

Chapter 1 LEAN

Learning Objectives

- Define and explain lean principles
 - Define and explain Just-In-Time (JIT) principles
 - Explain the relationship of lean and JIT
 - Describe the JIT/lean productivity cycling process
 - Describe lean methodologies
 - Use process and value stream mapping
 - Describe and explain the value of group technology
 - Describe tools of Six Sigma
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Introduction

In this textbook we use the term *lean* as a noun. We will be defining what lean is throughout this chapter, but for purposes of a beginning, a brief definition of *lean* is a means of waste identification (e.g., wasted labor, materials or some resource) in operations (e.g., manufacturing, service, administration, etc.) so that it can be removed (i.e., made lean) for greater efficiency. Lean is a dynamic process of continual change and is not a standardized, one-size-fits-all approach. It is an adaptive means of efficiency improvement.

The origin of the concept of lean or lean thinking cannot be easily assigned to any one person, company, or nation. Lean is the sum of millions of business organizations and their people who over many years have made contributions to the concept. Most practitioners and researchers would support the claim that Toyota Corporation of Japan has been and continues today to be the standard bearer of lean. Because of Toyota's heightened lean status, much of our discussion in this textbook will be focused either directly or indirectly on what Toyota does to nurture lean in their operations.

What Is Lean?

Lean has been referred to in the literature as a process, project, program, principle, approach, methodology, and philosophy. Don't be confused! Depending on the

lean application, it is all of these. Lean can be applied to individual processes, individual departments or entire organizations as a project for short-term efficiency improvements. Lean can be extended into longer-term programs where projects are undertaken to permanently install lean for continuous process improvement. Lean is also a set of principles, approaches, and methodologies that can be applied individually or collectively. When lean principles are used as an approach to management they are continuously applied and can become a long-term philosophy for guiding organizations toward world-class performance.

Origins of Lean Principles

The underlining principles that are the foundation of lean began in Japan during the 1950s with manufacturing firms that wanted to make maximum use of limited resources available at that time. A set of waste removal guidelines emerged, which were collectively referred to as Just-In-Time principles. The name *Just-In-Time* (JIT) refers to resource utilization, that is, units of material, subassemblies, and components arrive in a manufacturing setting “just in time” for their use. Suppliers deliver their supplies just in time for their use in production, and customers receive finished products just in time for their convenient use. Hence, there is no wasted movement of materials, use of labor or equipment, or idle inventory in a JIT system. All resources arrive just in time for their consumption.

The body of JIT principles initially evolved from manufacturers’ shop floors dealing with common shop floor production issues. These typical manufacturing issues dealt with inventory (see Table 1), production (see Table 2), human resources (see Table 3), and quality (see Table 4). Eventually, as those JIT principles took hold in manufacturing plants, JIT principles expanded to include longer-term considerations like facility design (see Table 5). For example, it is difficult to adopt JIT quality principles without considering the use of facility principles like the use of automation in facilities to improve quality. Continuing to expand outside the organization, JIT principles were added to include suppliers (see Table 6). Again, it is difficult to adopt unitary production and scheduling JIT principles without considering the external suppliers that must deliver materials in a way to support unitary production.

JIT authors (Schonberger, 1982; Wantuck, 1989) generally agree that JIT principles did not just appear all at once, but evolved on a continuous basis over many years. To understand lean principles, you also must understand JIT principles as lean is viewed as a synonym for JIT (Hanna and Newman, 2007, p. 632).

Some authors believe that JIT principles are limited to manufacturing or production systems (Hanna and Newman, 2007, pp. 630–635). In this view, JIT is

Table 1. Select JIT inventory principles

JIT Inventory Principle	Explanation
Seek reliable suppliers.	Having reliable suppliers allows for a reduction in the number of suppliers and the associated costs. It allows for less contingency inventory and frees up capital avoiding wasted interest cost.
Seek reduced lot sizes and increased frequency of orders.	Smaller more frequent deliveries (if they are reliable) reduces average inventory and those costs (e.g., insurance). It allows firms to need less physical facility space, reducing the waste of those costs.
Seek zero inventories and reduce buffer and work-in-process inventory.	Ideal goal in JIT is no inventory to completely eliminate all inventory costs. Other than work-in-process (WIP) inventory, the less inventory there is, the less cost of inventory
Seek improved inventory handling.	Avoiding damage to inventory avoids spoiled goods and helps to maximize product flow.
Seek to continuously identify and correct all inventory problems.	Continuous improvement is a requirement of JIT.

Table 2. Select JIT production principles

JIT Production Principle	Explanation
Seek a synchronized pull system.	The ideal goal is synchronizing demand and production to no units of product until an order is given, which eliminates unneeded production, unwanted inventory, and all the waste associated with them.
Seek improved flexibility in providing product changeovers and in scheduling production.	The faster changeovers and scheduling changes can be implemented, the less likely it is to waste production effort on unwanted goods, and the more likely it is to capture market share by offering customers what they want, when they want it. Utilizing <i>mixed model scheduling</i> (i.e., where multiple products can be produced without major changeovers in a production cell) is one of many JIT strategies.
Seek uniform daily production scheduling.	The smoother the production rate is, the less likely the need for overtime and other wasteful resource reallocations in making production changes from one day to the next.

Table 2. (Continued)

JIT Production Principle	Explanation
Seek improved communication.	The faster that managers can communicate solutions to problems, production changeovers, and new production processes, the faster unwanted and wasteful action will be removed from the system.
Seek reduced production lot sizes and reduce production setup costs.	Reducing lot sizes motivates employees to find better and more efficient changeover and setup processes. Also, the smaller lot sizes allow the manufacturer to ship smaller amounts of finished goods to customers. Ideally, under JIT one would seek a unitary production level, which would allow the greatest possible flexibility in responding to changing customer demands.
Allow employees to determine production flow and schedule work at less than full capacity	Permitting employees to determine the production flow and giving them some extra time at less than full capacity permits them to spend time finding better ways to do their jobs and perform expected quality control tasks expected under JIT.
Increase standardization of product processing.	Where possible, standardization of product processing can greatly increase productivity.
Seek improved visualization.	Making production efforts (i.e., employee performance on productivity and quality) available to the employees allows them to understand their individual contributions. This helps to identify methods for improving production and wasteful actions that reduce productivity. It is also used to motivate employees by allowing them to see how well their performance is based upon comparative statistics with other employees.
Seek to continuously identify and correct all production management problems.	Continuous improvement is a requirement of JIT.

internally applied within the manufacturing organization on immediate, first tier suppliers that directly impact internal operations (e.g., frequent delivery of small orders) and with distribution or warehouse operations that receive finished goods inventory for later distribution to final customers. This limited relationship is depicted in Figure 1. Other authors (Schniederjans and Olson, 1999, pp. 69–103) claim that JIT has been and continues to be applied in a broader context throughout

Table 3. Select JIT human resource principles

JIT Human Resource Principle	Explanation
Seek to establish a family atmosphere to build trust, empowerment, and pride in workmanship.	An environment of mutual respect of all employees will result in more willingness to contribute to team problem solving and product and process improvements that will lead to higher production quality. As management continues to empower employees to make suggestions, they will understand their suggestions are recognized and contribute to the final product.
Seek long-term commitment to employ all employees.	In an environment where employees are comfortable and believe their jobs will be around tomorrow, they will be more willing to suggest innovations to save time and avoid waste, even if such suggestions might reduce labor needs.
Maintain a substantial part-time workforce.	During shifts in demand, the number of part-time employees can be quickly adjusted to reduce wasted human resources in downtimes (i.e., It stops layoff costs of full-time employees.) or can be increased rapidly during demand surges with little cost (e.g., reduces expensive overtime).
Establish compensation plans that reward individual and team efforts. Encourage employee team approach to problem solving.	The more closely compensation is tied to efforts, the more likely the employees will see the benefits of the efforts they contribute. Team problem solving is particularly valuable for complex issues. Compensation must be focused on motivating collective team efforts.
Provide continuous and extensive training.	Better trained employees permit greater flexibility in work assignments, less wasted waiting time and more efficient work.
Seek to continuously identify and correct all human resource problems.	Continuous improvement is a requirement of JIT.

the entire *supply chain* (i.e., a set of sequentially related operations) similar to that of lean principles.

