001).

marketplace and customer needs, in particular, is a high priority for companies implementing lean. Such responsiveness involves meeting rapidly changing customer “just-in-time” demands through similarly rapid product mix changes and increases in manufacturing velocity. Time is often a critical dimension of customer responsiveness—getting the customer what they want when they want it. To compete successfully, many companies need to improve continually the time responsiveness both for current products (promptly delivering products meeting customer specifications) and new products on the horizon (by reducing total time-to-market for product development and launch).

For example, global competition, coupled with computer-aided design and advanced manufacturing techniques, has shrunk the new vehicle development process among leader companies in the automotive industry from 5 years to as little as 18 months. Fragmentation of market demand is expanding the mix of products, while customers are requesting shorter lead times for new vehicle delivery. Ford, General Motors, and other car makers are participating in the “3 Day Car” initiative to reduce vehicle lead times from 60 days to 3. The percentage of “built-to-order” vehicles is also rising, with customers requesting increased variety in vehicle types and features. Automotive companies indicate that diversifying product mix, shortening product lead times, and building to customer orders are key elements of their competitive strategies.¹⁷

Lean producers constantly strive to reduce “flow time” (total time to produce one unit of a product), “cycle time” (time it takes for a machine to perform a single operation), and “lead time” (the total amount of time it takes to get an order into the hands of the customer). In the lean operating environment, optimizing production around “takt time” (the rate at which each product needs to be completed to meet customer requirements) becomes a central focus. As a further example, stiff competition during the 1990s has led many aerospace companies to pursue lean production systems, enabling them to reduce lead times for filling customer orders and to shorten the time between outlaying cash for input procurement and collecting cash upon airplane delivery. For example, Boeing’s 737 airplane production facility in Renton, Washington until recently utilized three production lines and required more than 22 flow days to assemble an airplane. Upon collapsing the three lines to a single, more efficient, continuously moving, one-piece flow assembly line, Boeing has reduced flow time for the 737 to 15 days and envisions further reductions to as low as 5 days.¹⁸

C.3 Product Quality. Maintaining high and consistent product quality is a key dimension of competitiveness, affecting both product cost and customer loyalty. Product defects compound production costs due to added time and space for rework and repair, waste materials, and waste disposal costs. Recurring delays in product delivery and defects in products or parts can reduce sales or trigger the loss of lucrative supply contracts to large manufacturers, distributors, or retailers. For example, between 1993 and 1997, Delphi Automotive System’s Saginaw Steering Systems plant utilized lean methods to reduce defect rates from almost 2,000 defective parts per million (ppm) to 75 defective ppm, providing a key factor in General Motors’ decision to continue sourcing steering components from Delphi.¹⁹

¹⁷ “A Long March: Special Report on Mass Customization,” *The Economist*, July 14, 2001, 63-65. Also see Mickey Howard and Andrew Graves. “Painting the 3Daycar: Developing a new Approach to Automotive Coatings and Lean Manufacture,” *SAE Technical Paper Series* (Warrendale, PA: SAE International, 2001).

¹⁸ James Wallace. “Just 15 Days to Assemble a 737,” *Seattle Post-Intelligencer* (May 24, 2002) C1, and discussions with Boeing Company representatives on June 21, 2002 and October 23, 2002.

¹⁹ Daniel Woolson and Mike Husar. “Transforming a Plant to Lean in a Large, Traditional Company: Delphi Saginaw Steering Systems, GM” in Jeffrey Liker. *Becoming Lean: Inside Stories of U.S. Manufacturers* (Portland, Oregon: Productivity Press, 1998) 121-159.

There are a number of ways that lean production, when compared to conventional large-lot mass production, can significantly improve product quality. Under conventional “batch and queue” mass production methods, large quantities of inventory, or “work in process” (WIP), often remain on the factory floor for lengthy periods of time, increasing the probability of product deterioration or damage. Defects typically are not discovered until an entire batch is completed, at which point repair is often time consuming and costly. Lean production offers several techniques for identifying and addressing product defects at earlier (and less costly) stages of the production process. These include: *cellular, one-piece flow manufacturing*, which enables employees to quickly stop the production process at the first sign of quality problems; *kaizen-type rapid improvement processes* for rapidly involving cross-functional teams to identify and solve production problems; *Six Sigma*, a statistical process for controlling product defect rates; *poka-yoke*, which involves “mistake-proofing” equipment and processes; and *total productive maintenance*, a procedure that helps ensure optimal performance of equipment.

D. Who Is Implementing Lean?

Numerous companies of varying size across multiple industry sectors are implementing lean production systems, and the rate of lean adoption is increasing. Implementation of lean production systems in the U.S. has increased significantly since being introduced in the U.S. in the 1980s. Interest in lean began in the U.S. automotive sector, but has spread rapidly to other sectors such as aerospace, appliance manufacturing, electronics, sporting goods, and general manufacturing, and even in service sectors such as health care and banking. Some lean experts indicate that between 30 and 40 percent of all U.S. manufacturers claim to have begun implementing lean methods, with approximately five percent aggressively implementing multiple advanced manufacturing tools modeled on the Toyota Production System.²⁰ While a few companies in heavy industries such as steelmaking, primary metals, chemical production, and petroleum refining are adopting lean principles and methods such as kaizen and 5S, these sectors have not had areas of significant lean implementation activity to date. Much of the current lean implementation activity is focused in the manufacturing and service sectors.

Lean experts interviewed for this research suggested that the economic downturn in recent years has prompted an increasing number of organizations to look to advanced manufacturing techniques to remain competitive. Intensifying competitiveness and supply chain pressures are leading increasing numbers of small and medium-sized companies to implement lean systems. This coincides with the expansion of government, university, and not-for-profit technical assistance programs providing training and support for implementation of lean production systems. The transition to lean production systems frequently takes an organization from five to ten years (or more), and the degree of lean implementation can vary significantly among facilities across a company.

Implementation of lean production systems in the U.S. began in the early to mid-1980s in the automotive sector. Strong productivity and quality performance among Japanese auto manufacturers such as Toyota and Honda raised the competitiveness bar, prompting U.S. companies to investigate the Toyota Production System. The New United Motor Manufacturing Inc. (NUMMI), a joint venture initiated in 1984 between the classic mass producer, General Motors (GM), and the classic lean producer, Toyota, was one of the first plants to pioneer the implementation of lean production systems in the U.S. Compared to a conventional GM plant, NUMMI was able to cut assembly hours per car from 31 to 19 and assembly defects per 100 cars from

²⁰ Rick Harris, President of Harris Lean Systems, Inc. as quoted in Austin Weber. “Lean Machines,” *Assembly Magazine* (March 2002). Also based on interviews with lean experts.

135 to 45.²¹ By the early 1990s, the success of NUMMI, among other factors, made it increasingly clear to the “big three” auto manufacturers (DaimlerChrysler, GM, and Ford) that lean manufacturing offered potent productivity, product quality, and profitability advantages over conventional mass production, batch and queue systems. By 1997, the “big three” indicated that they intended to implement their own lean systems across all of their manufacturing operations.²²

In the 1990s, numerous small, medium, and large suppliers of automotive components began the transition to lean production systems. As auto assemblers moved towards just-in-time production, their expectations for improved responsiveness, quality, and cost from suppliers also evolved. Some companies indicated that they would not continue to pay the costs associated with their suppliers’ carrying large inventories. Increasing numbers of automotive suppliers view lean production systems as the key to meeting these evolving cost, quality, and responsiveness expectations and to improving profitability. In some cases, large auto manufacturers are supporting supplier implementation of lean systems. For example, Toyota established the Toyota Supplier Support Center in Lexington, Kentucky in 1992 to provide free assistance to U.S. companies interested to learn about lean manufacturing. Large integrated automotive suppliers such as Delphi Corporation, Donnelly Corporation, Eaton Corporation, and Johnson Controls, Inc. are among the leaders in lean implementation. Several other medium-sized companies in diverse manufacturing sectors were early adopters of lean systems. Companies such as the Danaher Corporation, Freudenberg-NOK, Garden State Tanning, and the Wiremold Company posted significant productivity, quality, and cost-competitiveness improvements.²³

During the early-1990s, the aerospace industry stepped up efforts to implement lean production systems. In 1993, the U.S. Air Force, the Massachusetts Institute of Technology, 25 aerospace companies, and labor unions initiated the Lean Aerospace Initiative to support lean implementation in the aerospace sector. Companies such as The Boeing Company, Lockheed Martin, and Raytheon are implementing lean production systems across many parts of their organizations. Lean implementation has also grown rapidly among aerospace parts and components suppliers, such as Goodrich Corporation. The U.S. Air Force has moved aggressively in recent years to implement lean production methods throughout its operations, from Air Logistics Centers to contractor manufacturing and maintenance operations.²⁴

Hundreds of other companies across multiple industry sectors are implementing lean production systems to varying degrees. Leader companies in lean implementation have emerged in numerous industry sectors, from Alcoa in metal processing to the Maytag Corporation in appliance manufacturing. Evidence of increasing business interest in and adoption of lean manufacturing can be found in the rapidly increasing rates of company participation and membership in lean networks and organizations.

- The Northwest Lean Manufacturing Network (NWLEAN) provides training and on-line forums through which lean practitioners can share lean experiences, knowledge, and practices. There are over 5,100 members of NWLEAN, representing organizations in diverse industry sectors including

²¹ Womack, Jones, and Roos, 1990, 83.

²² Jeffrey Liker, 1998, 6.

²³ See Womack, Jones, and Roos, 1990 and Jeffrey Liker, 1998 for discussions and case studies of early lean implementation in the U.S.

²⁴ Interview with Gary Waggoner, *Manufacturing News*, January 15, 2002.

automotive, aerospace, furniture, healthcare, luxury goods, metal processing, paper products, and sporting goods.²⁵

- The Shingo Prize for Excellence in Manufacturing awards companies that excel in lean manufacturing. Dubbed “the Nobel prize for manufacturing excellence” by *Business Week* magazine, applications for the prize have increased between 40 to 60 percent each year over the past several years. Past award recipients come from small, medium, and large manufacturers in industry sectors including aerospace, automotive, chemical processing, construction equipment, electronics, furniture, medical equipment, and metal processing.²⁶

Interviews indicate that lean production methods have made fewer inroads in industrial sectors and processes that have very large-scale, fixed capital assets, such as primary metals, foundries, bulk chemical manufacturing, and petroleum refining. Lean experts suggested that advanced manufacturing tool implementation in these sectors, where practiced, focus on work practice standardization (e.g., 5S, standard work, visual controls) and equipment effectiveness (e.g., TPM). The interviews and case studies conducted for this research did not identify sufficient information to understand potential barriers to applying fully lean techniques to these industry sectors and processes.

Recently, companies in service industries such as banking and health care have begun to adopt lean methods to reduce waste in service delivery and administrative processes and to more efficiently meet customer needs. For example, several hospitals across the Pacific Northwest are applying lean methods to hospital management, addressing processes such as supply inventory management, instrument sterilization and surgery prep, medical waste management, and patient appointment scheduling. For example, as part of a four-year strategic plan, Virginia Mason Hospital in Seattle, Washington has dedicated itself to “lean thinking,” applying lean production techniques to its healthcare administration operations. Virginia Mason is evaluating everything from how long a patient waits for an appointment to the amount of paper used in offices and waiting rooms to identify opportunities for minimizing “waste” (e.g., waiting, materials, inventory, movement). In 2002, Virginia Mason’s top 30 executives attended a two-week training session in Japan on lean production methods.²⁷

²⁵ Northwest Lean Manufacturing Network (NWLEAN), <http://www.nwlean.net>, September 1, 2003.

²⁶ See <http://www.shingoprize.org>

²⁷ Lisa Heyamoto. “Hospital on Cost-Cutting Mission Adds Trip to Japan.” *Seattle Times* (June 6, 2002).

III. Key Observations Related to Lean Manufacturing and its Relationship to Environmental Performance and the Regulatory System

Observation 1: Lean produces an operational and cultural environment highly conducive to waste minimization and pollution prevention

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 study and empirical evidence shows that the environmental benefits resulting from lean initiatives are typically substantial. The business case for undertaking lean projects—substantially lowering the capital and time intensity of producing products and services that meet customer needs—is frequently tied to “flow and linkage.” Although not explicitly targeted, 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.

Fostering a Continual Improvement, Waste Elimination Organizational Culture

Over the past twenty years, public environmental regulatory agencies have worked to promote waste minimization, pollution prevention, and sustainability through environmental management systems (EMS), voluntary partnerships, technical assistance, tools and guidance, and pollution prevention planning requirements. A common theme emerges when one looks across such federal, state, and local initiatives: to make sustained environmental improvement progress that moves beyond the “low-hanging fruit,” an organization must create a continual improvement-focused waste elimination culture. Common elements of this 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 impacts that 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, as outlined earlier in this report and described by experts in the interviews and case studies for this research, is remarkably similar to the organizational culture being promoted by public environmental management agencies. *Standard work* establishes clear procedures for the proper performance of jobs and tasks, and *visual controls* reinforce desired procedures and practices; *Kaizen* events involve employees from the shop floor in rapid process improvement events to identify and eliminate waste; *3P* taps worker creativity to develop innovative process and product designs that improve efficiency and effectiveness; and *total productive maintenance* empowers workers to maintain and improve operations and equipment in their work areas, preventing breakdowns, malfunctions, and accidents.

During the interviews, lean experts and implementers consistently pointed to culture change as the most difficult aspect of lean implementation. Overcoming the inertia, skepticism, and even fear that can inhibit behavior change is typically the greatest hurdle to creating and sustaining an organizational culture conducive to lean production and waste elimination. Leadership and organizational need were identified during the interviews and case studies as two key factors affecting the success of efforts to change organizational culture. These findings are consistent with the challenge often identified by environmental experts of incorporating pollution prevention and waste minimization into an organization's culture in a sustained manner.²⁸ Similarly, many organizations wrestle with the challenge of "breathing life" into their EMS and integrating EMS elements and procedures into organizational operations and activities, to avoid the EMS becoming just a paper pushing exercise.²⁹

Given the difficulty of creating and sustaining an operations-based, employee-involved, continual improvement-focused waste elimination culture, the observation that lean implementation is gaining momentum among U.S. companies and is creating a similar organizational culture is noteworthy. Several lean experts identified a boom in U.S. companies implementing lean systems in recent years, and indicated that the economic downturn and intensifying global competition are creating compelling reasons for many companies to attempt the culture change necessary to implement successfully lean methods. Our research indicates that the lean drivers for culture change—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 through the "green door," such as savings from pollution prevention activities and reductions in compliance risk and liability. To the extent that improved environmental outcomes can ride the coattails of lean culture change, there is a win for business and a win for environmental improvement. The next sections explore the actual relationship between lean implementation and organizational environmental performance.

