CHAPTER 11

Lean Techniques: Improving Process Efficiency

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About This Chapter

Lean is the process of optimizing organizational systems by eliminating, or at least reducing, the "waste" within them. Anything that does not provide value to the customer or the organization can be considered waste. This chapter introduces the Lean Methods and Tools and their relationship to managing quality and superior results. Lean methods and tools can provide significant improvements in organizational efficiency. In the past decade, Lean has experienced a rebirth in manufacturing-based industries as well as service and health care-based organizations.

High Points of This Chapter

1. Lean is based on creating a "pull system" to produce faster rather than the traditional "push" systems used by most organizations. One of the main goals of Lean is to always pull from the customer demand, not push to the customer.
2. Value Stream Mapping is an important Lean tool. It maps and documents all the tasks (material and information flow) and the metrics associated with them

(cycle time, costs) within a process, including inherent waste. This provides the guidance to select the right problems and solve them as process improvement projects.

3. There is a standardized approach and set of tools, such as rapid improvement events, or *kaizens* (Japanese word for "improvement") to attack embedded wastes and increase the velocity of a process. Improving velocity exposes the problems—waste—and eliminates them, thereby making the processes faster, better, and cheaper.
4. 6S (sort, set in order, shine, standardize, sustain, and safety) is a Lean method to achieve a highly effective workplace that is clean and well organized. The benefits of an efficient workplace include prevention of defects; prevention of accidents, and elimination of time wasted searching for tools, documentation, and other ingredients to produce goods or services.
5. The integration of Lean and Six Sigma has become known as Lean Six Sigma. Lean focuses on efficiency and Six Sigma focuses on how effectiveness can lead to faster results than either method applied independent of the other.

A Truly Lean Introduction

Lean is the process of optimizing systems to reduce costs and improve efficiency by eliminating product and process waste. The emphasis is on eliminating non-value-added activities such as producing late services, defective products, excess inventory charges and excess finished goods inventory, excess internal and external transportation of products, excessive inspection, and idle time of equipment or workers due to poor balance of work steps in a sequential process. The goal of Lean has long been a goal of industrial engineering—to improve the efficiency of all processes.

As Shuker states in his article "The Leap to Lean," creating a lean organization encompasses the delivery of goods and services using less of everything: less waste, less human effort, less manufacturing space, less investment in tools, less inventory, and less engineering time to develop a new product, and less motion, for example. Lean manufacturing was a process management philosophy derived mostly from the War Manpower Commission, a World War II U.S. agency, which led to the Toyota Production System (TPS) and from other sources. The War Manpower Commission is renowned for its focus on reducing the original Toyota seven deadly wastes: overproduction, wait time, transportation, processing methods, inventory, motion, and defects (sometimes called the eight deadly wastes) in order to improve overall customer satisfaction. The eighth deadly waste was the waste of people's unused creativity. Lean is often linked with Six Sigma because of that methodology's emphasis on reduction of process variation (or its converse smoothness) and Toyota's combined usage (with TPS). Although Lean concepts began in manufacturing operations, it has been successfully applied in many industries as diverse as hospital patient care, internal auditing, and insurance customer service. Lean principles can be applied in most processes because mosty all contain waste that a customer is not willing to pay for, nor is the business willing to accept higher costs because of them. For additional information the TPS please reference Spear and Bowen's article in the Harvard Business Review entitled Decoding the DNA of the Toyota Production System.

For many, Lean is the set of TPS "tools" that assist in the identification and steady elimination of waste (*muda* in Japanese terminology), the improvement of quality in production time, and costs. This and other Japanese terms used by Toyota are strongly represented in the Lean vernacular. To solve the problem of waste, Lean has several tools at its disposal, including continuous process improvement (*kaizen*) 6S, and mistake proofing (*poka-yoke*). In this way, Lean can be seen as taking a very similar approach to other improvement methodologies.

The second, and complementary approach to Lean, which is also promoted by the TPS, is the focus upon improving the "flow" or smoothness of work (thereby steadily eliminating *mura*, unevenness) through the system and not upon waste reduction per se. Techniques to improve flow include "production leveling," "pull production" (by means of *kanban*, signboard or billboard), and the *Heijunka* box (achieving smoother production flow).