Lean Principles

Lean principles at Toyota evolved out of their *Toyota Production System* (TSP). There are many different principles, but we will group our presentation into four

Table 4. Select JIT quality principles

JIT Quality Principle	Explanation
Seek long-term commitment to quality control efforts.	Enhancing product quality is a never ending task. Seeking better quality than competitors may be a goal that will take years to achieve. Everyone in the organization must accept that it is only through better quality that firms are able to successfully compete.
Use fail safe methods to help ensure quality conformity.	Automation is one example of a failsafe method that can greatly improve product quality in areas of production where precision is critical.
Utilize statistical quality control methods to monitor and motivate product quality.	Utilizing quality control charts to show the number of defects can be used by managers to monitor progress, but can also be used to let employees know how good (or bad) they are doing in regard to product quality. The goal should always be to maintain process control and strict product quality compliance of product specifications.
Maintain 100 percent quality. inspection of products through <i>work-in-process</i> (WIP) efforts.	Having robots or employees at each station along a production line checking the work of the prior station ensures that quality defects are found quickly, thus reducing waste in rework and scrap. It also ensures that each product has been 100% inspected for quality.
Seek to make quality everybody's responsibility. Seek to empower workers by sharing authority in the control of product quality.	Empowering the employees by seeking their help in the quality inspection process helps to give them greater responsibility for the finished product (i.e., They generally will take greater ownership.). With that responsibility self-correction of worker-generated defects should be required in order that they may learn from their mistakes. They should also be required to perform routine maintenance and housecleaning duties to ensure tools and facilities are available and in a condition, which leads to the highest level of performance (e.g., a sharp knife cuts clean).
Seek to continuously identify and correct all quality related problems.	Continuous improvement is a requirement of JIT.

Table 5. Select JIT facility design principles

JIT Human Resource Principle	Explanation
Seek a focused factory.	Limiting the number of products a manufacturing facility produces permits economies of scale and improved efficiency.
Identify and eliminate production bottlenecks.	Any production bottleneck creates wasted labor and technology by slowing down the production system as a whole.
Seek to maximize flow through layout.	By minimizing material flow congestion through designing replenishment systems closer to the point of use avoids wasted labor and technology. Reducing distance between all production activities saves time and helps speed flow of goods.
Use automation (i.e., robots) where practical.	For jobs that are highly repetitive or require a high degree of precision, automation will save labor and reduce wasted materials (i.e., scrap).
Use group technology cells (i.e., U-line or C-cells) in production layouts.	Group technology cells permit flexibility in layout and setup changes for new products. They also make better use of flexible employee skills by allowing ease in reassignment crossovers from one side of the cell to the other.
Seek continuous redesign efforts to improve facility layout and facility structure.	Continuous improvement is a requirement of JIT.

Table 6. Select JIT supplier relation principles

JIT Supplier Relation Principle	Explanation
Seek certification in quality of items purchased.	Certification provides insurance that the goods coming into a production facility have already passed some quality inspection. Many JIT operations only do business with JIT suppliers.
Seek timely communications and responsiveness.	Under JIT, production firms produce items in small lot sizes, so they seek smaller lots with more frequent deliveries from suppliers. They will also seek ordering flexibility responsive to their production needs as well as customers' needs.

Table 6. (Continued)

JIT Supplier Relation Principle	Explanation
Seek single-source suppliers.	<p>This in turn will allow the production firm to minimize inventory and require suppliers to further reduce inventory delivery lead time. The more responsive the supplier, the less inventory is needed by the manufacturing firm.</p> <p>By having a single-source supplier a manufacturer can save the wasted time and effort of dealing with multiple suppliers and can exert greater pressure (i.e., by virtue of the greater business) to motivate suppliers to reduce the cost of goods.</p>
Seek long-term relationships with suppliers.	<p>Having a long-term relationship with a supplier allows the supplier to know they can count on the business of the manufacturer, which in turn allows them to better customize service to the manufacturer. It also helps the supplier to reduce the cost of capital, since bank financing is easier for them when they have a major, long-term client.</p>
Seek to continuously identify and correct all supplier relation problems.	<p>Continuous improvement is a requirement of JIT.</p>

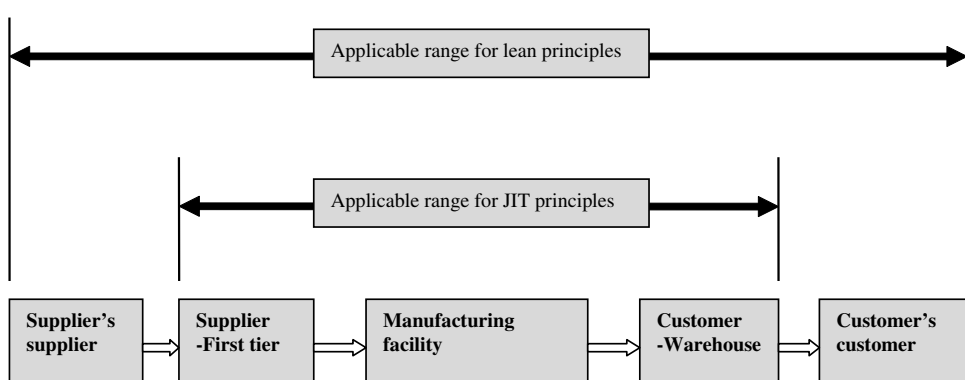


Figure 1. Supply chain comparison of lean and JIT principles applicability

broad categories: seek the elimination of waste, seek improved quality, seek increased product flow, and seek reduced cost.

Seek the Elimination of Waste

By eliminating wasted resources from any manufacturing or service system, we can immediately increase that system's productivity. If we increase productivity while reducing the resource inputs into the system, we reduce costs, which are passed along to the customer in terms of lower prices, resulting in an increase in market share that will improve profitability in the long-term. This has been a driving strategy of all Japanese manufacturers that have embraced lean principles.

Toyota classifies waste into seven major categories:

1. Waste from Inventory: *Idle stock* (i.e., buffer stock or any inventory that is not being used), which results in extra storage and handling labor as well as equipment needed to maintain it
2. Waste of Motion: Any unneeded movement of resources caused by factors such as misplaced or lost tools or an inefficient work station layout
3. Waste from Overproduction: Making additional inventory for back-up purposes that may never be consumed
4. Waste of Processing: Any scrap or wasted labor caused by unnecessary processing or procedures, rework, or repairs from damage incurred during the production process
5. Waste from Production Defects: Any product returns because of poor quality or engineering
6. Waste of Transportation: Any time wasted moving resources around a poorly designed plant floor layout
7. Waste of Waiting Time: Any time wasted by employees waiting for parts along an assembly line or from a supplier

Of these seven, Wantuck (1989, p. 24) views the greatest waste of all is overproduction. Why? Because it leads to the other types of waste listed above. If we produce too many products, we waste motion moving them to inventory. We waste processing of a product that may never be consumed. We waste transporting it to distribution centers where it may never be distributed to a final customer. We waste the costs of storing an inventory item, paying taxes on it, insurance, heating and security. We also incur unnecessary costs, like the cost of capital in the labor and materials in the product. All of that waste is incurred when a unit of product is overproduced.

Seek Improved Quality

Under this lean principle the goal is to eliminate sources of defects, errors and contributors to variation in the production processes. Why? Consider a situation where defective component parts are delivered to a manufacturing facility. This poor quality disrupts production schedules and reduces yields (e.g., extra production runs because of shortages due to defective items), slows the speed of product flow in the system (e.g., defective components do not always fit in modules that they were engineered to fit), adds to overall processing time (e.g., time wasted on scrap work due to poor quality), and wastes space (e.g., increased idle stock and buffer inventory of parts given that greater scrap will be required to make up for poor quality). Alternatively, if the quality of component parts are perfect, then fewer will be needed (e.g., no need for buffer stock), product flow will increase (e.g., no wasted labor time dealing with defective components), and production space can be reduced (e.g., no need for buffer inventory areas).

How do we seek improved quality? We design processes to avoid mistakes caused by human or mechanical error. We focus on identifying causes of variation in production processes and eliminate them. We work with suppliers to ensure their quality.

Seek Increased Product Flow

Lean operations need to be responsive to market changes. They need to be agile and able to quickly change processes and products as changes emerge from operations and market demand. Embodying the JIT ideas of having the supplier deliver items just in time for their use in production, manufacturing producing the product just in time for shipping to the customer, and order pulling the product through the system just in time for its use are supported by the notion of increasing the product flow in an operation.

How do we achieve increased product flow? One way to meet this goal is to design a production system that will maximize the flow of the product through operations quickly and efficiently. This might require information technology that would synchronize not only internal production operations, but all external supply chain partners as depicted in Figure 1, the supplier's supplier and customer's customers. Everyone pulls together to keep the various WIP and finished inventory in a constant movement toward the final consumer. This system might also require

the JIT approach to scheduling production and movement through operations in order to minimize wasted time.

Seek Reduced Cost

As we reduce wasted labor time, equipment, physical space or any resource, there is a corresponding reduction in the cost of the process. With lean, movement of the product through a system is increased. That by itself reduces the time materials and components remain as idle stock. Think of the various costs that are lessened by reducing the time whereby materials and components arrive at a plant until the finished product is available to the customer. The costs of capital, insurance, inspection, security, taxes, maintenance, spoilage, material handling, damages, auditing, accounting, and so on are all reduced proportionately by increasing the speed of flow in a lean facility. Minimizing waste, improving quality, and increasing product flow all add up to reducing the cost of production. This is true for all manufacturing and service organizations.