Establishing the Link Between Lean and Environmental Improvement

Research for this report indicates that 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.

Several lean manufacturing experts and company representatives indicated in the interviews 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 environment 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 P2 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. As mentioned, most case study

²⁸ Natural Resources Defense Council, Dow Chemical, et al. *Preventing Industrial Pollution at its Source: A Final Report of the Michigan Source Reduction Initiative* (New York: NRDC, 2000).

²⁹ Howard Brown and Timothy Larson, "Making Business Integration Work: A Survival Strategy for EHS Managers," *Environmental Quality Management* 7, no.3 (Spring 1998).

examples come from a handful of research projects and profiles of lean award-winning companies. 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.

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 analyses of lean principles and case study experience.³⁰ Joseph Romm’s 1994 book *Lean and Clean: How to Boost Profits and Productivity by Reducing Pollution* recognized the environmental benefits inherent in the waste elimination philosophies and tools espoused by Henry Ford and, later, the Toyota Production System. His book provides case study examples of the productivity and environmental improvements that companies such as Mitsubishi Electric America, Compaq, and Martin Marietta (now Lockheed Martin) have achieved through the use of lean methods.³¹ Results such as these have led some, including Paul Hawken, Amory Lovins, and L. Hunter Lovins in their book, *Natural Capitalism*, to 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.

³⁰ See Soltero and Waldrip, 2002; Pojasek, 1999; Florida, 1996; Hart, 1997.

³¹ Joseph Romm., *Lean and Clean Management: How to Boost Profits and Productivity by Reducing Pollution* (New York: Kodansha International, 1994).

Interest in the relationship between lean and environmental performance has continued to grow in recent years. In 1999, the National Institute of Standards and Technology's Manufacturing Extension Partnership (NIST/MEP), in collaboration with the National Environmental Policy Institute (NEPI), launched an initiative to raise awareness of this connection between lean manufacturing and environmental performance. This "Lean & Clean" initiative focused primarily on small and medium-sized manufacturers in the U.S., encouraging the integration of environmental management principles with lean manufacturing approaches. Policy-level "Lean & Clean Symposiums" were held in Washington, DC in 2000 and 2001, and a 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 small and mid-sized manufacturers.³² 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.³³

There is a growing body of evidence to support the theoretical links between lean production systems and environmental benefits. Most of this evidence comes 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. For example, Bridgestone/Firestone's Aiken County, South Carolina plant produces passenger and light truck tires. As this facility has implemented lean processes since 2000, they have seen a reduction in hazardous and solid waste generation of 53 percent and a decrease in material scrap of 38 percent.³⁴ Hyde Manufacturing, a Massachusetts tool maker, also implemented lean systems, which resulted in reduced hazardous waste generation by 93 percent and solid waste generation by 85 percent.³⁵ The Naugatuck Glass Company in Connecticut cut product lead time, enhanced equipment longevity, and improved quality while using lean and had a 50 percent reduction in material scrap, a 40 percent decrease in water use, and a 19 percent reduction in energy use.³⁶ In Michigan, Howard Plating, through implementing lean methods, lowered volatile organic compound (VOC) emissions by 90 percent, water use by 40 percent, and energy use by 25 percent.³⁷

³² 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 (e.g., NIST-MEP Centers), (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. See NEPI. *Getting to Green Through "Lean and Clean," White Paper: Findings and Recommendations of the Lean & Clean Project: Improving the Environmental Performance of Small and Mid-Sized Manufacturers*. Washington, DC: NEPI, (November 6, 2000).

³³ For example, see Dennis Rondinelli. *Rethinking U.S. Environmental Protection Policy: Management Challenges for a New Administration*. The PricewaterhouseCoopers Endowment for the Business of Government, November 2000.

³⁴ See Shingo Prize 2002 Business Prize Recipients at <http://www.shingoprize.org>.

³⁵ National Institute of Standards and Technology's Manufacturing Extension Partnership, *Clean Manufacturing Executive Overview* (Washington DC: NIST-MEP, July 2002) CD-ROM.

³⁶ NIST, 2002.

³⁷ NIST, 2002.

As previously mentioned, the EPA-supported case studies at the Boeing Company in 2000 found significant environmental benefits associated with Boeing's lean implementation efforts. The Boeing Company has consistently realized resource productivity improvements ranging from 30 to 70 percent when lean production programs are implemented. Boeing's Everett, Washington production facility implemented a lean chemical point-of-use system to reduce mechanic movement and downtime that also lowered chemical usage by 12 percent per plane.³⁸ The case studies conducted as part of this research effort also found evidence of environmental improvement associated with lean implementation efforts, as described in the examples below.

- Goodrich Aerostructures sites in California shifted to lean point-of-use chemical management systems to eliminate wasted worker movement and downtime. As an additional benefit, these shifts reduced chemical use and associated hazardous waste generation. Under the lean system, employees in many work areas that require chemical primers, bonders, or other substances receive right-sized amounts - just what they need to perform their job - in work "kits" or from "water striders" that courier materials to the point-of-use. This avoids situations where chemicals are dispensed or mixed in quantities greater than needed, which both decreases chemical use and hazardous waste generation. Goodrich has also worked with suppliers to get just-in-time delivery of chemicals in smaller, right-sized containers. This minimizes the chance of chemicals expiring in inventory. One lean expert from another company estimated that, prior to lean implementation, 40 percent of his company's hazardous waste generation resulted from chemicals that were never productively used (e.g., chemicals that were mixed in excess of the quantity needed, chemicals that expired in inventory). Goodrich's point-of-use and just-in-time chemical management system has enabled the company to eliminate four 5,000 gallon tanks containing methyl ethyl ketone, sulfuric acid, nitric acid, and trichloroethane. This eliminated the potential for large scale spills associated with these tanks, as well as the need to address risk management planning and other chemical management requirements for these tanks under Section 112(r) of the 1990 Clean Air Act Amendments.
- Using *3P*, a Pennsylvania company called Apollo Hardwoods has developed an innovative process and collection of right-sized machines for manufacturing wood veneer panels for cabinetry that require significantly less capital investment in equipment and facilities while enabling the company to use lower cost wood in the process. As additional benefits, the new process and right-sized equipment use less energy and conserve forest resources. A conventional veneer manufacturing process typically relies on large pieces of equipment that typically cost several million dollars. For example, conventional wood dryers typically cost \$1.5 million for a 20 foot by 100 foot oven that blows 180 degree forced air on the wood. These machines typically require 12 foot boards of fine wood for slicing, despite the fact that veneer panels are cut down to smaller sizes for most applications such as cabinets and furniture. The equipment developed at Apollo Hardwoods using the 3P process simplifies the flow of material and improves material yield. By converting the log into veneer in single piece flow, yields are improved and scrap is reduced. Through 3P innovations, the flow time from log to veneer has been reduced by more than 50 percent. In addition, energy consumption has been significantly reduced. (Apollo heats their production plant using natural gas rather than using wood scrap - a rather radical departure from the forest products industry norms.) Their strategic priority of converting logs into finished products with high yield and rapid flow results in the consumption of fewer trees to produce the same amount of product. Apollo's process also is well suited to using a wider variety of log grades, which allows the company to use logs that are more representative of what a given timber stand offers. This matching of the production process to the natural state of the forest also contributes to putting less consumption strain on the forest.

³⁸ U.S. Environmental Protection Agency, August 20, 2000.

- General Motors (GM) has implemented lean manufacturing principles and methods throughout many parts of the company, including its Saturn automotive manufacturing plant in Spring Hill, Tennessee, to reduce production costs, lower process flow time, and improve quality. Environmental performance benefits often accompany lean operational improvements. For example, Saturn now receives more than 95 percent of its parts in reusable containers as a result of implementing a *kanban* system to support its *just-in-time* efforts. This system eliminates tons of packaging wastes each year and reduces the space, cost, and energy needs of managing such wastes. A new process for molding interior plastic parts, designed to reduce process flow time and costs, also eliminated the need for painting. This saved 17 tons per year in air emissions and 258 tons per year in solid waste. Improved “first-time” quality and operational improvements linked to lean production systems reduced paint solvent usage at Saturn by 270 tons between 1995 and 1996. Through continual improvement efforts, Saturn reduced hazardous waste generation from 9.0 pounds per car in 1992 to 3.2 pounds per car in 1996.³⁹

GM’s Purchased Input Concept Optimization with Suppliers (PICOS) initiative has helped many GM supplier companies to implement lean techniques using technical assistance. Environmental benefits typically result from these lean implementation efforts as well. For example, GM worked with a supplier to reduce the flow time and improve the quality of its steering column shroud manufacturing operations. Incorporation of an injection molding step into the manufacturing process eliminated the need to send the parts to an external site for painting. This saved the supplier an estimated \$700,000 per year, while improving quality of the component for GM. The elimination of the time consuming painting step had the added benefit of avoiding paint and solvent usage, waste generation from overspray and clean-up rags, energy use and emissions from transporting the parts for the painting step, and 7 tons per year in air emissions.

Case study findings of environmental benefits stemming from lean implementation efforts are supported by the relatively few empirical academic research studies performed in the U.S.

- Research at New York University’s Stern School of Business, analyzing 17,499 U.S. facilities from 1991 to 1996, uncovered empirical evidence demonstrating a positive link between lean production practices and corporate environmental performance. Specifically, the researchers found that facilities engaging in lean-type quality activities and maintaining low inventory levels generate less waste and have “significantly lower total emissions” than facilities that are not, based on analysis of Toxic Release Inventory (TRI) data. The researchers report that weighting the results by toxicity does not change the findings.⁴⁰
- Researchers at the Rochester Institute of Technology, University of Pittsburgh, and the Massachusetts Institute of Technology examined the link between advanced manufacturing and environmental performance by focusing specifically on automotive assembly plants in the U.S. and Japan. Using statistical analysis and case study techniques, this study found that lean management process improvements contribute to improved production resource efficiency. For example, advanced production methods can result in more efficient use of paints and cleaning solvents for the

³⁹ Saturn Corporation, *Saturn Environmental Report: From the Beginning* (Spring Hill, TN: Saturn Environmental Affairs) 29-30.

⁴⁰ Andrew King and Michael Lenox. “Lean and Green? An Empirical Examination of the Relationship Between Lean Production and Environmental Performance.” Forthcoming in *Production and Operations Management* (September 13, 2000).

industry, which decreases air emissions and hazardous waste. The study did, however, find a more complex relationship between lean implementation and emissions of volatile organic compounds (VOCs). The research suggests that companies implementing advanced manufacturing systems are likely to emphasize pollution prevention over control equipment in meeting air emissions requirements. In this study, lean plants reported that 53 percent of their air emission reductions over a year were achieved through pollution prevention, compared to less than 37 percent for non-lean facilities (which relied more heavily on end-of-pipe pollution control equipment). This is not surprising given lean thinking's focus on eliminating non-value added capital investments. Pollution prevention improvements, on the other hand, are typically tied to value-creating operational and resource productivity improvements.⁴¹

While both lean and non-lean automotive manufacturers in the study maintained air emissions below required levels, the study found some evidence that increased reliance on emissions control equipment (instead of pollution prevention) can lead companies to have lower VOC emissions than companies implementing lean and emphasizing pollution prevention. This results when controls produce emissions reductions in large blocks, which sometimes creates larger margins between emissions levels and regulatory thresholds. On the other hand, lean implementation efforts may lead to greater overall emissions reduction in the longer-term as continual improvement and process optimization efforts incrementally lower emissions. Focus on lean implementation and P2 can also reduce the need for pollution control equipment and the environmental impacts that are associated with building and operating such equipment, such as energy use and criteria pollutant emissions (i.e., in the case of thermal oxidizers). In addition, lean initiatives to reduce flow time such as the 3-day Car initiative are actively driving research into alternative vehicle coating technologies (e.g., thermoplastic panels) that do not produce the VOC emissions associated with solvent-borne painting and coating operations.⁴²

As more companies move to implement advanced production methods, academic interest in the relationship between lean implementation and environmental performance is growing, according to researchers contacted through this project.

Mechanisms for Environmental Improvement Through Lean Implementation

With the expanding evidence consistently demonstrating that lean implementations yield environmental improvements, it seems appropriate to ask what are the mechanisms by which these improvements are being achieved. Conceptually, the link between lean production and environmental improvement is strong. As discussed in Section II of this report, the fundamental objective of lean systems is the systematic elimination of waste by focusing on production costs, product quality and delivery, and worker involvement. At a whole systems level, advanced manufacturing methods work to lower the resource intensity necessary to deliver a product or service to meet customer needs. This means that 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

⁴¹ Sandra Rothenberg, Frits K. Pil, and James Maxwell. "Lean, Green, and the Quest for Superior Environmental Performance." *Production and Operations Management*, 10, no. 3 (Fall 2001).

⁴² Mickey Howard and Andrew Graves, 2001, 1-4.

seven common types of waste that lean works to eliminate, along with the environmental impacts that are often associated with each of them.

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 creativity	Lost time, ideas, skills, improvements, and suggestions from employees	<ul style="list-style-type: none"> Fewer suggestions of P2 and waste minimization opportunities

An analysis of advanced manufacturing methods, accomplished through a review of publications documenting lean methods supplemented by input from lean experts, reveals multiple ways in which each of the lean methods has implications for environmental performance. 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 implementation (see discussion under Observation 2). The results of this analysis of lean methods are documented in Appendix B. These profiles of eight core lean production methods contain sections that discuss the range of potential environmental benefits and drawbacks that can result from implementation of the methods.

Lean Manufacturing's Coattails for Environmental Improvement

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. For example, Goodrich representatives indicated that had the business case for developing right-sized parts washers, paint booths, and chemical treatment baths been based on environmental improvement factors such as reduced chemical use, hazardous waste generation, and air emissions, they would not have been undertaken. In reality, the environmental benefits were not calculated in making the business case. 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. In other words, the business case for change did not enter through the “green door”.