Lean implementation and the TPS are therefore focused on getting the right things to the right place, at the right time, and in the right quantity to achieve perfect work flow while minimizing waste and being flexible and able to change. More importantly, all of these concepts have to be understood, appreciated, and embraced by the actual employees who build the products and therefore own the processes that deliver the value. The cultural and managerial aspects of a Lean organization are just as, and possibly more, important than the actual tools or methodologies of production itself.

Lean in Nonmanufacturing-Based Industries

Lean methods and tools have made their way into most industries. A method that was used in manufacturing to reduce waste is now used to improve cycle time, flow, and velocity, improve workplace department performance and, yes, reduce waste in hospitals, insurance companies, financial services, and more. Here is one example from a hospital (Volland 2005):

Adapted from *A Case Study: Now That's Lean*

Jennifer Volland

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In the hopes of improving workflow and patient throughput, the Nebraska Medical Center (Omaha) began implementation of Lean Six Sigma in December 2002. As a 735-bed nonprofit hospital, the center is the largest teaching hospital in Nebraska with both academic and private practice physicians. One of the first Six Sigma projects for the organization was in the Interventional Radiology (IR) department, where such invasive procedures are performed.

A project team—which included the lead nurse scheduler, lead technologist, and department manager—was assembled to address patient throughput problems. Physician involvement was initiated early with ongoing input and information sharing for process improvements.

The project team defined physicians who referred patients into the IR department as their primary customer. They quickly realized that current volumes supported by the department did not fully meet the needs of referring physicians. Patients were lost to other healthcare systems that could accommodate the additional patients within the community, resulting in loss of revenue and market share.

The project team measured the cycle time of each step to determine where to best focus improvement efforts. Reducing holding room (HR) time quickly became evident as an area of opportunity. A patient's HR time averaged 151 minutes with a standard deviation of 242.4 minutes (February 4-19, 2003). Upon further examination, however, many more problems were identified. First, patient flow coordination from the HR into one of three procedure rooms was problematic because of different equipment in the rooms. Often, the nurse scheduler was pulled to function as the department appointment scheduler as well as the person coordinating patient flow. The duality of tasks created problems for timeliness in appointment scheduling with the referring clinics and flow of patients through the HR.

Changes made during the Lean Six Sigma implementation had a significant impact on the amount of time patients spent in the HR. The amount of time a patient spent in the HR, after the improvements, averaged 32.7 minutes with a standard deviation of 37.71 minutes (March 17-24, 2003). Follow-up monitoring during the control phase showed sustained improvements, with the HR time leveraging 31.02 minutes and a standard deviation of 24.86 minutes (October 29-December 16, 2003).

Lean techniques applied within the IR department resulted in improved processes and an ability to better meet customer expectations. As a result of the project, referring clinics were successfully able to feel the impact of changes for improved interventional radiologists within the department. Not only were the changes significant, but, post-project, the department as been able to successfully sustain the gains made in the HR.

Reducing Waste Alone Is Not Lean

It is not enough to just believe "if I eliminate the nonvalued waste we will be Lean." This is only one aspect of a Lean organization. Although the elimination of waste may seem like a simple and clear subject, it is noticeable that waste is often very conservatively identified. This then hugely reduces the potential of an organization. Although the elimination of waste is the goal of Lean, the TPS defines three types of waste: *muri* or overburden, *mura* or unevenness, and *muda* or non-value-added work.

Muri is all the unreasonable work that management imposes on workers and machines because of poor organization, such as carrying heavy weights, moving things around, dangerous tasks, and even working significantly faster than usual. *Muri* is pushing a person or a machine beyond its natural limits.

Mura focuses on implementing and eliminating fluctuation at the scheduling or operations level, such as quality and volume.

Muda is discovered after the process is in place and is dealt with reactively rather than proactively with *muri* and *mura*. It is seen through variation in output (which as mentioned earlier) can blend well with Six Sigma applications. It is the role of management to examine the *muda*, or waste, in the processes and eliminate the deeper causes by considering the connections to the *muri* and *mura* of the system. The *muda* (waste) and *muri* (overburden) must be fed back to the *mura* planning stage for the next project.