Reducing costs is a key component to business success. As illustrated by Schniederjans (1993, pp. 10–12), in the adoption of JIT/lean principles there is a *JIT/lean productivity cycling process* that the application of these principles can create. This productivity cycling process is illustrated in Figure 2. By identifying production problems and solving them (some being related to quality) we increase productivity and improve quality. This results in reduced costs. If those reduced costs are passed on to the customer (rather than paying them out in short-term dividends to stockholders) it can lead to increased sales and market share. This will cause an increase in product demand, which will place pressure on production capacity, creating new production problems, requiring an additional cycling of lean principles for resolution. As the cycling repeats itself, it results in market dominance. An illustration of the power of this cycling process can be seen in how Japanese car manufacturers moved from their position in the early 1970s, where they had virtually no market share in the US auto markets, to one of domination in this sector today.

To implement the lean principles of eliminating waste, improving quality, increasing product flow, and reducing cost requires dedication and discipline on the part of everyone in an organization. As a way of integrating lean, a variety of lean approaches and methodologies have been developed. They can be applied in part or totally to make an organization a lean enterprise. Firms like Toyota developed a generalized decision making framework, called *Plan-Do-Check-Act*

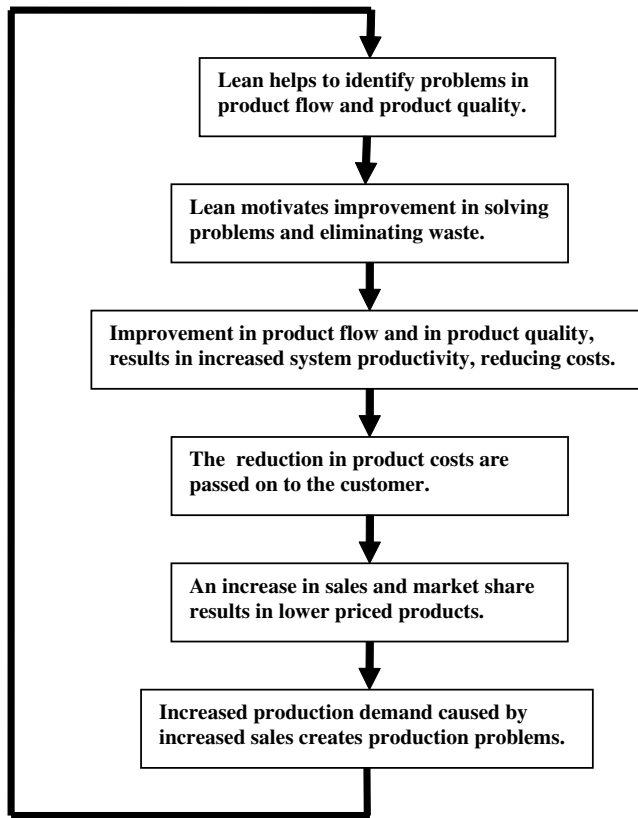


Figure 2. JIT/lean productivity cycling process

(PDCA) cycle (note Supplement 1 for Chapter 1 at the end of the chapter), to aid in the implementation of lean principles.

Lean Approaches and Methodology

To apply lean principles a number of conceptual and quantitative approaches or methodologies have been developed. Those described in this section are more commonly reported in the literature. Some lean approaches and methodologies are limited to manufacturing, while others are equally applicable to service operations.

Process Mapping and Value Stream Mapping

Process mapping is a graphic aid used to describe the sequence of all process activities and tasks necessary to create and deliver a desired product. It is a step-wise

flow chart of the activities and tasks that make up a process, which an employee or technology performs to complete jobs. A closely related map is called the value stream map. *Value stream* are the value-added activities and tasks for designing, producing and delivering goods and services to customers. A *value stream map* (VSM) is similar to a process map in that it shows the activities and tasks, which make up a process. However, in the VSM the value-added and non-value-added activities and tasks are highlighted. Also, cost and timing information on the value-added and non-value-added activities and tasks are usually included for comparative analysis in waste removal.

An important measure in value stream mapping is takt time. *Takt time* is the ratio of the available manufacturing or service time to the required production volume necessary to meet customer demand. We can use a VSM to measure the impact of value-added and non-value-added tasks and activities on total lead time of a process, and compare it to takt time. In situations where the value stream is faster than the takt time, it may mean waste in the form of overproduction is occurring. When the value stream is slower than the takt time, it may mean the firm cannot meet customer demand.

The most fundamental lean principle is waste removal from processes. VSM is ideal for identifying wasteful value-added and non-value-added activities and tasks. VSM is a primary tool for finding and eliminating waste in manufacturing and service processes. Additional discussion on process mapping and VSM is presented in Supplement 2 for Chapter 1 at the end of the chapter.

The 5 Ss

When work stations or employee tools are disorganized, employees can waste time looking for things they need to produce their products or provide needed services to customers. The 5 Ss are helpful guidelines on work space organization. They are:

- Sort (in Japanese: *Seiri*): Identify unnecessary work space items (e.g., tools, equipment, materials, etc.) and remove them.
- Set in order (*Seiton*): Arrange work space items for quick identification and use.
- Shine (*Seiso*): Keep the work space clean and equipment well maintained (e.g., tools oiled and sharpened).
- Standardize (*Seiketsu*): Formalize procedures to avoid wasted indecision times. Practice procedures for efficient application, for consistency in service implementation, and to ensure all steps are performed.

- Sustain (*Shitsuke*): Use training, communication, and other organizational methods to continuously perform all 5 Ss.

Single Minute Exchange of Dies (SMED)

When a new product is to be manufactured or a new service is to be offered to customers, there are some changeover efforts (e.g., new tools for new equipment) necessary in most instances. As the name implies, *single minute exchange of dies* (SMED) refers to the desire to reduce setup times (ideally to a minute) in changeovers during alternations in production processes. (A *die* is a stamp used to form or press sheet metal into parts, like the hood of a car.) This is accomplished both by using technology and equipment designed for quick changeovers and by encouraging employees to suggest new approaches to setups that will cut time and wasted effort.

In Figure 3 lean group technology U-cell and C-cell layouts are presented. In these *group technology* (GT) cells the layout is designed to group production technology together to permit a quick changeover of production resources. The key element of GT cells consists of grouping similar parts into families. Processes required to make the parts are arranged into specialized cells (i.e., more focused production cells on a limited number of products). In this way all of the operations required to complete a part (or any part within the designated family of parts) is located in one GT cell. GT cells help eliminate movement, reduce inventory (less area for inventory means less buffer inventory), and reduce labor (fewer numbers of employees because the employees are cross trained to do a greater number of tasks). By placing large tools and equipment on moveable platforms (e.g., roller wheeled tables or automated tables) that move from one station location along the assembly line to another (note darkened arrows), distance of movement and time can be saved during setups and changeovers in the U-cell and C-cell shapes. For example, in Figure 3 an employee X in the C-cell might be needed to perform two tasks for each product. This employee would perform the first task and then shift to a second position on the assembly line as the product moves along. If a different product enters the line that does not require the two tasks, the employee would simply stay in the position needed. This provides greater flexibility without having extra time and resources tied up in both locations. Likewise, in the case of the U-cell, because of the reduced distance resulting from the shape of the cell, tools can be moved quickly and easily from one position on an assembly line to another, minimizing waste of time and effort.

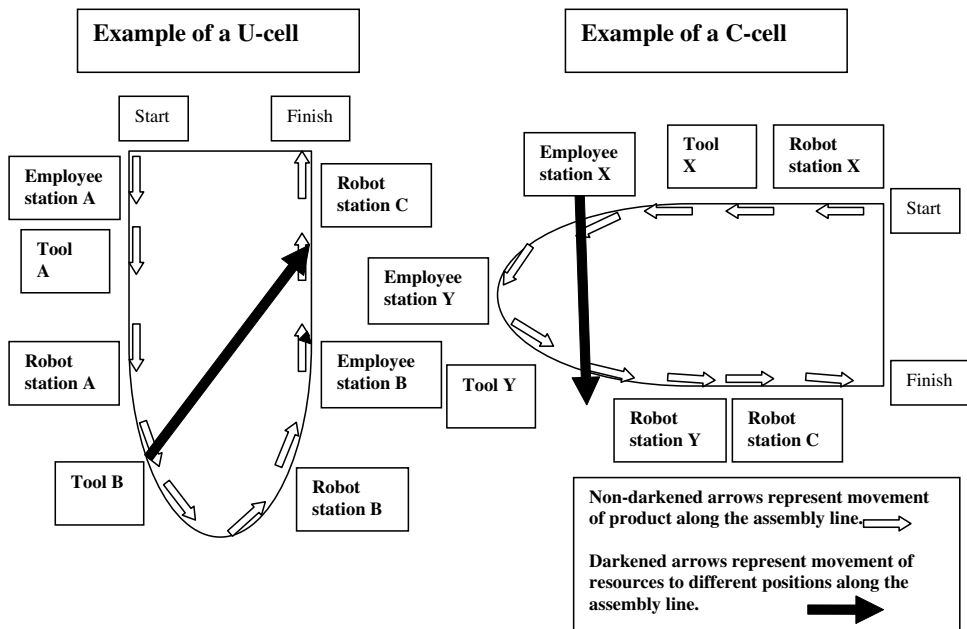


Figure 3. Lean group technology U-cell and C-cell layouts

Stable Production Scheduling

More of a guiding principle than a methodology, the notion of *stable production scheduling* (also called *level production scheduling*) is one where daily production is defined a week or a month in advance. That is, the same amount of manufactured units is produced or service units are delivered each day. Also, if demand changes, then only very small incremental changes in daily production or delivery are permitted. This approach to scheduling serves many purposes of waste removal. First, it will eliminate the need for wasteful overtime. It will also help reduce costs of hiring more employees during high demand periods or of terminating or laying off employees during low demand periods. Secondly, it makes the small but frequent unit production goal of lean management possible. By having a stable production schedule, small and frequent unit production becomes much easier to implement and plan for in most demand environments.