Even in cases where “pollution prevention pays,” such projects often have difficulty competing effectively for limited organization attention and investment resources. As documented in the Natural Resource Defense Council’s Report on the Michigan Source Reduction Initiative, even when P2 and waste minimization projects have very high positive rates of return (e.g., 300 percent) they often are too small in dollar value to capture organizational attention and resources from other larger and higher priority projects.⁴³

Lean implementation efforts, on the other hand, are typically central to an organization’s competitiveness and operational strategy. Interestingly, in discussions with several case study company representatives, it was evident that lean implementation had somewhat altered the process for evaluating and selecting internal projects. Several of the companies have moved away from traditional project evaluation processes that rely on calculating a project’s return on investment (ROI) and comparing it with a hurdle rate. They indicated that many lean implementation projects focused on particular process steps would not compete effectively on these grounds, since the real benefits arise from the optimization of the overall system’s flow and linkage. This is consistent with Joseph Romm’s findings in *Lean and Clean Management* that conventional project evaluation techniques often turn a blind eye to life-cycle costs or the impacts on the whole production system. Doug DeVries from Hyde Manufacturing indicated that lower cost equipment and components frequently have the highest lifecycle costs.⁴⁴ Instead, lean companies seem to have faith in the ability of their intense focus on reducing flow time and eliminating waste to deliver productivity and profitability gains. 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.

Observation 2: Lean can be leveraged to produce more environmental improvement, filling key “blind spots” that can arise during lean implementation

Despite the evidence of significant resource productivity and environmental benefits resulting from lean implementation efforts, there are signals that opportunities for additional environmental improvement are sometimes left untouched. Relative to the environmental performance preferences of public environmental

⁴³ NRDC, 2000.

⁴⁴ Romm, 1994, 158.

management agencies, lean exhibits “blind spots” with regard to environmental risk and product lifecycle considerations. This research identified three key gaps associated with these blind spots, that, if filled, could further enhance the environmental improvements resulting from lean implementation. Furthermore, evidence from the case studies suggests that the marginal effort of explicitly addressing environmental considerations during lean implementation can be low, particularly when compared with efforts to implement similar pollution prevention, waste minimization, and “eco-sustainability” activities in isolation and based primarily on their environmental performance and associated financial benefits. In effect, the complementarity of lean methods and existing voluntary environmental programs and initiatives, such as pollution prevention, waste minimization, Design for Environment, gives lean strong coattails for environmental improvement. In addition, the systemic, continual improvement-based waste elimination culture engendered by lean methods appears to create an effective platform to address environmental risk and lifecycle considerations.

Bridging Environmental Blind Spots and Gaps in Lean Methods

Interviews and case studies indicated that lean methods do not typically include consideration of environmental risk and lifecycle environmental impacts. As illustrated in Figure C, lean methods have a low attentiveness to environmental risks—such as the toxicity of substances—in the production process and in products. While lean implementation often reduces environmental risks (e.g., productivity improvements that reduce chemical use and hazardous waste generation), environmental risk factors are not routinely examined by lean methods. Similarly, lean methods do not typically identify or consider the environmental impacts or costs associated with the extraction of materials used in the manufacturing process, the disposal of non-product output or waste generated during production, or the use or disposal of the resulting product.

Figure C. Lean “Blind Spots”: Risk and Lifecycle Impacts

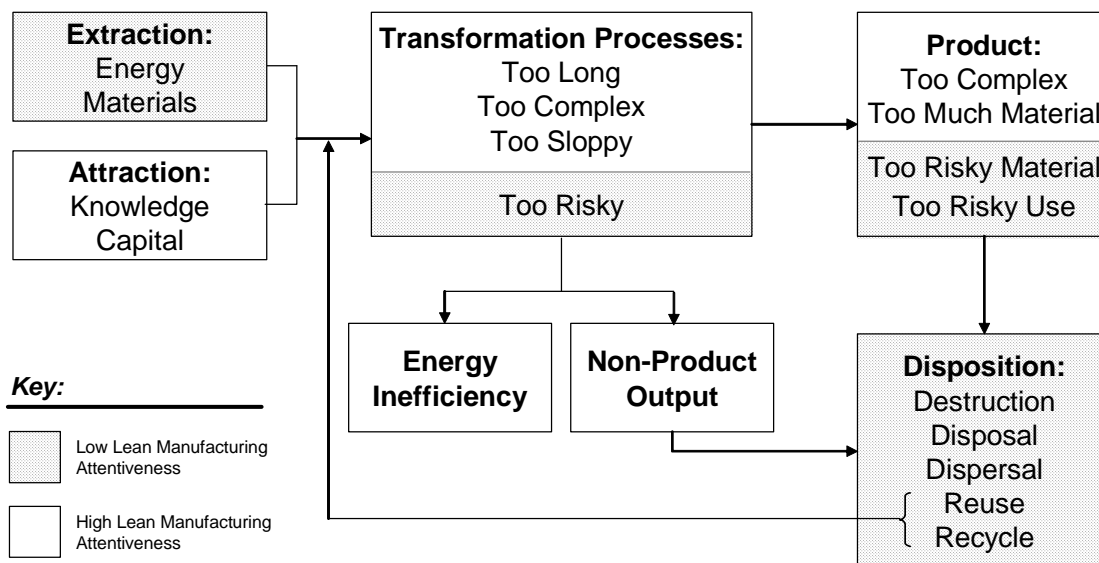


Figure C also highlights several areas in the product or service lifecycle where lean methods do address characteristics that align with the preferences of public environmental regulatory agencies, such as reducing energy inefficiency and decreasing the complexity and material in products.

The interviews and case study research indicate that there are three gaps associated with current lean implementation initiatives that result from lean methods’ lack of attentiveness to environmental risk and

lifecycle considerations. Case study evidence suggests that efforts by public environmental management agencies to address these gaps are likely to enhance the environmental benefits resulting from lean initiatives.

- First, lean methods do not explicitly identify pollution and environmental risk as “wastes” to target for elimination. When one looks at the list of eight common types of manufacturing waste targeted by lean methods (see Table 1 in Section II), it is interesting to note that the list does not include the types of wastes that are commonly targeted by environmental management activities. As representatives from case study companies pointed out, lean implementers often think of waste somewhat differently from the way environmental regulatory agencies think of waste. Pollution endpoints, such as solid and hazardous waste, air emissions, and wastewater discharges, are typically not explicitly addressed by lean initiatives; nor is resource consumption, such as use of materials, energy, and water, directly targeted. All of these environmental waste types, however, are often embedded in the eight manufacturing waste types. For example, as mentioned previously, reducing defects and inventories typically reduces material use, energy consumption, and environmental impacts stemming from unnecessary processing.

Efforts to expand the type of wastes targeted by lean methods to explicitly include pollution and risk are likely to have environmental improvement returns. Several lean experts suggested that by asking the right questions at key points during the implementation of lean methods such as *kaizen* rapid improvement processes and *3P* design sessions, organizations can leverage pollution and risk reductions. For example, a representative from Apollo Hardwoods indicated that *3P* events offer a good opportunity for designing environmental pollution and risk out of a production process or product. *3P* typically involves the development of multiple design approaches that meet customer needs while minimizing time, materials, and capital requirements. By also asking for design options that eliminate or minimize the use of toxic substances, the use of energy and water, or the generation of waste streams, *3P* events can unleash creative energy to reduce further environmental impacts and the life-cycle costs of managing the process or product. For example, Goodrich Aerostructures found that they could meet customer specifications, increase bond strength, and reduce process flow time, while eliminating chrome from some of its anodizing process steps.

- Second, in many organizations, environmental personnel are not well integrated into operations-based lean implementation efforts, often leading environmental management activities to operate in a “parallel universe” to lean implementation efforts. This appears to be particularly true in the early stages of lean implementation, when environmental managers may not be familiar with lean methods being adopted by their organization. As discussed more below, the involvement of environmental personnel in lean implementation efforts can both reduce the risk of non-compliance with environmental regulations and increase opportunities for realizing more environmental benefits through the more explicit consideration of environmental aspects. For example, representatives from General Motors indicated that the company found it beneficial to have personnel involved in their PICOS program, which provides technical assistance to suppliers on lean implementation, trained and mentored by representatives with environmental management expertise on how lean improvements impact environmental performance. Similarly, environmental managers at Goodrich Aerostructures and the Boeing Company reported that they have worked to become more involved in lean implementation activities and to utilize lean methods to implement environmental management practices and systems.
- Third, the wealth of information and expertise related to waste minimization and pollution prevention that environmental management agencies have assembled over the past two decades is not routinely making it into the hands of lean practitioners. The interviews revealed situations where *kaizen* rapid improvement events did not benefit from the extensive pollution prevention, waste

minimization, and Design for Environment information available about the targeted industrial process or activity. Public environmental agencies and non-profit organizations promoting P2 and waste minimization have compiled many specific actions that organizations can take to improve the resource productivity and environmental performance of environmentally sensitive processes. The interviews suggest that this information does not frequently find its way into the hands of lean practitioners, leaving them to reinvent many ideas on their own. For example, rapid improvement efforts at one manufacturer to improve yields in a paint process identified several techniques commonly promoted by pollution prevention advocates, such as optimizing hanging patterns for parts and adjusting spray nozzles to reduce overspray. The interviews suggest that finding effective mechanisms to get process-specific pollution prevention and waste minimization ideas and techniques into the hands of lean practitioners could help seed lean implementation efforts with ideas for both improving resource productivity and environmental performance.

Lean as a Platform for Sustainability

Interestingly, the case studies and interviews suggest that, over time, lean implementation can create an effective platform for addressing sustainability objectives, such as eliminating environmental risk and addressing environmental impacts throughout the product or service lifecycle. After firmly establishing lean methods and processes in their organizations, several companies have found benefits from closing the gaps identified above. The initial lean resource productivity (efficiency) drive established organizational cultures and methods that enabled a smooth transition to what is, in effect, “eco-effectiveness” thinking.⁴⁵

Once environmental personnel gain familiarity and proficiency with lean methods and processes, there is evidence that lean tools can be used to explicitly address environmental objectives such as waste minimization and risk reduction. For example, environmental personnel at Goodrich Aerostructures not only participate on kaizen teams, they have begun to lead *kaizen* events that target specific environmental endpoints such as hazardous waste generation and measurement. Similarly, environmental managers at the Boeing Company have found that the standard work procedures and visual controls implemented under lean provide an effective platform for integrating procedures and information from the organization’s environmental management system.

Lean implementation can also reduce the marginal effort and cost of implementing sustainability activities, such as Design for Environment and Extended Producer Responsibility, to eliminate environmental impacts at the product design stage and to manage products at the end of their productive use. One company found that its lean implementation activities, including 3P “design for manufacturability” techniques, drove many environmental impacts out of its production process, while simplifying its product line to a small number of parts made from recyclable materials. When new government environmental procurement guidelines addressing the company’s product line were adopted in one U.S. state, the company teamed with other companies in its industry to protest the difficulty of meeting the new standards. Much to the company’s surprise, when it assessed its product lines using the new standard, it found that one fully met the standard, and the second barely missed meeting the standard due to formaldehyde off-gassing. The company worked to address the off-gassing and subsequently landed a multi-year contract with the state that is valued at over \$60 million. This experience has led the company to integrate Design for Environment tools and practices into its lean design processes. Company executives now see advanced manufacturing and environmental management tools as complementary and integral to the company’s competitive advantage.

⁴⁵ See McDonough and Braungart, 2002, for a discussion of “eco-effectiveness” and how it relates to “eco-efficiency”.

Even if organizations implementing lean production processes naturally evolve to addressing environmental blind spots and gaps over time, environmental benefits can be enhanced by both ensuring this occurs and by shortening the time it takes for integration to occur.

Observation 3: Lean experiences regulatory friction around environmentally sensitive processes

The conversion to a right-sized, flexible, and mobile operating environment, which is often desired by organizations implementing advanced manufacturing methods, can be complex and difficult to implement around environmentally sensitive processes. Such processes, including painting and metal finishing, typically involve the use, generation, or release of regulated substances (e.g., toxic chemicals, hazardous waste, air emissions) that have the potential to adversely impact worker health and safety and the environment. When organizations consider applying lean methods to environmentally sensitive processes, “friction” can arise in the form of regulatory uncertainty or delay. This, in turn, can result in situations where either the risk of potential non-compliance with environmental regulations is increased, or environmental performance improvements are constrained. This section explores the interface between lean implementation and the environmental regulatory framework, with specific focus on requirements under the Federal Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Clean Water Act (CWA).

Understanding the “Friction” That Can Arise Between Lean and Environmental Regulations

“Friction” associated with the environmental regulatory framework can arise in two primary ways during implementation of advanced manufacturing methods.

First, there can sometimes be confusion or uncertainty over the applicability of certain environmental regulatory requirements or the acceptability of compliance strategies in the context of a cellular manufacturing environment with right-sized, flexible, and mobile equipment. In some cases, this can result from a lack of regulatory precedent for requirements in a lean operating environment. For example, as discussed later in this section, there appears to be recurring confusion over acceptable compliance strategies for satisfying satellite hazardous waste accumulation requirements when implementing a dispersed chemical point-of-use management system. For the most part, environmental regulations and relevant guidance evolved to address conventional mass production processes, where large pieces of equipment are installed and remain in a fixed location. Right-sized machines, on the other hand, are often built on wheels or easy to move skids to increase production flexibility. As such, a mobile, right-sized environment, where multiple small and mobile paint booths and parts degreasers are spread around the plant floor can trigger the need for new compliance strategies to meet regulatory requirements. The uncertainty surrounding environmental obligations can be troublesome in the context, for example, of a lean implementation exercise (such as a *kaizen* event) where quick factory floor changes may face considerable delay while regulatory obligations are researched, or where workers may not fully understand how regulatory requirements may be in play due to certain equipment reconfigurations or modifications.

Second, regulatory time frames can sometimes be poorly aligned with the operational change time frames needed to implement lean methods. Lean methods’ focus on rapid, continual improvement frequently necessitates making rapid, and often iterative, operational and equipment changes. Lag in these improvement time frames can undermine the key drivers for change. For example, *kaizen* improvement events typically depend on making (or “closing out”) all changes within one week to achieve the desired productivity improvements and sustain momentum. Situations where a company must wait weeks for a regulatory applicability determination or months for a permit, permit modification, or other regulatory action can conflict with lean implementation initiatives and valuable waste reduction. In such instances, regulatory

requirements and processes can act as a barrier to systemic, continual improvement efforts that have been promoted for years as critical to sustained pollution prevention progress.