How do we achieve a stable production schedule with lean? Stable production can be achieved by having *uniform plant loading* (in Japanese, *heijunka*), which is accomplished by setting a specified plant production output rate for a fixed period of time. Since lean seeks to use an ordering *pull-system* (i.e., pulling orders through the system by known customer demand), these known orders can be grouped and produced-to-order in fixed time periods in focused factories. For products that do

not operate in a make-to-order environment (i.e., make-to-inventory), improved forecasting and better utilization of sales force product demand estimates are essential to better match inventory to demand levels. As a rule forecasting is more useful as a planning guide, rather than a production scheduling guide.

Quality at the Source

Quality at the source refers to employees maintaining quality and doing their work right the first time. The employees performing the production or service tasks are closer to the product or service and therefore are in a better position to ensure quality. Under this principle employees are asked to inspect the work that they do and that others along the line have done in order to identify defects. Moreover, employees are asked to inspect and analyze the work as it passes through their work space for quality assurance in meeting product specifications. Whether the operation is a manufacturing assembly line or a fast food restaurant, products go through a series of steps to completion. As the product or service is passed along the production process, each employee is asked to perform some rudimentary quality checks. If they find a defect from the work of a previous employee, they can send it back to that employee for correction, which helps the prior employees learn from their mistakes. If no defect is found, the employee continues his or her work, but also performs some quality checks of his or her own efforts. Not all quality aspects of a product are checked by each employee, but enough checks and double checks are performed to ensure the finished product is thoroughly inspected and of high quality.

Continuous Improvement

Seeking zero defects in manufacturing or zero errors in service is a goal of JIT and lean programs. *Continuous improvement* (CI) is an incremental conceptual approach for improving products and processes. As shown in Figure 4, CI projects represent a method of small, incremental improvements in manufacturing or service processes, as well as product improvements over time. The CI function in Figure 4 could be expressed as a linear function (note dashed line in the figure). Depending on the number of CI improvements in a given period of time, and their additive impact on the firm, a more realistic non-linear function that describes the potential enhancement impact of CI is presented in Figure 5.

CI chiefly relies on employees, managers, consultants, industrial engineers and more generally, everyone in an organization to come up with ideas for improvements in processes, product innovations, product quality, etc. Replacing the old

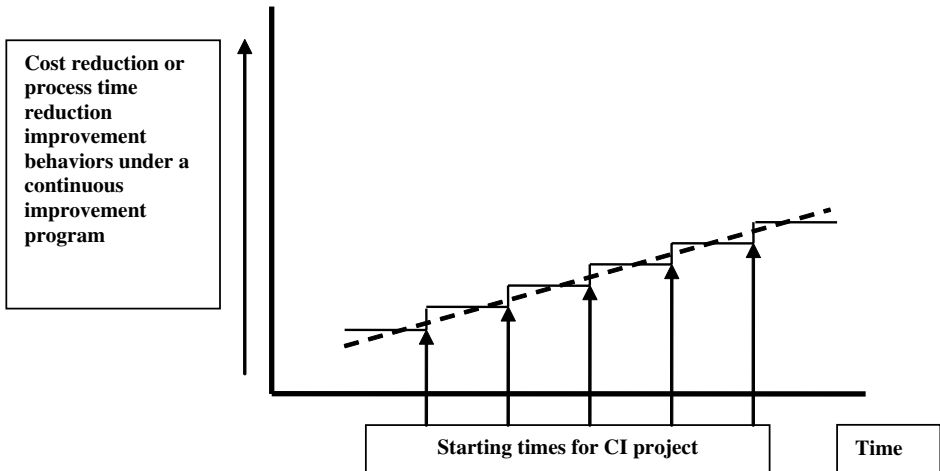


Figure 4. Incremental CI project impact behaviors for improvement

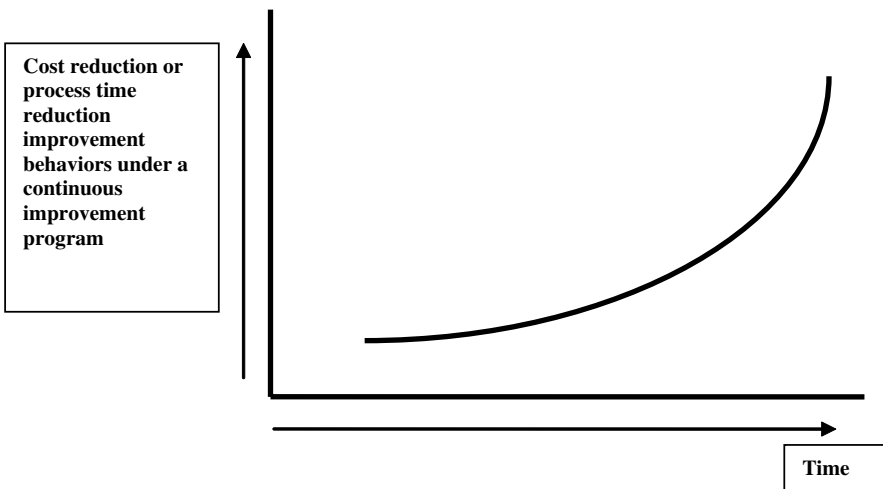


Figure 5. Typical improvement behaviors under continuous improvement

notion of the “suggestion box”, where employees would make written suggestions for improvements, a lean approach requires everyone to come up with new suggestions to enhance business operations and the products or services. CI is proactive. It invites, encourages, and in most organizations rewards contributors of ideas. CI can provide many opportunities for waste removal.

CI is embodied in other programs as well. In Japan the CI approach is called *Kaizen*, which similarly focuses on small, gradual, and frequent improvements over a long period of time with a minimum investment of financial resources. Like CI,

everyone in an organization embracing Kaizen is expected to make contributions to improve every aspect of business operations. Most Kaizen programs require operating practices like JIT to stimulate ideas for improvement. Total involvement by all members in the organization with top management championing the efforts must be clearly promoted in any Kaizen program. A clear and consistent program of support with reward systems helps Kaizen become a habit. In addition, training is used to remind and encourage the identification and application of new ideas to solve problems and improve operations.

Six Sigma

Six Sigma is a quality improvement approach that seeks to eliminate causes of defects in manufacturing and service processes. The term, Six Sigma, originates from the statistical measure that permits at most 3.4 defects per million opportunities. In other words, virtually no defects are allowed in products under this principle. A *defect* in Six Sigma is defined as any error that is passed on to the customer in a way that the customer views the error as product nonconformance. We can measure output quality by *defects per unit* (DPU):

$$\text{DPU} = \text{Number of defects discovered} / \text{Number of units produced.}$$

To illustrate, if we have a computer service center that sells 500 computers in a day and only fails 4 times to properly set up computers in the same day, their DPU would be 0.008 (i.e., 4/500). The concept of Six Sigma characterizes quality performance by *defects per million opportunities* (DPMO):

$$\text{DPMO} = \text{DPU} \times 1,000,000 / \text{Opportunities for error.}$$

Again, looking at the computer service center example, suppose there are 100 possible items on a checklist that need to be completed for each computer setup. For a day with 500 computers at 100 opportunities per computer, that would translate to 50,000 (i.e., 500 × 100) opportunities for error in the set up of the 500 computers. The resulting DPMO is 0.16 (0.008 × 1,000,000/50,000), which is fairly high and should call for corrective actions to seek approaches to lower the resulting value.

In service applications of Six Sigma the formula is changed to *errors per million opportunities* (EPMO) or:

$$\text{EPMO} = \text{DPU} \times 1,000,000 / \text{Opportunities for error.}$$

Six Sigma is a program that organizations must embrace fully in order to maximize its benefits. Key concepts to implement Six Sigma usually include the following:

- Ensure appropriate metrics are identified in the manufacturing or service processes that are focused on business results. Eliminating defects will result in less costs and more profit.
- Emphasize DPMO or EPMO as a standard metric that can be applied to all functional areas in the organization. Eliminating defects is an organization-wide activity. Six Sigma will work just as well in accounting as it will in manufacturing.
- Establish a Six Sigma champion to sponsor and coordinate team activities, help to overcome employee resistance to change, seek funding and resources, and develop implementation strategies.
- Develop in-house experts that can train others in Six Sigma, such as qualified process improvement experts (referred to as *black belts*) who can lead teams and train others in the use of improvement methodologies.
- Provide extensive training in quality project planning (since a Six Sigma program is made up of Six Sigma projects) for identifying non-value added activities and setup reduction opportunities.
- Develop a specific and detailed plan to aid Six Sigma implementation.

There are many different tools that can augment the Six Sigma statistical approach. Some of these Six Sigma and lean related tools are presented in Table 7.

Table 7. Six Sigma tools

Six sigma tool	Description
<i>Cause-and-Effect Diagrams</i>	A visual aid diagram that permits a user to hypothesize relationships between potential causes of a problem — This diagram lists potential causes in terms of human, technology, policy, and process resources. The diagram is then used to trace the problem back to possible causes and allows the user to better picture sources of potential causes that could affect the problem. Sometimes referred to as a <i>fishbone diagram</i> .

Table 7. (Continued)

Six sigma tool	Description
<i>Checksheets</i>	A standardized listing of items to check — This tool helps to ensure all the items on the list are checked (e.g., an airline pilot checking necessary electrical switches before takeoff), promotes efficiency in inspection efforts and helps in service jobs to perform all tasks required in the delivery of a service product.
<i>Pareto Charts</i>	A visual aid chart used to breakdown types of problems into several categories by frequency of occurrence — It is based on the logic that the largest proportion of manufacturing and service problems are usually small in number, but occur frequently. The idea is to rank these problems, usually based upon frequency of occurrence, and then devote the most resources to solving the highest ranked problem first, second highest ranked problem next, and so forth.
<i>Control Charts</i>	Statistically based charts that compute acceptable ranges of performance with a mean value as a target for product specifications — These visual aids are ideal for monitoring how close production processes meet desired product specifications. These charts have upper and lower control limits based upon statistics, usually plus or minus three sigma. Examples include a <i>runs chart</i> used for measuring quality between production runs, <i>Range chart</i> , also called an <i>R-chart</i> , used to measure range values between a desired target specification and actual performance, <i>C-chart</i> used to measure defects by counting and plotting them by number of occurrences, and a <i>P-chart</i> used to measure and track percentage of defects in a production process.

Table 7. (Continued)

Six sigma tool	Description
<i>Opportunity Flow Chart</i>	<i>Flow charts</i> are graphic aids that are used to identify the tasks that make up a process. <i>Opportunity flow charts</i> are an application of flow charts that are specifically used to identify tasks that have waste in them. Then the chart can be used as an opportunity to remove or reduce the tasks, which make up a process.
<i>Failure Mode and Effect Analysis (FMEA)</i>	FMEA is a structured means to identify, estimate, prioritize, and evaluate risk of a manufactured product or service at each stage in the process of production. The analysis helps to identify and assess the probability that a product will fail (occurrence), the damage in a product failure (severity), and the probability that failure will be detected by the firm (detection). FMEA analysis also includes suggested means by which to eliminate the failure condition through redesign of the process.
<i>Design of Experiments (DOE)</i>	DOE is a statistical approach used for determining the cause-and-effect relationships between process variables and output variables.

One of the most recognized Six Sigma implementation planning approaches is that of General Electric's *Define, Measure, Analyze, Improve, and Control (DMAIC)*. The DMAIC problem solving framework is briefly presented in Table 8.

Total Productive Maintenance

Total productive maintenance (TPM) is a means to help ensure operating systems will perform as intended and to do so reliably. TPM seeks a goal of zero equipment failures and downtime. Ideally, TPM will maximize overall equipment effectiveness and encourage employees to take on the responsibility of keeping equipment well maintained. Well maintained equipment increases productivity, helps eliminate product quality problems (a sharp knife cuts cleaner), reduces energy losses and rework, and reduces production line shutdowns due to equipment failure.

Table 8. General Electric's Six Sigma DMAIC problem solving approach

Problem solving phase	Description
1. Define (D)	<ul style="list-style-type: none"> — Identify target customers and their priorities — Identify type of Six Sigma project consistent with business objectives and customer needs and feedback — Identify <i>critical to quality</i> (CTQ) characteristics that customers must have or that will make the greatest impact on quality
2. Measure (M)	<ul style="list-style-type: none"> — Identify quality performance measurements to use — Determine current state of quality performance measures — Identify key internal processes that impact CTQs — Determine current status of key internal processes that impact CTQs and the defects currently generated by those processes
3. Analyze (A)	<ul style="list-style-type: none"> — Identify most likely causes of defects — Identify key variables that are causing process variations and defects
4. Improve (I)	<ul style="list-style-type: none"> — Determine the key variables and quantify their impact on CTQs — Identify maximum acceptable ranges of key variables and systems — Determine means to remove the causes of defects — Change the process to stay within acceptable ranges
5. Control (C)	<ul style="list-style-type: none"> — Determine means to maintain improvements — Install monitoring system to control future variation in key variables

TPM is a departure from the past, where maintenance was performed exclusively by maintenance personnel. Under a TPM program, employees are asked to perform rudimentary maintenance tasks on their own equipment. Complex maintenance is still performed by maintenance experts, but some of the more routine maintenance is performed by the employees. They are in a better position to know

when their equipment may need a little oil or sharpening. This also encourages employees to explore and develop new ideas concerning equipment setups, which can save time.

Green Manufacturing and Service

In line with the origins of JIT and lean from the 1950's in Japan, the idea of *green manufacturing* or *green service* refers to converting what was waste into something of value. This lean approach seeks to turn waste into a productive resource. At each stage of the process of manufacturing a tangible product or delivering a service, there are possibilities for waste. Some of that waste (e.g., discarded napkins at a restaurant or discarded scrap metal in a manufacturing facility) could possibly be used again in a different form or application. Today, wasted or soiled paper goods are commonly recycled and used as housing insulation, printing paper, or other paper goods applications. Some of the common “green” options are:

- **Recycling:** Glass, paper, and plastics are commonly recycled in business operations and made into new products that serve as inputs for both manufacturing and service operations.
- **Repairing:** High cost products (e.g., manufacturing equipment, like robots and trucks) can be repaired for an extended useful life.
- **Refurbishing:** Products that are returned by customers to retailers can be cleaned up, sometimes requiring installation of minor parts, and resold.
- **Remanufacturing:** Products that are returned by customers to retailers can be reengineered with newer features and resold as an improved or new product, rather than being scrapped.
- **Charitable reusing:** Some products that are used can be redistributed to other customers. For example, hotels often donate their soap and towels to charitable organizations.
- **Conservation of resources:** Hotels and restaurants in areas where water is limited often have programs to invite customers to use less water or fewer linen washings (to reduce laundry water and pollution).

Automation

Some of Six Sigma statistical tools (e.g., checklist) embody *fail-safe procedures* (in Japanese called *poka-yoke*), which seek to ensure manufacturing and service product quality. This is an approach for mistake-proofing processes using automated devices or methods to avoid simple human error. Eliminating boring tasks

for employees by allowing a robot to perform them not only can improve product quality consistency, which is a quality attribute, but frees the employees to perform more challenging tasks better suited for taking advantage of their abilities and helps to enrich their jobs, which research demonstrates enhances employee motivation and productivity.

There is a balancing factor that must be considered in a lean enterprise regarding automation. The investment in automation has to meet an acceptable *return on investment* (ROI). The ROI may be qualitatively based upon achieving better quality or quantitatively based upon a reduction in the cost of operations. Service automation, like an X-ray machine in a hospital, has to be justified in order to warrant the investment. Information system technology to track and maintain production scheduling can be very expensive, but provides necessary communication to coordinate production activities, particularly those in relation to supply chain partners. Any production automation is usually expensive and must achieve an ROI that justifies investment.

Visual Management

Visual management involves the actions of designing and running facilities to maximize the use of visual observation in the production process. On a macro-level, it might mean eliminating walls so managers have a broad view of the work environment. This allows one manager to see more of the operations from any one place in the facility, thus facilitating visually managing employees and improving the manager's productivity. On a micro-level, this might mean installing systems to enhance employee control of tasks. *Visual controls* (i.e., electronic or mechanical control gauges devices) can be placed in a work stations or other locations where they can quickly communicate if a production or service problem is present. For example, production assembly line work stations can have multi-color lights (i.e., red means stop the line a serious problem has been found, yellow means a possible problem with the line, green means no problems) for employees to quickly and visually communicate possible problems to managers, rather than wasting time going and finding them to report difficulties.

There are other technologies used in visual management. The *andon board* for example, is a large electronic sign board that provides real-time operational performance and system status information. These boards can communicate daily production goals and current progress toward those goals. Andon boards can also provide detailed assembly line work information on targets and progress toward targets, line stoppage information when problems occur, and let managers know where the line stoppage occurred.

Supplier Relationship Management

Key to timing production scheduling is the delivery of materials needed to produce a finished manufactured product or to deliver a service. This requires a close relationship with suppliers, achieved in part by allocating most of a firm's business to one or just a few suppliers that can be trusted to perform deliveries without failure. The idea of having only one or a few suppliers serves two purposes: (1) The amount of business with the supplier will make the lean firm a dominant customer, which in turn can demand greater respect and service. (2) It reduces the paper work and unnecessary waste of time dealing with large numbers of suppliers.