Discussions with lean experts and case study company representatives indicate that there can be a range of responses to these two types of regulatory friction. Frequently, organizations slow down their lean implementation process to accommodate time frames necessary to secure input, approval, or permits from regulatory agencies. At the other end of the range, organizations opt to bypass certain environmentally sensitive processes during lean implementation. In a few cases, companies have participated in innovation pilot projects with EPA and state and local agencies to develop regulatory approaches that are better aligned with the operational and equipment change time frames needed for rapid continual improvement and quick changeovers. For example, automotive manufacturing plants in Spring Hill, Tennessee (Saturn) and Newark, Delaware (DaimlerChrysler) have worked with EPA and State permitting authorities to develop Title V air permits that advance approve broad categories of operational and equipment changes.⁴⁶

The regulatory friction discussed above can have two implications that are likely to be of interest to environmental regulatory agencies. First, the friction can increase the likelihood of organizations being out of compliance with environmental regulatory requirements. This scenario could be exacerbated at organizations where personnel with environmental regulatory expertise are not well integrated into operations-based implementation teams. Second, the friction can lead organizations to delay or not pursue lean projects around environmentally sensitive processes, even when the lean projects would ultimately result in environmental improvements, such as reduced hazardous waste generation, air emissions, or wastewater discharges.

Environmentally Sensitive Processes and Monuments

Research indicates that a relatively limited number of industrial processes have the potential to pose regulatory challenges for organizations implementing lean systems. These include:

- Chemical point-of-use management;
- Chemical treatment;
- Metal finishing processes (anodizing, electroplating, passivation, etc.)
- Painting and coating; and
- Parts cleaning and degreasing.

According to lean experts and company representatives contacted through this research, most regulatory friction appears to arise around the industrial processes listed above. While it appears that some organizations have successfully applied lean methods to some or all of these processes, others have chosen not to apply lean techniques around these processes. Processes that are purposefully excluded from ongoing advanced manufacturing initiatives are often referred to as “monument” processes. Monument processes typically cause a break in the product-aligned cellular manufacturing layout, as product components must leave the one-piece flow production cells to go in batches through the monument process (e.g., paint shop, chemical treatment area), before returning to the cells for continued processing.

⁴⁶ EPA conducted an evaluation of these and other flexible air permits in 2002. See the following websites for information on this evaluation and the DaimlerChrysler and Saturn flexible air permits: <http://www.epa.gov/ttncaaa1/t5/meta/m24005.html>; <http://www.epa.gov/ttncaaa1/t5/meta/m24297.html>; and <http://www.epa.gov/ttncaaa1/t5/meta/m24902.html>.

Lean experts and company representatives were clear to indicate that environmental regulatory factors were not the only factors that can make leaning of environmentally sensitive processes more complex or difficult. Depending on the process, other factors such as the capital cost of conversion, availability of (or complexity of designing) right-sized equipment, OSHA safety requirements, and building and fire codes can also lead companies to postpone or not undertake lean implementation for monument processes. In addition, they did not characterize environmental regulatory requirements as barriers to lean implementation, but rather as factors that can increase the complexity or difficulty of applying lean methods to these processes. The bottom line, however, is that the industrial processes that environmental management agencies are most interested in improving are, for a variety of factors, some of the most resistant to leaning. As a result, substantial performance improvements occur all around these processes while they continue to operate in a less environmentally friendly manner. The sections below examine the interaction of lean implementation and environmental regulatory areas in greater detail.

Several lean experts indicated that, over the past few decades, many companies (particularly small and medium-sized organizations) outsourced environmentally sensitive processes, such as metal finishing and painting, to avoid dealing with the regulatory and environmental and safety management complexities that can accompany these processes. Increasingly, companies implementing lean are finding that such outsourcing can substantially lengthen production flow time, leading them to investigate bringing these processes in-house. This process of bringing environmentally-sensitive processes back in house can encounter the challenges discussed above.

RCRA and Lean Implementation

Regulations and requirements under the Federal Resource Conservation and Recovery Act (RCRA), which addresses the identification, tracking, and management of solid and hazardous wastes, can result in some friction when companies are implementing lean principles and methods. While some friction areas, such as those related to the definition of solid waste or delisting, are not limited to organizations implementing lean production systems, they can emerge during rapid continual improvement events that seek to eliminate various types of waste from a process. In a 1998 EPA survey of stakeholders, RCRA was deemed “the most problematic of the major environmental statutes” due primarily to its “cradle to grave” requirement for the tracking and treatment of hazardous wastes, and the definition of solid waste that forms the basis of determining what substances need to be regulated in such a manner.⁴⁷ While difficulties surrounding regulatory interpretations of RCRA have been an issue for the regulated community for some time (and EPA is aware of and engaged in efforts to address some of these issues), framing concerns in the context of lean manufacturing may be a new and valuable reference point to consider. Interviews and case studies have revealed two primary ways in which RCRA can increase the complexity and difficulty of implementing lean improvements and reducing waste.

Chemical Point-of-Use and Satellite Accumulation of Hazardous Waste. The interviews and case studies indicated that many companies implementing one-piece flow advanced manufacturing methods move to a point-of-use system for managing material inputs to a production process, including chemicals and resulting hazardous wastes. Under point-of-use systems, chemicals are typically stored at or delivered to the point-of-use in small quantities, as opposed to conventional batch and queue systems that frequently utilize centralized chemical disbursement centers. For example, when chemicals are delivered to the point-of-use, they often come in right-sized containers (e.g., containing just the right amount of the material to do the job) as part of

⁴⁷ As quoted in: Environmental Law Institute, *Innovation, Cost and Environmental Regulation: Perspectives on Business Policy and Legal Factors Affecting the Cost of Compliance* (Washington D.C.: ELI, May 1999) 11.

a “kit” for performing the job. Hazardous wastes from the job, or unused chemicals, may be placed back in the kit for collection at the end of a job or shift. While right-sized, point-of-use chemical management systems can often reduce the amount of chemicals used and waste generated, they typically require reorganization of the organizations’ satellite hazardous waste accumulation and management activities.

Interviews with case study organization representatives and lean experts indicated that there can be considerable confusion surrounding the application of RCRA requirements to point-of-use chemical management. Chemical waste in factories is conventionally stored in central locations; this consolidation facilitates the identification of hazardous wastes (i.e., the waste designation process) and subsequent waste management. While RCRA does allow the accumulation of hazardous chemical waste in “satellite” areas “at or near the point of generation [of the waste],” provided such areas are under “the control of the operator,” neither the regulations nor the preamble to the regulations expressly define the terms “at or near the point of generation” or “under the control of the operator” with reference to the distance from the point of generation or the level of control required. Therefore, EPA regions (or more typically, authorized state environmental agencies) evaluate each situation on a case-by-case basis in order to determine if a storage area qualifies as a satellite accumulation area. While this site-specific flexibility is important to the success of satellite accumulation approaches, interviews also revealed that the uncertainty (and potential inconsistency between authorized states) concerning requirements and procedures for satellite accumulation has created confusion among some organizations implementing point-of-use systems.

This study identified three organizations that have moved to lean, chemical point-of-use systems in their facilities, and that have engaged in a detailed analyses of hazardous waste accumulation rules to ensure that they were comfortable with their interpretations of satellite waste accumulation requirements. The interviews and case study discussions indicated that enhanced predictability regarding acceptable compliance strategies in the context of a point-of-use chemical management system would have greatly facilitated this process. They also suggested that increased clarity or guidance would reduce the likelihood of inconsistent regulatory interpretations and lessen the risk of non-compliance.

While uncertainty over acceptable compliance strategies for addressing satellite hazardous waste accumulation requirements in a lean operating environment was clearly the most significant RCRA-related area of friction identified by lean experts and implementers, three other areas were also identified. As mentioned previously, these other potential areas of regulatory friction—definition of solid waste, delisting, and RCRA permitting—are not issues that are new or limited to companies implementing lean systems. Rather, several lean experts indicated that lean implementation can increase the frequency with which these issues surface, due to lean methods’ emphasis on making rapid changes to optimize production processes.

Definition of Solid Waste, Process Improvement, and Reclamation. Determining what is and what is not classified as a hazardous waste is central to the RCRA program. The regulations contain guidelines for answering this question, as well as for determining which wastes are exempt from certain RCRA requirements when recycled in an appropriate manner. Although recycling is encouraged under RCRA, some recycled materials can still pose a threat to the environment and are therefore not always exempt from the definition of solid waste and continue to be regulated. The decision to exempt a recycled substance generally is determined by the manner in which the material is recycled, and the ultimate use of the recycled material. This, however, is not always a clear-cut decision, leaving uncertainty as to the regulatory status of many recycling efforts. This lack of clarity has the potential to result in non-compliance situations for even well-intending manufacturers.

The uncertainty surrounding the “status” of a given substance (hazardous waste or reclaimed material) can be particularly troublesome in a lean manufacturing environment that is focused on rapid continual process improvement. A by-product can, for example, start out (briefly) as a waste and then be reclaimed into a

usable product input that may result in waste or another reusable by-product at the end of the stream. Similarly, although recycling processes are clearly exempt from RCRA requirements, management leading up to an actual recycling process may be regulated. Finally, some recycled hazardous wastes remain subject to certain notable RCRA requirements if they are “used in a manner constituting disposal,” that is, used to make products that will be placed in or on the land as part of their normal use. Determining where recycling processes begin and where management is occurring outside of recycling can be difficult, especially for complex manufacturing processes or systems. This complexity can be exacerbated by the uncertainty of any given interpretation of what constitutes a “waste” (as opposed to a “by product” or other designation), and can impair lean implementers’ ability to drive waste out of certain industrial processes. For example, a representative from one company indicated that reclaiming paint solids and solvents in paint booths, identified as a process improvement area during the company’s lean implementation efforts, has been impeded by the RCRA definition of solid waste that treats the substances as hazardous wastes as soon as they leave the spray guns, thereby requiring both management activities (e.g., inspections and monitoring) and record keeping activities (e.g., waste tracking) during the time that it takes overspray to be collected in the booth and routed to the reclamation system.

There are two other areas under RCRA—delisting and permitting—that were identified by several lean experts and case study company representatives as having potential to affect lean implementation efforts due to the lead times typically associated with these regulatory processes. It should be noted that specific instances where these regulatory processes have actually created friction (e.g., uncertainty or delay) during a lean implementation effort were not found during this research. Several lean experts suggested, however, that there are likely to be ways to streamline or otherwise reduce the lead times associated with these regulatory processes without adversely impacting public participation processes, technical or scientific review, or environmental protections.

Delisting. Part of the waste identification approach under RCRA is to list as hazardous wastes the by-products from certain industrial processes or other sources. These hazardous waste listings are source dependent, based on an assessment by EPA of representative processes or other sources and their wastes, rather than on case-by-case waste stream testing. Because of facility-specific changes in raw materials and process designs, on occasion, wastes from a specific process or source may not exhibit qualities that warrant their management as hazardous wastes, even though it remains listed. In these situations, facility owners/operators can apply to EPA for a site-specific delisting of a waste stream.

The delisting process is facility-specific, and the petition containing information about the waste along with rationale for delisting is initiated by the facility generating the waste in question. The petition undergoes extensive review by EPA or an authorized state environmental agency, and is published in the Federal Register for public review and comment. While recent improvements to the delisting process have dramatically decreased review times, in some situations, delisting can take years to complete and cost a company over \$100,000.⁴⁸ Interviews suggest that this potential expense, coupled with the uncertainty associated with the final outcome (between 1980 and 1999, only 13 percent of delisting petitions made were

⁴⁸ As quoted in: U.S. Environmental Protection Agency, Office of Solid Waste. *RCRA Hazardous Waste Delisting: The First 20 Years*, EPA/530-R-02-014 (Washington DC: US Government Printing Office, June 2002). See http://www.epa.gov/earth1r6/6pd/rcra_c/pd-o/delist.htm for information on various innovations that have been developed to improve the delisting process.

approved),⁴⁹ can inhibit efforts to use delisting as a positive step towards eliminating application of hazardous waste regulations to materials that do not warrant such controls.

Interviews suggest that lead times and uncertainty associated with delisting can create disincentives for discovering innovative processes to reduce the hazardous characteristics of wastes. Interviews also suggested that these issues could be heightened by lean implementation, due to the increased frequency and scope of process and material changes that is often associated with lean implementation. There may also be instances where wastes are rendered less hazardous through application of lean techniques, but where the cost, time, and unpredictability associated with delisting are deemed too cumbersome. Here, lean facilities will continue to be burdened by a disruption in production processes associated with implementing hazardous waste regulations, a disruption that can inhibit other waste reduction as traditionally defined by lean.

It should be emphasized that, as with the discussion of satellite accumulation, above, it is not clear whether the issue with delisting is the actual cost and lead time associated with the decision making or simply interviewees fears and perceptions about potential costs and lead times. In recent years, EPA has undertaken a number of initiatives to improve the delisting process – perhaps increasing awareness of these improvements (rather than additional changes) would be adequate to address the issue.

RCRA Permitting. Interviews indicate that the lead times that are often associated with obtaining or modifying a RCRA permit for waste treatment, storage, or disposal have potential to delay an organization's ability to treat, store, or dispose new types of waste. If rapid material changes driven by lean implementation efforts resulted in the generation of new types of wastes not contemplated in the source's permit, then the organization may be required to ship the new waste off-site for treatment or disposal, rather than being able to use existing on-site capabilities. This activity could be less efficient, more costly for the source, and more risky due to the need to transport the waste to a different site. The interviews and case studies completed for this research effort did not yield sufficient evidence to determine the likelihood of this situation actually occurring or creating friction around lean implementation efforts.

The Clean Air Act and Lean Implementation

The case studies and interviews suggest that potentially the greatest area of environmental regulatory friction that can arise during lean implementation relates to air permitting under the Clean Air Act. Organizations implementing advanced manufacturing techniques are typically engaged in making rapid, and often iterative, changes to processes and equipment. The conversion from a batch and queue mass production layout to a cellular layout generally entails significant movement of equipment, where production activities are rearranged so as to link process steps in the order needed to create a continuous, one-piece flow to make the product. For example, Goodrich Aerostructures representatives reported that the company used a 5-day kaizen event to rearrange a 100,000 square foot facility. In addition to the movement of equipment under such a conversion, new, right-sized, mobile equipment is often introduced to replace larger, less flexible equipment. Such changes in the location and type of equipment, particularly where the process has associated air emissions or the potential to "debottleneck" air emissions elsewhere, can often trigger the need for a major or minor New Source Review construction permit and/or a modification to an existing air operating permit.

In addition to the major operational and equipment changes that often accompany the conversion to cellular manufacturing, ongoing rapid continual improvement events often identify changes to equipment and

⁴⁹ 56 percent of petitions were withdrawn; 15 percent denied; and 13 percent remained incomplete or in process. *RCRA Hazardous Waste Delisting: The First 20 Years* (June 2002).

equipment location. In some cases, this may involve an iterative process where the performance changes from an operational or equipment modification are measured, and based on that information, additional modifications are made to further optimize the process. In most cases, organizations seek to complete actions identified during kaizen rapid improvement events within one week. The need to make rapid operational and equipment changes can also arise when existing product designs are modified or new products are introduced into the factory for production. To accommodate these different rapid change scenarios, right-sized equipment is often built on wheels or easy-to-move skids.