A lean operation seeks to establish long-lasting and trusting relationships with suppliers. This is a relationship where the lean firm supports and in some cases finances the supplier to ensure continued support of the lean operation. While competitive costing of suppliers is not ruled out of the relationship, it is expected that suppliers will seek the lowest costs and pass those savings on to the lean firm.

Today, most firms place orders over the Internet or use *electronic data interchange* (EDI) systems (i.e., hardware/software systems that automatically place orders between suppliers and customers). As JIT and lean methods evolved, the least expensive means of communicating and placing orders with suppliers were sought. One such method was the *Kanban* card system, which does not use computers or any electronic technology. Kanban card systems were used to physically signal suppliers to deliver goods. Kanban is a paper system where a card is employed to notify the supplier that a unit or group of units is requested by the lean firm. Typically, Kanban cards are placed in a location in the plant where suppliers can visit, pick up the card (used here like an order form), and return with the necessary supplies. Kanban cards have uses other than just ordering inventory from suppliers. They are also used to signal the production of units and movement or conveyance of units within a plant.

Final Comments on Lean

In comparing the JIT and lean principles there appears to be considerable similarity in the literature. Schniederjans and Zuckweiler (2007) have observed the terminology used to describe JIT and lean principles in books and articles is virtually the same. Note the comparison of explanations between JIT and lean by various authors in Table 9. The reality is that JIT is incorporated within lean to achieve a broader base of objectives and better coordination within a firm's entire supply chain. Jacobs *et al.* (2009, pp. 207–208) views JIT principles as a requirement for lean.

Table 9. Comparison of JIT and Lean Principles

Principle	Explanation of JIT principle	Explanation of lean principle
Inventory: Seek Continuous Improvement in Inventory Management	“Continuous sorting through inventory and equipment to discard what is unnecessary (<i>seiri</i>) and arranging what is left in an efficient manner for use (<i>seiton</i>) will reduce future work motion activities. Finally, and most importantly, these efforts for improvement must become habitual (<i>shitsuke</i>) for continued long-term improvement in performance.” (Schniederjans, 1993, p. 7)	“Continually evaluate the materials handling process to uncover more ways to reduce waste. No matter how many times... employees improved a given activity to make it leaner, they could always find more ways to remove <i>muda</i> (waste) by eliminating effort, time, space, and errors.” (Womack <i>et al.</i> , 1990, p. 90)
Suppliers: Seek Long-Term Relationships with Suppliers	“JIT supplier relations are long-term partnerships with single-source suppliers who provide certified quality material while continuously reducing costs.” (Wantuck, 1989, p. 297)	“The supplier company is no longer exposed to annual contract bidding in its longer-term relationship with the (manufacturer).” (Klier, 1994, p. 7)
Production Planning: Seek Uniform Daily Production Scheduling	“Level loading...is planning to build the same product mix every single day during a given month. The production level and product mix can vary from month to month to meet changing customer demands but will flow smoothly and evenly each day within the month.” (Schonberger, 1982, p.226)	“The success of lean manufacturing... depends on a level production schedule; that is, the production of different items must be distributed evenly to minimize uncertainty for upstream operations and suppliers.” (Liker and Wu, 2000, p. 86)
Quality: Visibility Management	“...Visibility Management is a vital principle of ‘Quality at the Source’.” (Wantuck, 1989, p. 59).	“Visual controls (must be used), ranging from the 5 Ss (where all debris and unnecessary items are removed and every tool has a clearly marked storage place visible from the work area) to status indicators (often in the

Table 9. (Continued)

Principle	Explanation of JIT principle	Explanation of lean principle
HR: Seek to Empower Employees	<p>“The five S’s ... are also a daily part of a worker’s maintenance and housecleaning duties.” (Schniederjans, 1993, p. 122)</p> <p>“By placing <i>andon</i> systems at the workers’ command, management shows a commitment that quality is important and that the worker’s opinion about quality is vital.” (Schniederjans, 1993, p. 8)</p> <p>“...it will become apparent that the emphasis should be placed on individual growth, team building and management style, using continuous improvements the agenda to provide a focus for everyone’s development.” (Wantuck, 1989, p. 104)</p>	<p>form of <i>andon</i> boards), and from clearly posted, up-to-date standard work charts to displays of key measurable and financial information on the costs of the process.” (Womack <i>et al.</i>, 1990, p. 61)</p> <p>“Lean production is impossible without an empowered and participating workforce.” (Cook and Graser, 2001, p. 19)</p> <p>“When all the relevant individuals, who are engaged in an operational process, can participate in its redesign from the beginning, the jointly developed solutions are likely to be better both in productivity and work satisfaction.” (Smeds, 1994, p. 71)</p> <p>“A focus on building in quality is another requirement for effective lean manufacturing. Instead of relying on a formal inspection process to uncover defects after they occur... workers can stop the production flow immediately whenever they detect abnormalities.” (Liker and Wu, 2000, p. 88)</p>

Table 9. (Continued)

Principle	Explanation of JIT principle	Explanation of lean principle
Factory Design: Seek a Focused Factory	<p>“In a focused JIT operation, the required layout is substantially smaller and requires less material handling.” (Schniederjans, 1993, p. 73)</p> <p>“The use of U- and C-shaped cells is often used because of their usefulness in minimizing the distances between machines, increasing flexibility, enhancing group effort, and providing for better communication among workers.” (Schniederjans, 1993, p. 97)</p>	<p>“Product flow and material handling are dramatically reduced using cellular layout, which requires less floor space.” (Bartholomew, 1999, p. 26)</p> <p>“Each machine cell arrangement resembles a focused factory arrangement.” (Sahin, 2000, p. 58)</p>

Another issue about lean principles concerns the nature of the product being produced. Some scholars feel that lean will only work in high volume operations that have a fairly standardized product or family of products. They use as an example the focused factory approach that limits product range flexibility, which conflicts with lean principles seeking flexibility. This is not the case at all. Automobiles increasingly have a wide range of car models with an even wider range of options. Toyota utilizes mixed model production on a daily basis in focused factories, so a small range of differing models are produced each day in each plant. Thus, some focused effort achieves the efficiencies on a limited number of models in any one focused plant, yet other focused plants provide a variety of models at the same time. In addition, the layouts and automation of the plants permit a wide range of optional features to be built into any one vehicle, thus achieving a unity production of a custom product.

A final issue about lean principles concerns their failed applications in industry. Some scholars believe lean principles are not workable and do not always lead to world-class operations. They point to firms, such as Chrysler and General Motors that have had to shut down plants and waste millions of dollars in idle production resources. Operating under JIT, they became too dependent on suppliers who did not deliver components and materials when needed. Strikes can occur that delay shipments of needed parts, and long supply chains reach into foreign countries where wars and natural disasters can prevent timely shipment

of goods to manufacturing or service operations when needed. Decades ago firms built up inventories in anticipation of labor strikes, estimated stock out inventory levels based upon demand surges or added wasteful inventory in anticipation of poor quality components going into operations. All of these wasteful practices are still available if firms want to revert back to them for security purposes. However, under lean we seek to develop trusting relationships with suppliers that will not disappoint a lean firm partner. Even when natural disasters threaten, suppliers are expected to deliver and provide what they promise. It should be remembered that client lean firms must work with their suppliers to help them provide the type of ensured coverage they need. For firms where the likelihood of a production stoppage or costs are very great, lean firms should seek to undertake a risk analysis of these factors and take measures to ensure against them. Identifying problems and solving them to improve efficiency is what lean is all about. Being caught in a situation where a firm is stocked out is not a failure of lean, but one of management.

Not all lean principles can be applied to any one organization. Lean must be tailored to the needs of the firm. It must be adapted, and only those principles that have applicability should be utilized. Regardless of whether the firm is a manufacturing or service operation, lean collectively provides the best and most common sense approach to world-class operations yet devised.

Summary

In this introductory chapter a variety of lean principles and methodologies has been presented. Lean principles included seeking the elimination of waste, improved quality, increased product flow, and reduced cost. Lean methodologies included process mapping and value stream mapping, the 5 Ss, single minute exchange of dies, stable production scheduling, quality at the source, continuous improvement, Six Sigma, total productive maintenance, green manufacturing and service, automation, visual management, and supplier relationship management.

The application of lean principles as presented in this chapter is greatly dependent on suppliers. In the next chapter we examine supply chains and the critical roles they play in helping organizations achieve world-class operations.