Friction often arises due to the time frames that are typically associated with permitting planned changes, or modifying permits to accommodate them. New Source Review permitting processes in many jurisdictions often take from three to nine months, or longer. These changes are typically significantly out of alignment with the time frames associated with lean implementation efforts, where an organization desires to make the change within one week. This results in situations where either environmental performance improvements are constrained or delayed, or the risk of potential non-compliance with air permitting requirements is increased.

The Clean Water Act and Lean Implementation

The interviews and research for this project did not identify instances where Clean Water Act regulations and requirements create significant friction for lean implementation. One area surfaced during the interviews with lean experts, however, that may warrant further investigation by the EPA. Several lean experts indicated that, over the past few decades, many small and medium-sized companies outsourced environmentally sensitive processes, such as metal finishing and painting, to avoid dealing with the regulatory and environmental and safety management complexities that can accompany these processes. Increasingly, companies implementing lean are finding that such outsourcing can substantially lengthen production flow time, leading them to investigate bringing these processes in-house. The interviews suggest that as they contemplate this change, businesses are often not aware of more environmentally friendly technologies, such as citric acid based passivation as an alternative to nitric acid based passivation,⁵⁰ that may reduce wastewater discharge pollutants and volumes. In addition, even right-sized environmentally friendly technologies may trigger federal effluent limitations (e.g., metal finishing) that require a source-specific NPDES permit (for direct dischargers) or compliance with categorical standards for indirect dischargers, both of which involve more rigorous monitoring requirements. Several lean experts suggested that guidance and other efforts to facilitate the implementation of environmentally friendly technologies in processes such as metal finishing, painting, parts cleaning and degreasing, and chemical treatment may aid companies in reducing production flow times while improving overall environmental performance.

As the above discussions of the relationship between lean implementation and RCRA, Clean Air Act, and Clean Water Act requirements highlight, there appear to be two key implications that are likely to be of interest to environmental management agencies. First, lack of regulatory precedent or clarity around acceptable compliance strategies for lean operating environments can increase the risk of non-compliance

⁵⁰ Passivation is an industrial process that involves the chemical treatment of stainless steel for the purpose of enhancing corrosion resistant properties. Traditionally, a nitric-acid bath is the oxidant used, which removes excess “free iron” contamination from the steel surface, thereby enhancing the steel’s chromium-based layer and its corrosion resistant properties. A citric acid based alternative is available for some applications (e.g., approved in 1999 for some uses in the aerospace sector per SAE specification guidelines) that is non-toxic, non-corrosive, and biodegradable. The citric acid based process can occur at room temperature (requiring less energy) and it takes less time, thereby improving production flow. For a description of one citric acid based passivation technology, see <http://www.stellarsolutions.net>.

situations. For both the company and the regulatory agency, uncertainty and friction increases the overall transaction costs of managing each change in the most environmentally appropriate manner. It is possible, too, that lack of regulatory precedent or clarity in these areas will cause even the most well meaning companies to misinterpret requirements and experience violations, even where environmental improvement has been achieved. To the extent that environmental regulatory agencies can clarify acceptable compliance strategies that accommodate lean operating environments and mobile, right-sized processes and equipment, it is likely that non-compliance situations can be minimized.

Second, environmental regulatory processes that have lead times for providing companies with regulatory information and determinations or source-specific approval (e.g., permits) that are incompatible with lean operating environments can delay or deter lean implementation projects. Where companies are delayed or deterred from leaning environmentally sensitive processes, not only are they less able to address competitive industry pressures, but they also do not realize the waste reduction benefits that typically results from lean implementation. From an environmental performance standpoint, enabling organizations to lean environmentally sensitive processes is likely to have the greatest impacts on reducing hazardous waste and toxic releases. To the extent that environmental regulatory agencies can improve the responsiveness of key regulatory processes, such as permitting and other approvals and applicability determinations, it is likely that more environmental improvement will be achieved faster, while increasing the competitiveness of U.S. businesses.

Observation 4: Environmental agencies have a window of opportunity to enhance the environmental benefits associated with lean

An assessment of lean implementation trends indicates that public environmental regulatory agencies have a key window of opportunity over the next few years to both enhance the environmental benefits and reduce the risk of non-compliance situations resulting from lean implementation. This window of opportunity stems from both the overall status of lean implementation in the U.S., as well as its status within organizations pursuing lean methods. The Recommendations section of this report discusses key opportunity areas that the EPA might consider to advance environmental improvement through lean manufacturing efforts. When contemplating potential actions, EPA may want to consider opportunities to partner with organizations already engaged in promoting and supporting lean implementation among U.S. companies. A strong and growing network of organizations and consulting firms are promoting advanced manufacturing principles and techniques and are assisting companies to implement them. This lean manufacturing network has a shared goal—elimination of waste from business—with the environmental management network promoting environmental improvement, waste minimization, pollution prevention, Design for Environment, and sustainability. At present, however, there is very little coordination or collaboration between these networks.

Ripe Timing for Coordination and Collaboration on Lean and Environment

Lean implementation in the U.S. is past the “early adoption” stage and is becoming mainstream in multiple industry sectors. As previously mentioned, some lean experts indicate that between 30 and 40 percent of all U.S. manufacturers report to have begun implementing lean methods, with approximately 5 percent well down the road of implementing multiple advanced manufacturing tools.⁵¹ Advanced manufacturing methods are sufficiently established in the U.S. for public environmental management agencies to take active steps to engage with lean practitioners and promoters. As more companies and organizations move to implement

⁵¹ Rick Harris, President of Harris Lean Systems, Inc. as quoted by Austin Weber. “Lean Machines,” *Assembly Magazine* (March 2002). Also based on interviews with lean experts (see list of interviewees in Appendix C).

advanced manufacturing systems, occurrences of the friction described in Observation 3 are likely to increase. Failure to address this friction has potential both to increase the likelihood of regulatory compliance violations and to discourage or delay organizations from achieving resource productivity and environmental performance improvements by applying lean methods to environmentally sensitive processes.

At the same time, environmental regulatory agencies have a window of opportunity to work with lean implementers and promoters to incorporate environmental performance considerations into lean methods, tools, resources, and training programs. Small additions to lean methods, such as incorporating questions or design criteria that encourage teams to identify and consider options to reduce risk and pollution endpoints during *kaizen* and *3P* events, create opportunities to achieve more environmental improvement faster. The more time that elapses before this integration occurs, the more environmental improvement opportunities will be left unrealized. In addition, it may become more challenging to leverage modifications to lean methods once they have been firmly established in numerous industries and companies and if lean promotion networks fragment to focus on specific industries or geographical regions. Interviews with lean experts indicate that the demand for and availability of books, videos, computer tools, and publications on lean production is rapidly increasing.

An important window of opportunity for enhancing environmental improvements stemming from lean implementation also relates to the status of lean implementation within organizations. Many companies are in the early stages of lean implementation and are engaged in a transition that frequently takes from five to ten years (or more). At the point where an organization begins the conversion to a cellular, one-piece flow process layout, an important window of environmental performance improvement opportunity opens, while the likelihood that regulatory friction will emerge increases. This conversion typically initiates the acquisition or development of right-sized, mobile equipment and process infrastructure. While interviews indicate that the capital cost of such equipment is often one-twentieth that of conventional equipment, the point of investment in new equipment is a crucial time for the economics of pollution prevention and waste minimization. During the investment in new equipment, the marginal cost of addressing additional environmental considerations is likely to be relatively low. The business case for investing in the right-sized equipment is based on powerful financial drivers that result from improved process flow and linkage. Following the investment, the business case for switching to a more environmentally friendly right-sized machine or lean process approach must rest primarily on the environmental management and regulatory compliance benefits. Once investments have been made, lean companies will likely continue to improve equipment yield and efficiencies, but new investments whose business cases are primarily based on environmental benefits are much less likely to be undertaken.

For example, a company considering a conversion to a right-sized passivation process may not be aware of the citric acid based wash that results in significantly less environmental impact compared to nitric acid based solutions. By investing in a right-sized nitric acid based unit, they miss a potential opportunity for additional environmental improvement while increasing the marginal cost of moving to a more environmentally friendly process down the road. In other words, there is a far greater likelihood of a given company investing in or developing more environmentally friendly lean equipment if they contemplate or are aware of the possibilities *before* their capital investments are made. EPA therefore has a key opportunity to work with companies and organizations supporting lean to incorporate potential environmental and pollution prevention considerations into their investment decisions that ultimately can improve waste reduction results while facilitating even greater economic benefits of lean.

Lean Support Networks as Potential Partners

Fortunately for public environmental management agencies, there are a number of well positioned associations, non-profit organizations, publishers, and networks of lean practitioners and promoters that could be potential partners for public environmental agencies in efforts to enhance further the environmental benefits of lean implementation. Organizations such as the Lean Enterprise Institute, the Association for Manufacturing Excellence, SAE International, and numerous university-based centers are promoting advanced manufacturing techniques through research, publications, and conferences. Productivity, Inc., a leading publisher of lean production materials, offers translations of classic lean books by Japanese lean masters such as Taiichi Ohno, Hiroyuki Hirano, and Shigeo Shingo, along with a full line of lean curriculum materials, tools, and resources. Manufacturing publications such as *Manufacturing News* and *Assembly Magazine* are increasingly publishing articles on lean manufacturing topics. Finally, scores of management and engineering consulting firms have emerged to deliver lean manufacturing consulting services to U.S. businesses.

There are also a few organizations working to bridge lean promotion and support efforts with environmental improvement methods. For example, the National Institute of Standards and Technology's Manufacturing Extension Partnership (NIST/MEP), a nationwide network of not-for-profit manufacturing assistance centers in over 400 locations nationwide, provides training and technical assistance to small and medium-sized companies on lean production. As of June 2002, more than 20,000 business employees have received training on how to implement lean production systems in their organizations. Over the past year, NIST/MEP has developed a new training program for small and medium-sized businesses called "Clean Manufacturing" that integrates environmental considerations into a lean manufacturing framework and methods.

Importantly, as more and more businesses and business sectors are adopting a lean manufacturing mind set, an increasing number of organizations are focused on providing critical support, through conferences, training, publications, and consulting, to facilitate these manufacturing transitions. As mentioned in Observation 2, however, very few of these organizations incorporate environmental considerations into their lean guidance, nor are they positioned to clarify or address regulatory friction that may arise when leaning environmentally sensitive processes. As these organizations continue to build upon their lean production support efforts and tools, the EPA has an opportunity to work with these organizations to optimize the incorporation of environmental considerations into lean methods.

Pitching Environment to Lean Practitioners

Lean is fundamentally about competitiveness, not environmental improvement. Attempting to change this basic premise would undermine the powerful drivers that are compelling organizations to make major changes in organizational culture and production processes. Weakening the engines driving the creation of continual improvement-focused, employee-involved, waste elimination cultures also stands to weaken the environmental benefits that ride the coattails of lean implementation. This has important implications for the manner in which public environmental management agencies approach opportunities to build a bridge between lean and the environment.

As several lean experts suggested, efforts to "paint lean green" are not likely to get far with most lean practitioners and promoters. Instead, public environmental management agencies will be better served by being at the table with practitioners and promoters, seeking opportunities to fit environmental considerations and tools, where appropriate, into the context of operations-focused lean methods. Entering through the "operations door" rather than the "green door" may require some environmental managers to become conversant with lean principles, drivers, and methods, but it is likely to expand markets for environmental tools and information. Such integration may seem somewhat subtle, but opens a significant new market for

the expertise and tools developed by environmental management agencies over the past decades, including P2 and waste minimization techniques, design for environment methods, environmental management systems and procedures, and life-cycle analysis techniques.

That said, the business and economic value of incorporating environmental considerations can be significant. Numerous publications discuss the multiple direct and indirect ways that environmental improvement activities can add value to organizations, ranging from waste disposal cost savings to less tangible value of enhanced company image.⁵² The more that lean practitioners become aware of the business value that can stem from folding environmental considerations into their lean initiatives, the more environmental improvements will result.

⁵² For example, see U.S. EPA Office of Pollution Prevention and Toxics. 1995. *Introduction to Environmental Accounting as a Business Management Tool: Key Concepts and Terms*. Washington, DC: U.S. EPA. and Global Environmental Management Initiative. 1998. *Environment: Value to Business*. Washington, DC: GEMI.

IV. Recommendations

The observations gathered in this report indicate a clear connection between lean manufacturing and environmental improvement. In many respects, lean implementation engenders organizational cultures and operating environments that are very similar to those desired by public environmental management agencies and pollution prevention advocates, and that appear to be effective platforms for advancing sustainability objectives. Furthermore, the evidence suggests that public agencies have an opportunity to leverage more environmental improvement from lean initiatives by addressing key blind spots and gaps, and by reducing regulatory friction that can inhibit organizations' abilities to lean waste out of environmentally sensitive processes. This represents an important opportunity to align the environmental regulatory system to address key business competitiveness needs in a manner that improves environmental performance.

Three primary recommendations, detailed below, capture this opportunity for EPA to enable additional environmental improvement from lean manufacturing endeavors.

Recommendation 1: Work with lean experts to identify and address the environmental "blind spots" that typically arise in lean methods

As mentioned throughout the report, what drives companies to implement lean manufacturing is not the environmental improvement that results, but the substantial profitability and competitiveness gains that driving time and capital out of the product production and service delivery process creates. The objective of Recommendation 1 is not to change the perspective of lean implementers so that environmental considerations become their primary goal, to turn lean practitioners into environmental experts, or to overtly make lean *green*. This could run the risk of dampening the powerful profitability and competitiveness drivers that lean depends on to drive nearly complete cultural and operational overhaul within organizations. Instead, the goal is to ride these powerful coattails by filling the gaps between lean objectives and environmental improvement opportunities. By filling these gaps, EPA can ensure companies engaging in lean are attentive to environmental considerations and aware of environmental performance improvement opportunities such that they are more likely to seek the support of environmental professionals, and more likely to be cognizant of ways to incorporate important environmental questions and criteria into their leaning endeavors. With such a "bridge," it is anticipated that environmental agencies will be in a better position to ensure even greater environmental improvement can result from lean manufacturing. This can begin by training select EPA staff in the fundamentals of lean methods, so a common language can be developed, and so that staff are better able to identify ways existing agency programs can work to further incorporate environmental benefits and pollution prevention expertise into lean initiatives.

By addressing the few environmental blind spots and gaps in lean manuals, publications, training, and lean implementation, environmental regulatory agencies have an opportunity to harness even greater environmental improvement from industry lean implementation efforts. To address this opportunity, EPA should consider involving "lean experts" in developing and implementing strategies for raising awareness among companies of opportunities to achieve further environmental improvements while leaning, and developing books, fact sheets, and website materials for corporate environmental managers that articulate the connection between lean endeavors and environmental improvements. More specific actions the EPA can take to facilitate this process include:

- Develop an action plan for raising awareness among companies of opportunities to achieve further environmental improvements during lean implementation. Engage "lean experts" (academics, consultants, industry organizations, companies, right-sized equipment suppliers, publishers) in developing and implementing a strategy and action plan for raising awareness among companies of

opportunities to address the key gaps discussed in Observation 2 of this report and to achieve further environmental improvements during lean implementations. The goal would be to have key lean promoters incorporate key environmental information and tools, where appropriate, into their methods, publications, and/or consulting approaches.

- Develop resources, fact sheets, and website materials that highlight important environmental questions and criteria that can be incorporated into lean methods. Such materials would articulate the connection between lean endeavors and environmental improvements, and explains ways in which additional environmental considerations can potentially be incorporated into lean manufacturing methods. Questions could draw on EPA's substantial pool of waste minimization and P2 methodologies that could be considered in the context of a kaizen event (e.g., Does the process have waste streams? If so, what are the pollutants? Can materials with lower toxicity be used? Can they be reduced or eliminated?). Identify and disseminate P2 guidance and resources applicable to environmentally sensitive processes (e.g., painting and coating, parts cleaning, chemical treatment) that are most frequently targeted for leaning.
- Develop and disseminate resources and tools for pollution prevention and environmental practitioners to help them better understand and become more proficient in lean manufacturing techniques and benefits. Such resources could introduce P2/environmental practitioners to key lean methods (e.g., kaizen, 5S, TPM, standard work, visual control systems, cellular manufacturing, JIT/kanban, Six Sigma, 3P, lean enterprise/supply chain, design for manufacturability), profile links to environmental performance for each method, and articulate recommendations for working with lean manufacturing managers to identify and realize optimal environmental improvement from lean implementation.
- Partner with organizations engaged in promoting lean manufacturing such as the Lean Enterprise Institute, the Association for Manufacturing Excellence, Productivity Press, the Shingo Prize for Manufacturing Excellence, and NIST's Manufacturing Extension Partnership to develop and adapt lean tools, training, and conference sessions to address or incorporate environmental performance topics.
- Conduct explicit outreach (e.g., materials, conference presentations, workshops) to corporate environment, health, and safety (EHS) managers to raise awareness about techniques they can use to integrate environmental considerations into their companies' lean initiatives.

Recommendation 2: Develop a pilot/demonstration program to encourage companies who are implementing lean to achieve more waste reduction and P2 by explicitly incorporating environmental considerations and tools into their lean initiatives.

EPA can help build the bridge between lean manufacturing initiatives and environmental management by assisting companies who are implementing lean to achieve more waste reduction and P2 through the explicit incorporation of environmental considerations and tools into their lean initiatives. Beginning a pilot/demonstration program with specific companies could open avenues for putting the wealth of pollution prevention expertise, techniques, and technologies developed in recent decades for driving waste and risk out of these processes into the hands of lean practitioners who are engaged in process innovation. By building such a "bridge," environmental agencies will be better positioned to understand lean implementation processes and to realize greater environmental improvement result from lean initiatives. Specific pilot/demonstration activities could include:

More specific examples of actions EPA could consider to address recommendation 1 are listed below.

- Expand existing EPA waste elimination initiatives by incorporating lean considerations. For example, EPA could seek to involve more companies implementing lean into the National Waste Minimization Partnership Program and WasteWise Partnership Program by inviting the participation of lean practitioners. EPA could also work with existing current partnership members implementing lean to better understand the waste minimization implications of lean and to identify opportunities for enhancing these benefits.
- Document and disseminate case study examples of companies that have successfully integrated environmental activities into lean. In addition, EPA could explore and highlight case study examples that illustrate how companies have effectively used lean as a platform for implementing environmentally sustainable tools (e.g., life-cycle analyses, Design for Environment, etc.).
- Partner with selected industry sectors and associated organizations in which there is large amount of lean activity to improve the environmental benefits associated with lean. For example, EPA could explore partnership opportunities with the Lean Aerospace Initiative or the Society for Automotive Engineers to bridge lean and the environment in these sectors.
- Expand individual EPA initiatives, such as OSWER's "Greening Hospitals" initiative, by integrating waste reduction and product stewardship techniques into the organizations' lean initiatives. This effort could include conducting a pilot project with a hospital implementing lean, designed to integrate waste reduction and product stewardship techniques into its lean initiatives. The resulting lessons could then be publicized for the benefit of other hospitals.

Recommendation 3: Use pilot projects and resulting documentation to clarify specific areas of environmental regulatory uncertainty associated with lean implementation and improve regulatory responsiveness to lean implementation.

This research identified that there are certain environmentally sensitive processes that can be difficult for companies to lean due to a lack of regulatory certainty and/or regulatory response times. Such regulatory "friction" can not only hinder a company's profitability, but can also stand in the way of achieving optimal environmental improvement. To facilitate common goals of factory efficiency and environmental gain, EPA can initiate efforts to promote greater clarity and responsiveness to lean initiatives that will touch environmentally sensitive processes. To understand the nuances and effectively tailor guidance and regulatory innovation in this area, it will be useful to work with specific companies in "pilot project" mode that will best facilitate an understanding of "friction" areas, and result in the most effective solutions. Pilot projects could involve one company with the environmentally-sensitive process, plus appropriate local, state, regional, and federal environmental agency representatives. Companies would be recruited if they have encountered regulatory friction or anticipate encountering friction associated with an upcoming "lean implementation."

Using pilot projects with specific companies, EPA can address specific areas of environmental regulatory uncertainty associated with lean implementation as well as improve regulatory responsiveness to lean implementation. EPA can then communicate the results of such endeavors through guidance documents for companies implementing advanced manufacturing methods that clarify the appropriate regulatory procedures for leaning environmentally-sensitive processes, and replicable models for reducing the lead times associated with certain regulatory processes. More specific actions EPA can take to facilitate this process include:

- Develop guidance that clarifies acceptable approaches for addressing RCRA satellite hazardous waste accumulation requirements in the context of implementing lean chemical point-of-use management systems. This could involve analyzing the relationship of RCRA to material point-of-use management systems by working with different companies who have begun to implement, or are about to implement, chemical point-of-use management systems.
- Develop replicable models for reducing the lead times associated with air permitting and other regulatory processes to accommodate the lean transition to mobile, right-sized operating environments. Such efforts could help harness lean implementation efforts to drive waste from environmentally sensitive processes, while reducing the pressures that can result in non-compliance with environmental regulations. In addition, these efforts could draw on regulatory innovations developed as part of other initiatives, such as the air permitting techniques developed and piloted through EPA's Pollution Prevention in Permitting Program (P4).
- Develop documentation regarding acceptable compliance strategies for applying lean methods to other environmentally sensitive processes, including painting, chemical treatment, and metal finishing.

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Appendix A: Lean Terms and Definitions

Batch and queue	The mass production process of making large lots of a part and then sending the batch to wait in the queue until the next operation in the production process begins. Contrast with single-piece-flow.
Bottleneck	Any part of a production line that adversely affects throughput. See also <i>constraint</i> .
Cell	An arrangement of machinery, tools, and personnel designed to most logically and efficiently complete a production sequence. Cells help enable <i>single-piece flow</i> .
Cellular Manufacturing	An approach in where manufacturing work centers (cells) have the total capabilities needed to produce an item or group of similar items; contrasts to setting up work centers on the basis of similar equipment or capabilities, in which case items must move among multiple work centers before they are completed.
Chaku-Chaku	A method of conducting single-piece flow, where the operator proceeds from machine to machine, taking the part from one machine and loading it into the next.
Changeover Time	The time that elapses between the completion of one production run and the beginning of another production run.
Constraint	Anything that limits a system from achieving higher performance, or throughput.
Cycle Time	The amount of time to accomplish the standard work sequence for one product, excluding queue (wait) time. If the cycle time for every operation in a complete process can be reduced to equal takt time, products can be made in single-piece flow.
Inventory	The money the system has invested in purchasing things it intends to sell.
Just-in-Time	A production scheduling concept that calls for any item needed at a production operation – whether raw material, finished item, or anything in between, to be produced and available precisely when needed.
Kaikaku	Japanese for “radical improvement of an activity,” designed to eliminate waste.
Kaizen	The incremental and continual improvement of production activities aimed at reducing waste, and designed around planned, structured worker-oriented events. Japanese for “to take apart and make good.”
Kanban	A card or sheet used to authorize production or movement of an item. See also <i>Kanban System</i> .
Kanban System	A system that controls production inventory and movement through the visual control of operations. See also <i>Kanban</i> .
Large Lot Production	The manufacture of the same product in large quantities during a single, designated period of time.
Lead Time	The total amount of time it takes to complete an order for a customer.
Lean Supplier Network	A buyer-supplier relationship where designated lean production protocols, supporting sustained interactions between members, helps produce a network-based competitive advantage.
Mistake Proofing	Technology and procedures designed to prevent defects and equipment malfunction during manufacturing processes. Also known in Japanese as <i>Poka-Yoke</i> .

Monument	A production machine or tool that is difficult and/or costly to move (e.g., into a single-piece flow) due to its size or other physical constraint. Often, materials must instead be brought to the monument in batches.
Muda	The Japanese term for any human activity which absorbs resources, but creates no real value, i.e., “waste”; activities and results to be eliminated. Within manufacturing, categories of waste include: excess and early production; delays, movement and transport; poor process design; inventory; inefficient performance of a process; and defective items.
Non-Value-Added	Activities or actions taken that add no real value to the product or service, making such activities or actions a form of waste.
Point-of-Use	A system in which all necessary supplies, chemicals, etc. are within arm’s reach of the worker, and positioned in a logical sequence of use.
Poka-Yoke	See <i>Mistake Proofing</i>
Pull Production System	A production system in which nothing is produced by the upstream supplier until a need is signaled by the downstream customer. See also <i>Kanban</i> .
Right-sized	The matching of production tooling and equipment in a scale that enables its use in the direct flow of products such that no unnecessary transport or waiting is required.
Queue Time	The time a material spends waiting in line for use in the production process.
Single-Piece Flow	A situation in which products proceed, one complete product at a time, through various operations in design, order-taking, and production, without interruptions, backflows, or scrap. Also known as <i>one-piece flow</i> .
Supply Chain	A group of all suppliers involved in the manufacture of a product, beginning with the simplest part and ending with the production of the final product.
Takt Time	The available production time divided by the rate of customer demand. Takt time sets the pace of production to match the rate of customer demand and becomes the heartbeat of any lean system.
Value Stream	The set of specific actions required to bring a specific product through three critical management tasks of any business: problem solving, information management, and physical transformation.
Visual Controls	Displaying the status of an activity so every employee can see it and take appropriate action.
Work In Progress (WIP)	Production material in the process of being converted into a saleable product.

Appendix B: Lean Experts and Case Study Companies

Lean Experts Interviewed

George Koenigsaecker
Lean Investments LLC

Jeff McAuliffe
Swedish Medical Center

Ross Robson
Shingo Prize for Excellence in Manufacturing

Sandra Rothenberg
Rochester Institute of Technology

Kevin Spencer Smith
Productivity, Inc.

Conrad Soltero
Texas Manufacturing Extension Center

Gregory Waldrip
Manufacturing Extension Partnership
National Institute of Standards and Technology (NIST)

Judy Wlodarczyk
The Connecticut State Technology Extension Program (CONNSTEP)

James Womack
Lean Enterprise Institute

Companies Addressed by Case Studies

Apollo Hardwoods Company

General Motors Corporation

Goodrich Corporation - Aerostructures Group

Warner Robins U.S. Air Force Base

Appendix C: Case Study Summaries

Apollo Hardwoods Company

Background

- The start-up of Apollo Hardwoods in 2003 provides a unique example of a business enterprise designed and launched with lean principles in mind from the beginning. The company is applying lean production techniques to manufacture custom “cut-to-size” cherry plywood for cabinetry made from fine northwestern Pennsylvania cherry wood.
- Ed Constantine founded Apollo Hardwoods in Pennsylvania after leading numerous lean implementation efforts at HON INDUSTRIES and with Simpler Consulting (a lean consultancy which he founded) and Lean Investments LLC.
- Apollo Hardwood's founders and investors saw the wood products manufacturing industry as an industry ripe for the successful application of lean techniques. First, veneer manufacturers typically have significant capital tied up in large “monument” processes and equipment (e.g., slicers, dryer ovens). Second, wood products manufacturers generally carry large inventories of wood which requires substantial space and can result in damage or spoilage to inventories. Third, the manufacturing processes typically result in significant amounts of wood scrap and waste, which is often burned for energy recovery. It became apparent that because the 12 foot slices produced by the conventional process and equipment were ultimately trimmed down to a usable (less than 6 foot) size, using a veneering process that is “right-sized” to more usable dimensions would not only require smaller, less expensive equipment, but also will allow the business to use a much wider variety of logs all while obtaining similar quality end-results.

Conventional Veneer Manufacturing

- The conventional veneer panel manufacturing process typically consists of six main steps:
 - (1) Slicing. The log is cut into a square and left to soak in 160oF water for up to several days. The log, up to 12 feet long, is then held horizontally in a vice-like fixture. A razor sharp blade then vertically slices the log into veneer.
 - (2) Drying. Veneer is fed into large dryer ovens designed to reduce the moisture content of each piece to facilitate a strong, permanent adhesive bond.
 - (3) Lay-up and Gluing. When the veneers have been dried to their specified moisture content, they are conveyed to a lay-up operation, where a urea-formaldehyde adhesive is applied. The pieces are then glued to a plywood core.
 - (4) Pressing. The laid-up assembly of veneers is then sent to a press designed to press the glue into a thin layer. After being unloaded from the press and after cooling, panels are trimmed to precise sizes.
 - (5) Sanding. To smooth raised grains and/or remove glue from the surface, the panel product is often sanded using manual or automated sanders.
 - (6) Grading. After sanding, the plywood is graded and prepared for storage or shipping.
- A conventional veneer manufacturing process typically relies on large pieces of equipment (e.g., hot water soaking tanks, veneer slicers, drying ovens) that typically cost several million dollars. For example, conventional wood dryers typically cost \$1.5 million for a 20 foot by 100 foot oven that blows 180 degree forced air on the wood.