◆ **Review Terms**

Andon board	Opportunity flow chart
Black belts	Pareto charts
Cause-and-effect diagrams	P-chart
C-chart	Plan-Do-Check-Act (PDCA)
Checksheets	Poka-yoke
Continuous improvement (CI)	Process mapping
Control charts	Pull-system
Critical to quality (CTQ)	Range chart
Defect	R-chart
Defects per million opportunities (DPMO)	Return on investment (ROI)
Defects per unit (DPU)	Runs chart
Define, Measure, Analyze, Improve, and Control (DMAIC)	Seiketsu
Design of experiments (DOE)	Seiri
Die	Seiso
Electronic data interchange (EDI)	Seiton
Errors per million opportunities (EPMO)	Shitsuke
Fail-safe procedures	Single Minute Exchange of Dies (SMED)
Failure mode and effect analysis (FMEA)	Six Sigma
Fishbone diagram	Specific, Measurable, Attainable, Results oriented, and Time (SMART)
Green manufacturing	Stable production scheduling
Green service	Standard operating procedures (SOPs)
Group technology (GT)	Supply chain
Heijunka	Takt time
Idle stock	Total productive maintenance (TPM)
JIT/lean productivity cycling process	Toyota Production System (TSP)
Just-In-Time (JIT)	Uniform plant loading
Kanban	Value stream
Key Performance Indicators (KPI)	Value stream map (VSM)
Lean	Visual controls
Level production scheduling	Visual management
Meets Value, Flow, Mastery (VFM)	Work-in-process (WIP)
Mixed model scheduling	

◆ Discussion Questions

1. How are JIT and lean similar? How are they dissimilar?
2. Why are JIT principles divided into process areas, like quality and human resources, rather than listed as broad concepts, like lean's waste removal principle?
3. Under lean principles there is one that seeks to eliminate waste. What is waste? How can it be eliminated?
4. How does lean seek improved quality through the elimination of waste?
5. Why maximize product flow with lean?
6. How does eliminating waste, improving quality, and improving product flow reduce costs?
7. What is the JIT/lean productivity cycling process? Why is it recommendable?
8. How does process mapping and value stream mapping help implement lean?
9. How do the 5 Ss help to implement lean?
10. How does SMED help to implement lean?
11. How does group technology help to implement lean?
12. How does stable production scheduling help to implement lean?
13. How does quality at the source help to implement lean?
14. How does continuous improvement (CI) help to implement lean?
15. How does total productive maintenance (TPM) help to implement lean?
16. How does green manufacturing and service help to implement lean?
17. How does automation help to implement lean?
18. How does visual management help to implement lean?
19. How does supplier relationship management help to implement lean?
20. How can the Plan-Do-Check-Act cycle approach be used to implement lean?

◆ Problems

1. A robot in a manufacturing plant occasionally becomes disoriented and produces defective component parts. In a period of one month the number of defective components was 25 out of 10,000 components produced during the same time. What is the DPU of this robot for this month?
2. One work station on an assembly line produces 15 defects out of 10,000 units of product manufactured. Each product could have as many as five defects. What is the DPU for this work station?
3. A four star restaurant sets tables by a checklist method to ensure consistency. Another staff member performs a check on the table arrangements to ensure quality compliance with the checklist. Based on one week's worth of checks, a total of 12 defects of nonconformance were identified out of 8,000 place settings. What is the DPU for this problem? What is the EPMO if there are a total number of opportunities for errors of 50,000 for all place settings?

4. Draw the process map for the assembly of a boxed bicycle. The process includes the following with graphic elements: Tasks: 1. Unpack box parts; 2. Assemble frame; 3. Fit and balance wheels; 4. Add on chain; 5. Finish adding other parts; Decision: 1. Have the wheels been balanced (performed after the Task 3)?
5. Draw the process map for the painting of an office. The process includes the following with graphic elements: Tasks: 1. Deliver paint and painting equipment to office; 2. Prepare office by covering floors and equipment with tarps; 4. Tape off all electrical fixtures; 4. Paint ceiling; 5. Paint walls; 6. Remove tarps and tape; 7. Check for flaws in paint job; 8. Repair paint flaws if necessary; 9. Remove all paint and painting equipment from office; Decision: 1. Are there flaws in the paint job (performed after the Task 7)?

Supplement 1 for Chapter 1: Toyota Plan-Do-Check-Act Cycle Approach to Operational Problem Solving

There are many problem solving frameworks used as lean implementation strategies in the literature. Of all of the potential problem solving strategies that integrate and apply lean principles, perhaps the best known lean-associated methodology is Toyota's *Plan-Do-Check-Act* (PDCA) cycle approach to operational problem solving. This framework can be viewed as a structured, step-wise process that guides users to identify, suggest solutions, implement solutions, learn from the implementations, and if necessary cycle the problem solving effort to obtain better results and further improvements in operations.

A general description of the PDCA framework is presented in Table S1.1. The PDCA can cycle if the results observed on the first round of steps are not

Table S1.1. PDCA framework

Prerequisite Action	<ul style="list-style-type: none"> — Managers or consultant formally authorizes PDCA. — This makes support and accountability clear to all participants.
Prerequisite Information	<ul style="list-style-type: none"> — Identify start date and members of the team responsible for PDCA undertaking — Introduce the process, project, or problem to be addressed — Define boundaries

Table S1.1. (Continued)

1a. Plan	
— State Problem Situation	<p><i>Current Situation</i></p> <ul style="list-style-type: none"> — Overview statement on current process, project or problem — Interview employees related to current process, project or problem — Utilize charts, graphs, and diagrams (Pareto, Cause-and-effect, Fishbone, etc.) <p><i>Ideal Situation</i></p> <ul style="list-style-type: none"> — Utilize charts, graphs, and diagrams to suggest the ideal situation for the process, project or problem <p><i>Problem Statement</i></p> <ul style="list-style-type: none"> — Define the problem as the difference between the current and ideal situations
1b. Plan	
— Target Setting	<ul style="list-style-type: none"> — Define a target that will solve the problem in the Problem Statement above — Define <i>Specific, Measurable, Attainable, Results oriented, and Time</i> (SMART) based targets
1c. Plan	
— Root Cause Analysis	<ul style="list-style-type: none"> — Identify all possible root causes that lead to the problem
1d. Plan	
— Identify and Select Best Alternative Solution	<ul style="list-style-type: none"> — Brainstorm list of possible solutions to the problem — Explore the potential of each solution — Test best candidates <ul style="list-style-type: none"> — Do they meet <i>Value, Flow, Mastery</i> (VFM) criteria? — Are they financially or physically possible? — Make selection of best alternative
1e. Plan — Formalize Plan Steps	<ul style="list-style-type: none"> — Identify steps to implement best alternative solution — Define potential expected results for each step

Table S1.1. (Continued)

	<ul style="list-style-type: none"> — Define <i>Key Performance Indicators</i> (KPI) — Measure and analyze current KPI — Estimate cost and productivity savings — Identify key stakeholders and how they will be impacted by plan — Explain how key stakeholders will be informed about plan results
2. Do	<ul style="list-style-type: none"> — Implement plan — Define the actions to be taken, who is responsible for the actions, and when they should be completed — Monitor step-wise actions — Adjust plan as needed
3. Check	<ul style="list-style-type: none"> — Measure KPI — Target SMART target goals — Use lean metrics — Clearly define actual results — Evaluate results using criteria (exceeds target, meets target, below target, unsatisfactory, etc.)
4a. Learn and Cycle — Reflections	<ul style="list-style-type: none"> — Explain what would be done differently if plan is repeated — Explain what was learned in the PDA steps — Explain how the learning would be transferred to a new plan
4b. Learn and Cycle — Future Actions	<ul style="list-style-type: none"> — Determine if future cycles of this plan are needed — If results of SMART targets are not satisfactory, repeat all steps again — Identify areas in the plan that will require further follow-up
Final Action	<ul style="list-style-type: none"> — Managers or consultant formally sign-off on PDCA.

acceptable. PDCA can be repeated and modified for improvement through learned experiences from earlier cycles of the plan.

Supplement 2 for Chapter 1: Process Mapping and Value Stream Mapping

As previously stated, processing mapping and value stream mapping are graphic aids to help define the tasks and activities that make up a process or a system. The value stream map graphs utilize a variety of graphic symbols as elements to describe the process or system under study. While the literature reveals minor differences in the symbols, those presented in Figure S2.1 are typically used in both process mapping and value stream mapping.

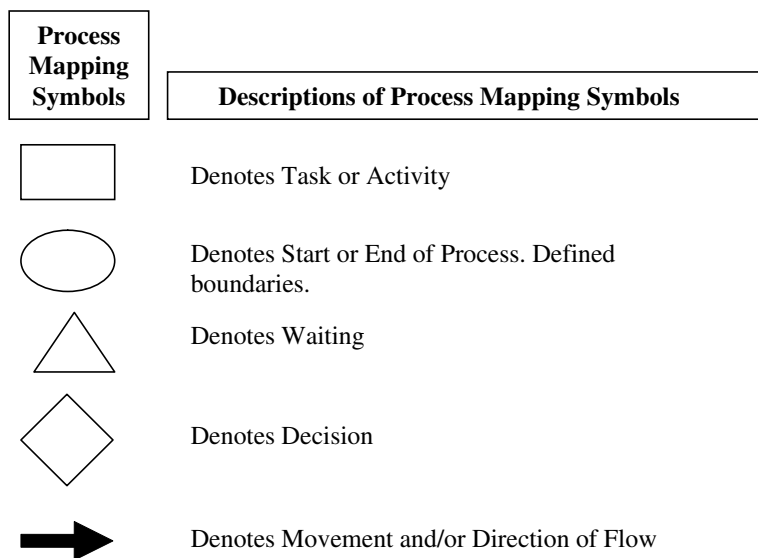


Figure S2.1. Process mapping symbols

To illustrate process mapping and value stream mapping, consider a simple example. In Figure S2.2 a process map of the tasks and other graphic elements required to bake a cake are presented.