- The primary environmental impacts from conventional veneer manufacturing include air emissions, energy use, and run-off. The primary source of air emissions are organic compounds from the drying process. The type and quantity of emissions depends on the wood species and type of dryer, but are typically ducted through separate stacks (for heating zones and cooling sections). Hot pressing operations also release some volatile organic compounds (VOCs), but these emissions typically remain uncontrolled. Particulate emissions (PM) typically result from log debarking, cutting and sanding, and drying and pressing. Organic compound emissions (formaldehyde and other hazardous air pollutants) can also result from gluing and hot pressing. Sawdust and other small wood particles are generated by cutting and sanding operations, which are typically controlled and collected to use as fuel. Wood storage piles can also be a source of PM and VOC emissions. Uncontrolled runoff can also result from large inventory piles, because unused logs need to be sprayed with water to prevent cracking.
- Another environmental dimension of cherry veneer manufacturing is the deteriorating supply of black cherry trees in Pennsylvania. Although the Allegheny Plateau contains some of the highest quality black cherry trees in the world (particularly well suited for high quality veneer), their supply is limited. In part, this is because conventional veneer manufacturing practices require high quality, defect-free logs that can produce 12-foot veneer slices. This length requirement, in turn, frequently requires companies to harvest large diameter mature black cherry trees.
- Veneer products can provide environmental benefits by significantly reducing the consumption of slow growing, high quality hardwoods. With veneer which is typically 1/42" thick, one hardwood tree can cover approximately 20 times as much furniture when compared with using solid hardwoods. Often, veneer is laminated onto cores of particle board or mdf which often contain a combination of wood waste products and chipped up low grade logs. Putting lower cost faster growing species in the core of a veneer-covered furniture component is good for the forest.

Applying Lean Principles to Veneer Manufacturing

- Apollo Hardwood's founders see an opportunity to significantly reduce the amount and cost of capital required for veneer manufacturing. This opportunity stems from lean principles that emphasize making capital investments only where necessary and when necessary, allowing for the highest possible return-on-investment. This strategy is particularly relevant to start-up companies, where one of the quickest routes to profitability is minimizing capital costs while producing a quality product. Conventional manufacturing wisdom might lead a company to buy larger equipment, so that the plant can accommodate production increases. Lean thinking, however, suggests that the company may be better served by investing in capital needed for current production, and adding additional capital incrementally to meet growth needs. This lean strategy relies heavily on the availability of "right-sized" (and sometimes mobile) equipment that can be easily replicated (and improved) at significantly lower cost when compared with large, conventional equipment (e.g., "monuments").
- Conventional debarking, cutting, slicing and drying equipment have many attributes of monuments, and these processes were targeted by Apollo Hardwoods. The goal was to find a less capital intensive process for slicing and drying veneer that would also address other business needs such as product quality, flow time, and cost. Since such a process and associated equipment were not available, Apollo Hardwoods sought to develop them in-house using the lean method typically referred to as 3P (pre-production planning). The 3P method was initially developed as part of the

Toyota Production System, and it focuses on optimization and waste elimination at the product and/or process design stage.

- Apollo Hardwoods recruited a team to assist in a series of 3P events to design a lean veneer slicing and drying process and associated equipment. Team members were carefully selected to ensure that the team did not have too much familiarity with conventional veneer manufacturing methods, which could limit creativity during the 3P events. Success parameters were set for the 3P events that articulated the desired takt time (i.e., the rate at which product must be turned out to satisfy market demand) and a dollar limit for building the process equipment.
- The 3P team assembled for a week-long event to work through the following steps. First, the team described and mapped the steps necessary to produce veneer, and brainstormed key words to describe each step, such as “shave” and “cut.” Second, the group went through a “back to nature” step in which they considered where in the natural world these processes took place. For example, they identified that beavers' tree gnawing activity resembles the slicing activity that they were trying to mimic in the plant. Research at the local library revealed useful information about beaver cutting “techniques.” The team found that beaver teeth have a harder enamel layering on the front sides of their teeth than on the back, enabling their teeth to self-sharpen and to therefore be “built to wear.” Third, the group engaged in a “try-storming” exercise in which they developed prototype equipment to test various approaches and techniques identified through earlier brainstorming activities. For example, the team mocked up a slicing tool, with the metal on one side of the blade harder than on the other, mimicking beavers' teeth. The team tested and evaluated the various prototypes, and eventually selected those that appeared to be most promising for meeting the success criteria defined at the beginning of the 3P event. Following the 3P event, the process of building actual production equipment from the 3P prototypes began. The 3P method was also applied to the drying process with similar results.
- By applying lean principles and methods to veneer manufacturing, Apollo Hardwoods has achieved significant results. Production is arranged in one-piece flow cells, where production operates in a continuous flow with no piling of inventory in-between process steps. The equipment comes in at approximately half the capital intensity of the industry's conventional machinery, has much lower energy demands, and fits into small production cells that can be easily replicated to accommodate production increases. The machines also work with smaller pieces of wood that require less trimming to meet customer size specifications. This means that Apollo will use less logs to deliver the same amount of finished product. The right-sized equipment and smaller veneer pieces also significantly reduce the amount of wood scrap generated. Whereas most veneer companies burn their wood scrap for energy recovery, Apollo sees high quality cherry wood as an expensive energy source. By reducing wood scrap and energy use through lean implementation, the company is creating a highly competitive business model that significantly lessens the environmental impacts of veneer manufacturing.
- Apollo Hardwoods indicated that future lean improvement events will likely target other aspects of the production process, such as the gluing process. In particular, the company is interested in finding ways to reduce formaldehyde emissions by exploring alternative adhesives in the future.

General Motors Corporation

Background

- General Motors Corporation (GM) has one of the most wide-spread lean manufacturing initiatives in place in the U.S. GM grew interested in lean manufacturing in the early 1980s, as it examined elements of the Toyota Production System that had been adopted by several Japanese auto manufacturers.
- In 1994 GM and Toyota formed a joint venture called the New United Motor Manufacturing Inc. (NUMMI) to pioneer implementation of lean methods at an automotive manufacturing plant in the U.S. Compared to a conventional GM plant, NUMMI was able to cut assembly hours per car from 31 to 19 and assembly defects per 100 cars from 135 to 45. By the early 1990s, the success of NUMMI, among other factors, made it increasingly clear that lean manufacturing offers potent productivity, product quality, and profitability advantages over traditional mass production, batch-and-queue systems. By 1997, the “big three” U.S. auto manufacturers indicated that they intend to implement their own lean systems across all of their manufacturing operations.
- Since the early 1990's, GM has worked actively to integrate lean manufacturing and environmental initiatives through its PICOS Program (described below). In addition, GM's WE CARE (Waste Elimination and Cost Awareness Reward Everyone) Program complements lean implementation efforts at GM facilities, as many projects result in both operational and environment improvements. The WE CARE Program is a corporate initiative that formalizes Design for the Environment and Pollution Prevention efforts into a team-oriented approach.

Example Lean Projects and Results

- *Saturn Kanban Implementation.* Saturn's Spring Hill, Tennessee automotive manufacturing plant receives more than 95 percent of its parts in reusable containers. Many of these reusable containers also serve as kanban, or signals for when more parts are needed in a particular process area. This “kanban”-type system eliminates tons of packaging wastes each year and reduces the space, cost, and energy needs of managing such wastes. Saturn has also implemented electronic kanban with some suppliers, enabling the suppliers to deliver components “just-in-time” for assembly. For example, seating systems are delivered to the shop floor in the order in which they will be installed. Saturn also found that improved “first-time” quality and operational improvements linked to lean production systems reduced paint solvent usage by 270 tons between 1995 and 1996.
- *Fairfax Assembly Paint Booth Cleaning.* At GM's Fairfax Assembly Plant, paint booths were originally cleaned every other day (after production) to prevent stray drops or chips of old paint from attaching onto subsequent paint jobs. It was discovered, however, that the automated section of the painting operations really only needed to be cleaned once a week, as long as the cleaning was thorough, and larger holes were cut in the floor grating to allow for thicker paint accumulations. The reduction in cleaning frequency facilitates improvements in the process “up-time” and flow. As an additional benefit, through this and other more efficient cleaning techniques, use of purge solvent decreased by 3/8 of a gallon per vehicle. When combined with reductions achieved by solvent recycling, VOC emissions from purge solvent reduced by 369 tons in the first year following these adjustments.

- *Application of Lean Methods to Administrative Processing in the Purchasing Group.* In addition to applying lean thinking to manufacturing processes, GM has looked at ways to lean its internal administrative processes. For example, GM's purchasing group investigated the company's Request for Quote (RFQ) processes by which supplier products are sought. Because each RFQ has to include a detailed listing of system requirements, RFQ's under the prior paper-based system could be quite large, ranging in size (in total paper "thickness") from 3/4 of an inch to 6 inches thick.

Upon applying a value stream mapping and analysis, GM identified a number of ways in which this process produced an excessive amount of waste. Not only did it require GM to purchase and use a great deal of paper, but also incurred costs and used raw materials associated with printing and packaging, in addition to cost and energy required to deliver each package to each potential supplier. GM's solution was to transform the RFQ process into an electronic-based system that is not only paperless, but that avoids the additional costs and waste associated with printing, packaging, and shipping each RFQ. Using an internet-based system called Covisint, GM is able to improve procurement efficiency while lowering costs by saving time and eliminating waste. By distributing RFQ's electronically, GM estimates that the company will save at least 2 tons of paper each year.

- *Lean Enterprise Supply Chain Development.* In the early 1990s GM assigned a group of engineers to work more closely with its suppliers to reduce costs and to improve product quality and on-time delivery. GM realized that it was not sufficient to just lean GM's operations, as GM (and the customer) directly bears the costs of supplier waste, inefficiency, delays, and defects. This effort has involved over 150 supplier development engineers conducting lean implementation workshops called Purchased Input Concept Optimization with Suppliers (PICOS). As part of PICOS, small teams of GM engineers visit GM suppliers for several days to conduct training on lean methods and to lead a focused kaizen-type rapid improvement event. Follow-up was conducted with the suppliers at 3 and 6 months to determine if productivity improvements had been maintained, and to assist with additional process fine-tuning.

Over time, GM found that having an engineer involved in the PICOS program who is familiar with environmental management provided important benefits for leveraging additional environmental improvement from the PICOS events. By working with suppliers on environmental improvement, GM has also, among many things, been able to promote the use of returnable shipping containers in lieu of single-use, disposable ones; communicate GM's guidelines for designing for recyclability and broadly disseminating its list of restricted or reportable chemicals; and communicate success stories to the supplier community as examples of what can be done. GM also announced recently that by the end of 2002, suppliers will be required to certify the implementation of an EMS in their operations in conformance with ISO 14001. GM is currently developing a broader supply chain initiative, with involvement from EPA and NIST, that some participants hope will become a vehicle to integrate technical assistance on advanced manufacturing techniques and environmental improvement opportunities. Two PICOS events are described below.

- *Steering Column Shroud PICOS Event.* GM conducted a PICOS rapid improvement event with a key supplier to enhance the cost competitiveness and on-time delivery of steering column components. The GM team used value stream mapping and the "five whys" to assess the existing process for steps that cause long lead times and delays. The assessment revealed that the supplier shipped the steering column shrouds (or casings) to an outside vendor for painting prior to final assembly with the steering column, adding significant flow time to the production process. Using the "five whys" technique, the team asked why the shrouds needed to be painted in the first place. The answer was "because the die (plastic mold) creates flaws that need to be covered." This led the team to a simpler, less wasteful solution - improve the quality of the die, and mold the part using

resin of the desired color. After some research, and capital investment of \$400,000, the supplier incorporated an injection molding process for the shrouds into the assembly line, eliminating the need for the time consuming painting step. This project saved the supplier approximately \$700,000 per year, while shortening lead times and improving on-time delivery to GM. This lean project produced environmental benefits, although they were not needed to make the business case for pursuing the project. Elimination of the painting process step also eliminated 7 tons per year of VOC emissions from the painting process step, all hazardous wastes associated with the painting process step (including clean-up rags, overspray sludge, off-spec and expired paints), and environmental impacts associated with transporting the shrouds to the painting vendor and back.

- *Thermoplastic Color Purging PICOS Event.* While working with a supplier to reduce lead times and improve quality for the production of a thermoplastic molded component, a GM-facilitated team found additional waste elimination opportunities associated with color changeovers. At this time, the suppliers' operations were running seven days a week to meet customer demand. The team found that each time the supplier changed resin colors to produce a new batch of parts, as many as 5 to 10 large plastic parts needed to be scrapped. The accumulated scrap typically would fill a 30 yard dumpster every day, resulting in \$3,000 to \$4,000 per week in disposal costs. In addition, the supplier consumed more resin than necessary, contributing to higher material costs. By focusing the rapid improvement event on streamlining the die set up and color changeover process, the team was able to reduce the need to run overtime shifts to meet customer demand while eliminating a significant waste stream, as well as the extra resin and processing associated with the scrap.

Goodrich Corporation - Aerostructures Group

Background

- Goodrich Corporation is a leading global supplier of nose to tail products and services to the aerospace industry, making everything from landing gear to evacuation systems and flight controls to engine satellite systems. Major customers include commercial, military, regional, business, space, and general aviation aircraft manufacturers, operators, and suppliers. The company is also a globally recognized premier supplier of aircraft maintenance, repair and overhaul services. Goodrich Aerostructures, a division of Goodrich Corporation, is the world's leading independent full-service supplier of nacelles, pylons, thrust reversers, and other structural aircraft components.
- In the early to mid-1990s, customer pressure to improve performance at the Rohr Riverside, California facility was of such concern that management evaluated options that included moving work and closing the plant. Airframe & engine customers were putting increasing pressure on the plant to improve its production activities. While attending a Lean Manufacturing training seminar offered by James Womack's Lean Enterprise Institute (see www.lean.org) the General Manager of the facility realized that the continuous improvement efforts that they had started were in fact a "rudimentary model" of the Toyota Production System. Soon after this, the Riverside plant began to implement Lean Manufacturing techniques with vigor.

Lean Implementation at Goodrich

- In 1995 and 1996, the Riverside plant worked to aggressively implement lean techniques, adapting tools from the Toyota Production System. Efforts expanded as early successes and productivity improvements won increasing commitment from company senior leadership. Later in 1996, Goodrich Aerostructures began applying lean techniques to administrative processes at the Riverside plant. In 1997, Goodrich Aerostructures moved to improve alignment of its organizational culture, structure, and strategy with its expanding lean operational initiatives through policy deployment. By 1999, Goodrich Aerostructures was expanding lean implementation efforts throughout many of its U.S. production facilities, and lean enterprise, and the ability to continually improve, was becoming a core competency of the organization. Since 2000, efforts have focused on continual improvement and "value stream alignment"-structuring the organization around value streams (e.g., pylon components for Boeing's 757 airplane, or nacelle components for Airbus A319, A320, A321) instead of around a conventional functional orientation (e.g., milling, chemical treatment).
- Goodrich Aerostructures managers indicated that the impending crisis of facility closure was a powerful driver for the transition to lean. Significant focus and energy were necessary to implement the "mechanical" aspects of change, including (1) linkage and flow of process steps, (2) right-sizing of tooling and equipment, (3) identification of standard work, and (4) the implementation of visual controls. Company representatives reported, however, that the "cultural" aspects of change, including (1) leadership role, engagement and behavior, (2) employee engagement, and (3) real time problem resolution, have proven to be most challenging. As one strategy to address the cultural aspects of change, manufacturing managers and engineers have moved their offices out to the shop floor, improving real time problem resolution. Even with senior management support and commitment, however, changing organizational culture requires substantial effort and powerful drivers.

- As part of its lean implementation efforts, Goodrich Aerostructures uses a variety of tools which the company has adapted from the Toyota Production System. Goodrich Aerostructures managers indicated that “policy deployment provides focus, alignment, and linkage. Lean tools provide the means to identify and eliminate waste.” Rapid improvement events serve as a key tool for driving a waste elimination-focused culture change. For example, Goodrich Aerostructures facilities conduct more than 350 kaizen rapid improvement events each year to identify and eliminate waste from particular business and production processes. Goodrich Aerostructures also uses 3P (Pre-Production Planning), which focuses on eliminating waste through process and product design. In these rapid improvement efforts, employee teams are encouraged to move toward the “least waste way”.
- As the use of lean tools became a mainstream part of facility operations, company Environmental, Health, and Safety (EHS) personnel have worked to integrate EHS considerations and needs into lean tools and initiatives. For example, EHS objectives must be identified for each kaizen event and recorded on the “scope sheet” for the event. Efforts are also made to involve EHS personnel in events that are likely to have important environmental dimensions, risks, or opportunities. More recently, Goodrich Aerostructures has begun to use kaizen and other lean techniques to explicitly target EHS issues, expanding the lean definition of “manufacturing wastes” to include environmental wastes and risks (see Hazardous Waste Minimization Kaizen Event summary below). As another example, a safety kaizen event included having a team identify trip hazards in the plant and mark them with helium balloons to raise employee awareness and to ensure their elimination.
- Goodrich Aerostructures managers identified an interesting transition at the plants that has moved them away from the use of conventional “return-on-investment” (ROI) decision-making for determining whether to make operational or capital improvements. Many change projects are now driven by company lean continuous improvement efforts, with attention paid to process flow and linkage, cycle times, and other capital productivity metrics, as driven by Policy Deployment, instead of relying solely on a conventional ROI-based project proposal and approval process. An interesting question is “do traditional accounting practices provide an balance sheet rather than a tool to manage a business ?”

Examples of Lean Initiatives and Results

- *Conversion to Product-Aligned Cellular Manufacturing.* As part of its lean focus several Goodrich Aerostructures sites have dramatically changed the manufacturing layout of their facilities. The conversion from a batch and queue mass production layout to a one piece pull, cellular layout generally entails significant movement of equipment. In this lean approach, production activities are rearranged into cells which link process steps in the order needed to create a continuous, one-piece flow to make the product. Instead of big centralized departments and machines for milling, parts cleaning, painting, and other process steps, small, “right-sized” machines are placed where they are needed in production cells. In effect, the cellular approach brings the process to the product component, rather than continually moving and storing the product component to take it through process steps.

At Goodrich Aerostructures Chula Vista, California facility, several production cells include right-sized painting and degreasing stations. Referred to as “little houses on the prairie,” these movable (on metal skids), enclosed stations enabled workers to degrease and paint small parts without needing to take them to large, centralized degreasing tanks and paint booths. This creates substantial improvements in productivity, with ancillary environmental benefits associated with

reduced chemical and paint use, waste generation, and air emissions since the equipment is sized to clean and paint the particular components produced in the cell.

Goodrich Aerostructures representatives indicated that had the business case for developing right-sized parts washers, paint booths, and chemical treatment baths been based on environmental improvement factors such as reduced chemical use, hazardous waste generation, and air emissions, they would not have been undertaken. In reality, the environmental benefits were not calculated in making the business case. 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. In other words, the business case for change did not enter through the “green door”.

Significant productivity benefits, a primary driver for the conversion, improve the “flow and linkage” of production process steps. For example, metal skins for the Boeing 717 fan cowls traveled 17,000 feet through the plant and took 43 days to manufacture. Following the conversion to cellular manufacturing, the metal skins travel 4,300 feet and are made in 7 days. In addition, since products and parts typically are not produced in large batches in cellular manufacturing, inventory needs are dramatically reduced, freeing up plant floor space.

As a result of its conversion to a cellular manufacturing layout, Goodrich Aerostructures consolidated the manufacturing operations at the Chula Vista facility into two buildings from five while doubling output as a result of implementing lean methods. This decreased overall facility space needs by more than 50 percent, enabling the facility to sell property to the city for waterfront redevelopment.

In most situations, reconfiguration of the manufacturing layout requires rapid, and sometimes iterative, change. Conversions must be made quickly to reduce production downtime. For example, Goodrich Aerostructures Group's San Marcos plant reconfigured the production layout of its 100,000 square foot facility in one week-long kaizen rapid improvement event. To facilitate such a massive and rapid configuration, the plant assembled a cross-functional team that included diverse skill-sets ranging from fork lift operation to electrical work to plumbing. Iterative changes are often necessary to optimize the cellular layout, or to accommodate the addition of new production cells.

- *Standard Work and Visual Controls.* A core element of lean manufacturing at Goodrich Aerostructures has focused on reducing the variability in work practices by identifying standard work. In some cases, standard work procedures are documented in easy to read, laminated checklists affixed in production cells. Goodrich Aerostructures representatives indicated that they seek to incorporate environmental, health, and safety activities directly into standard work practices. Other visual controls are added throughout the plant to ensure that standard work practices are followed and to keep the facility well organized. For example, “kits” are assembled for workers that include only those parts, tools, and chemicals needed to perform their standard work practice. The primary driver for the use of kits is to save time and ensure consistent quality by eliminating the need for the workers to “chase down” parts, tools, and materials or to use tools or materials that are not optimal for the job. At the same time, there are numerous environmental benefits that can result from standard work and visual controls. For example, standard work, visual controls, and kits can significantly reduce waste from defective work, scrap material, and packaging. With “everything in its place,” trip and spill hazards are also reduced. Goodrich Aerostructures representatives provided numerous examples of environmental benefits that resulted on the coattails of lean

implementation efforts, although these benefits did not factor into the business case for change and were seldom quantified. It should also be noted that standard work and visual controls do not eliminate opportunities for workers to exercise creativity, since they are engaged in defining their standard work practices, developing associated visual controls, and working to continually improve these systems through kaizen rapid improvement events.

- *Lean Chemical Management.* Goodrich Aerostructures facilities in California shifted to lean point-of-use chemical management systems to eliminate wasted worker movement and downtime. As an additional benefit, these shifts reduced chemical use and associated hazardous waste generation. Under the lean system, employees in many work areas that require chemical primers, bonders, or other substances receive right-sized amounts - just what they need to perform their job - in work "kits" or from "water striders" who courier materials to the point-of-use (sometimes on tricycles). This avoids situations where chemicals are dispensed or mixed in quantities greater than needed, which both decreases chemical use and hazardous waste generation. Goodrich has also worked with suppliers to get just-in-time delivery of chemicals in smaller, right-sized containers. This minimizes the chance of chemicals expiring in inventory. At one California plant, Goodrich Aerostructures point-of-use and just-in-time chemical management system has enabled the company to eliminate four 5,000 gallon tanks containing methyl ethyl ketone, sulfuric acid, nitric acid, and trichloroethane. This eliminated the potential for large scale spills associated with these tanks, as well as the need to address risk management planning and other chemical management requirements for these tanks under Section 112(r) of the 1990 Clean Air Act Amendments.
- *Hazardous Waste Minimization Kaizen Event.* Now that kaizen rapid improvement events have become a routine aspect of plant operations, EHS personnel are beginning to explicitly target environmental waste streams and risks with lean techniques. For example, one kaizen event in 2002 focused on conducting a rapid assessment of hazardous environmental waste streams at the plant. Activities during the 2-day kaizen event included (1) identification of all hazardous environmental waste streams in a portion of the plant, (2) estimation of the total costs associated with managing these waste streams, (3) survey of staff about hazardous waste management practices, and (4) development of measurements to track progress toward reducing waste streams. Follow-on activities and kaizen events have identified and implemented various pollution prevention and process improvement techniques that target reductions in priority waste streams.
- *3P and Product & Process Design.* Goodrich Aerostructures has increasingly focused lean thinking on the design of products and processes. Lean techniques, such as 3P, are being used to eliminate waste-including materials, time, and complexity-out of products from the beginning. In some cases, Goodrich Aerostructures involves representatives from its customers or supply chain in these design events to ensure that diverse perspectives and needs are considered. In some cases, rethinking product and process design can produce significant environmental benefits. For example, Goodrich found that they could meet customer specifications, increase bond strength, and reduce process flow time, while eliminating chrome from some of its anodizing process steps. Product & Process Design continues to be a significant focus for Aerostructures. Designing parts, products, processes and supportive processes & systems that provide the opportunity to maximize the return to the business by, amongst other things, minimizing E,H & S issues is of paramount importance. This aspect of the business is reaping rewards much beyond expectations.

Warner Robins U.S. Air Force Base⁵³

Background

- RAFB is home to the Warner Robins Air Logistics Center, a major depot for repairing aircraft and producing spare parts for the U.S. Air Force, and is the largest industrial complex in the State of Georgia. Occupying about 85 percent of the installation (and employing 11,600 workers), the Air Logistics Center manages the Air Force's F-15 fighter aircraft, C-141 and C-130 transport aircraft, 11 types of cargo and utility aircraft, 4 series of helicopters, 3 types of remotely piloted vehicles, and 8 missile systems. Robins AFB is also the exclusive technology repair center for Air Force airborne electronics, gyroscopes, and life support systems.
- Faced with base closures, outsourcing of military repair and maintenance operations, and pressures to avoid the need to purchase new aircraft while increasing the number available for service, RAFB began to implement lean in the late 1990s.

Example Lean Projects and Results

- *Lean and the C-5.* In its first round of lean projects, RAFB improved resource productivity in targeted aircraft repair and maintenance shops by 30 percent to 50 percent and saved \$8 million in the F-15 wing shop alone in the first year. Maintenance "flow days" for the C-5 cargo plane dropped from 360 days to about 180 days. As part of this effort, RAFB implemented numerous projects that have (1) eliminated or reduced the use of hazardous chemicals, (2) reduced raw material consumption, (3) eliminated or reduced waste generation and/or emissions from a process, and (4) significantly reduced facility space needed for these operations. In addition, the reduced flow time increases the availability of C-5 aircraft by 180 days for every period between servicing, reducing the overall number of planes needed.
- *Applying Lean to the C-130 Hercules Aircraft Paint Shop.* RAFB lean teams used an adapted version of 5S, called "Six S" (safety, straighten, sort, scrub, standardize, and sustain), to begin applying lean to its C-130 aircraft paint system. 24 instructional classes were conducted on lean, and 44 new initiatives came from mechanics as a result. These initial lean projects reduced flow days; increased production and worker safety; reduced emitted VOCs; reduced excess tools, materials and equipment by 39 percent; reduced the number of chemicals used from nine to three, as well as the overall amount of chemicals used; reduced storage space by 228 square feet; and generated \$373,800 in direct operating savings.
- *Plastic Media Blast (PMB) Paint Stripping.* Dichloromethane (methylene chloride) was once the base's primary means of removing paint from aircraft and parts. Annual use of dichloromethane was over one million pounds, with a large amount of resultant hazardous waste. In applying lean to maintenance operations, RAFB sought approaches that would both reduce flow time and lessen environmental risk. The base identified the PMB method as an optimal lean process to remove paint from the F-15 fighter aircraft. This method uses compressed air to blast small beads of plastic at the painted surface and works well on aircraft with thicker skins (e.g., fighters) but not on thin-

⁵³Information in this case study was drawn from several articles and web sites, including: "Lean Takes Root At Warner Robins AFB," *Manufacturing News*. Volume 8, No. 20, November 16, 2001; Lanorris Askew, "C-130 Paint Shop Leans Into Cutting Flow Days," *Aerospace News and Review, Journal of Aerospace and Defense Industry News*. January 4, 2002; also see <http://www.robins.af.mil/index.htm>.

skinned aircraft (e.g., C-130 and C-141 transport aircraft). The spent PMB with paint chips is shipped to a manufacturer who uses the PMB/paint chip mixture to make a variety of plastic fixtures such as bathroom accessories.

- *Alternate Depaint System.* RAFB is taking other steps to further lean and improve the environmental performance of its paint removal activities. There are two main layers of paint on an aircraft: the primer coat and the top coat. The primer coat contains strontium chromate for corrosion protection, and the topcoat is for appearances. Finding a method that only removed the topcoat but leaving the primer coat intact, could save a great deal of time and money, reduce hazardous material consumption, reduce hazardous waste generation and reduce health risks to the work force—providing a good example of ways in which lean objectives and environmental objectives are frequently aligned. The base is researching a two phase system that will allow it to remove the topcoat, leaving the primer coat intact. This will be accomplished by using medium pressure water (12,000 pounds per square inch pressure) with a semi-automated removal machine and a barrier coat that can be applied over the primer coat. RAFB estimates that the project will reduce the number of man-hours to depaint an aircraft by 15 percent the amount of hazardous material used by 50 percent.
- *Next Steps.* Based on the success at RAFB, the U.S. Air Force is moving aggressively to implement lean throughout its network of logistic centers, and beyond. The drivers include:
 - The Air Force can significantly increase the percentage of its total aircraft fleet that is available for use at any given time without purchasing more aircraft due to the reduction in repair and maintenance flow days (saving billions of dollars).
 - RAFB has demonstrated that lean can shave millions of dollars off logistic center operating budgets of by increasing efficiencies and reducing material costs.
 - Lean has successfully fostered a continual improvement-based waste elimination culture that engages employees from all parts of the organization and that can continue to achieve performance improvements.