To change the process map in Figure S2.2 to a value stream map, denote any tasks, decisions, or waiting that might be wasteful. Include cost and timing information by each of the elements in the value stream map for comparative purposes. The cost and timing information allows the identification of important map elements (i.e., relative to their cost and time requirements of other elements).

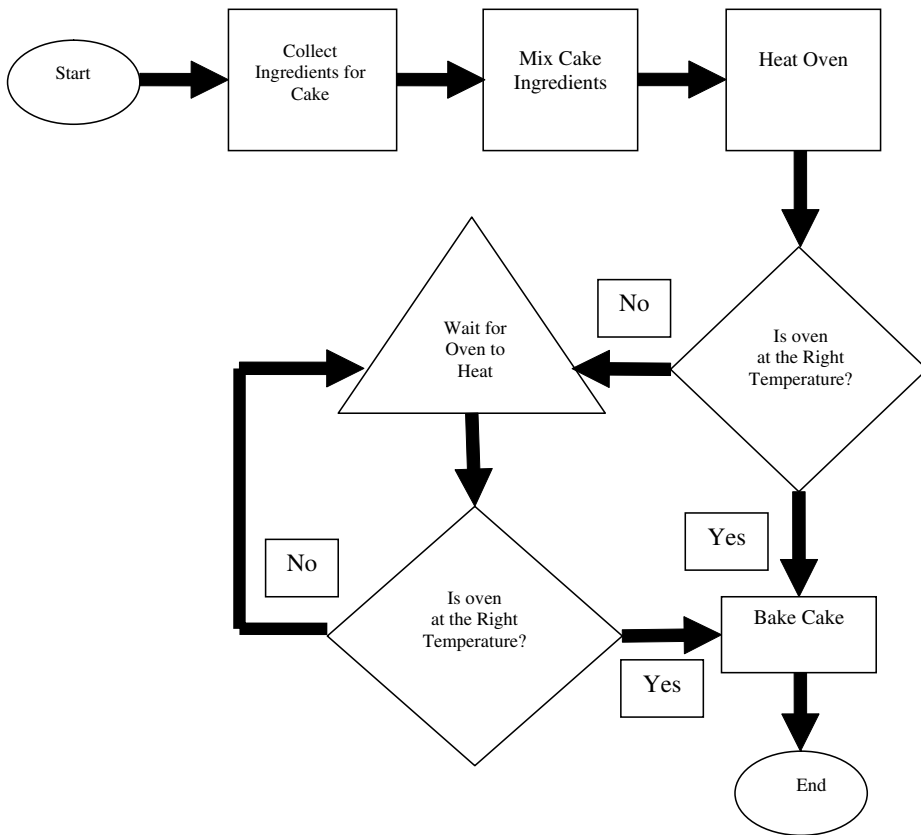


Figure S2.2. A process map for baking a cake

If tradeoffs in changing the tasks or identification of candidates for change, including the elimination of some tasks, are needed, users can quickly spot the relative importance of the elements in the process that denote the greatest opportunities for improvement. As we can see in Figure S2.3 the value stream map is the same process map, but now includes cost and timing information. In addition, several elements (darkened symbols) are designated as potential waste candidates.

Using the value stream map in Figure S2.3, we can see that the waiting and decision elements can be removed, and still the product can be produced. This might be accomplished by changing a task in the process such that the Heat Oven task is changed to include a Preheating of the Oven task and having the employee check it ahead of time as noted in Figure S2.4. Alternatively, this might be accomplished by acquiring a new technology (i.e., a new oven)

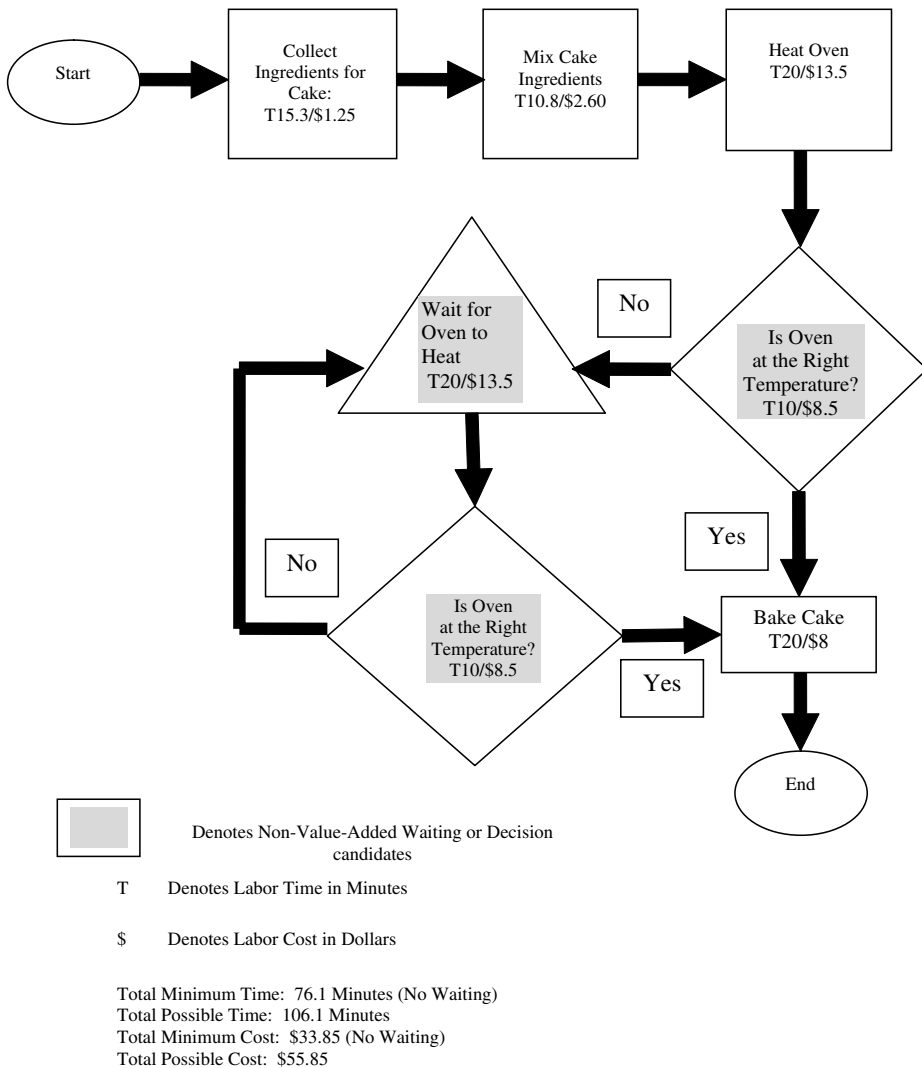


Figure S2.3. A value stream map for baking a cake

that assures an immediate desired heat will be achieved when it is turned on. How do we identify what is waste in a value stream map? If cost information is provided, starting with the tasks or decisions that are the most costly is one suggestion. Generally, waiting time is often an ideal target for consideration of waste. Also, decision making can be very time wasteful. Where possible a lean approach would suggest converting decisions into standard operating procedures. *Standard operating procedures* (SOPs) formalize decisions to

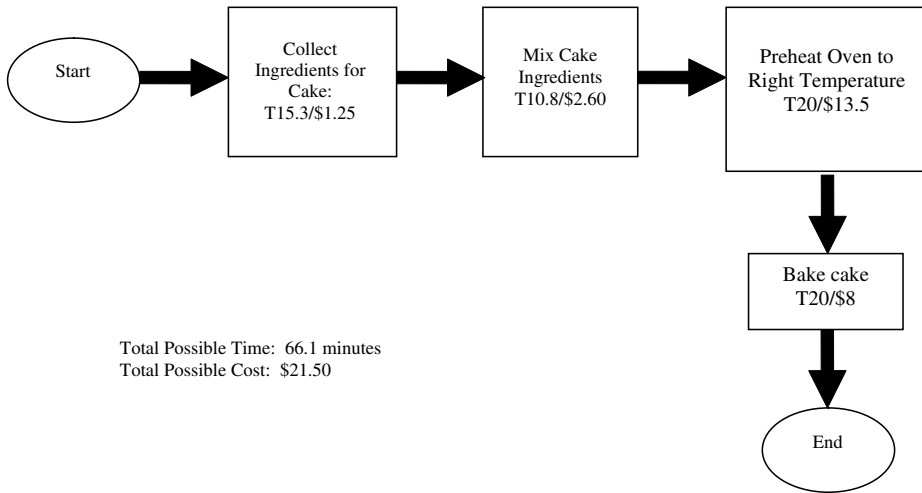


Figure S2.4. A revised value stream map for baking a cake

permit an immediate response by employees that requires no decision making time. However accomplished, the value stream map identifies possible waste reduction that can be used for process planning and implementing lean.

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