More often than not, most organizations improperly only focus on *muda* or non-value-added waste and fail to understand this approach is reactive and will only partially position the organization for success (if at all). One must ensure that all three waste types are addressed.

Muri can be avoided through standard work disciplines. To achieve this, a standard condition or output must be defined. Then every process and function must be reduced to its simplest elements for examination and later recombination. This is done by taking simple work elements and combining them, one by one, into standard work sequences.

Mura is avoided by using Just-in-Time (JIT) systems that are based on little or no inventory by supplying the production process with the right part, at the right time, in the right amount, and first-in, first out component flow. JIT systems create a "pull system" in which each subprocess withdraws its needs from the preceding subprocesses, and ultimately from an outside supplier. When a preceding process does not receive a request or withdrawal, it does not make more parts.

To properly manage outcomes in a Lean organization, you must ensure that all three types of waste are managed and controlled. Demand and capacity must be balanced to that demand must be fully understood. Current state conditions must be understood in order to move to future state pull production and the elimination of non-value added activities creating waste. Standard work must be institutionalized, which alleviates overburdening associates as they perform activities. These activities will create the model for cultural transformation from a batch-and-queue operation to an operation with synchronous flow, team-based activities, and a true focus on the customer mindset.

Lean Manufacturing Case Study

AGC Flat Glass North America, a wholly owned subsidiary of the world's second-largest glass producer, Asahi Glass Company, operates 45 facilities throughout North America, and all were experiencing pressure to provide the lowest total cost product with rapid order fulfillment in a highly competitive market. In September 2006, AGC launched an initiative to drive operational excellence and improve profitability. This initiative was coined JPI (Jikko Process Improvement) by AGC and is based on the principles of the TPS and Lean enterprise.

One of the first facilities to implement the JPI process was AGC Hebron, a fabrication facility located near Columbus, Ohio. Hebron serves the Ohio market and neighboring states. Hebron receives glass from one of AGC's primary glass facilities and transforms these raw materials into a number of end products, including single-pane products, sealed insulated units for window manufacturing, and tempered (heat-treated) glass for safety applications. The Hebron fabrication processes include cutting, tempering, and insulating unit assembly. An initial assessment of the facility was performed, and the results indicated that manufacturing lead times were exceeding seven days with wide swings up to weeks in some cases. Excess inventory made it nearly impossible to quickly find a specific job or determine what to fabricate next. There was also a concern for employee safety, specifically increased risk of injury attributed to the large cut-glass inventory. Wide swings in product demand placed on manufacturing also served to complicate the business. Some days, the plant capacity was underutilized while other days customer demand exceeded capacity by twofold.

A cross-functional team was formed to drive the improvement efforts. Team members included sales, production control, purchasing, production employees, corporate JPI members, and a transformation coach. In the first days, the team was introduced to the concepts of the TPS and Lean manufacturing.

One of the first things the team quickly developed was a "Current State Map," a valuable tool to understand the actual situation on the production floor and in-order fulfillment activities. Once completed, the current state map clearly told the present story and set a firm direction for future improvement.

The first step to improve the efficiency of the workplace focused on implementing the 6S (sort, set-in-place, sweep/shine, standardize, self-discipline and safety) process. After the initial training, the team began to attack waste; sorting unnecessary items from needed items, implementing visual control for tools and materials, cleaning everything, and putting in place a robust auditing system to sustain the gains. From there, the team focused on their "Current State Map." Points of delay and inventory builds were addressed and, in most cases, eliminated. Equipment was relocated to aid product flow, which reduced movement and product queues. To further consolidate inventory, over half the material-handling racks used to store glass were removed. The reduction in inventory in a matter of days translated to improved lead times to the customer. At this point, the Hebron team adopted the motto, "There is no tomorrow." A key to a Lean enterprise and the TPS inherent in this philosophy is the idea that customer delivery requirements will be met and that all products can and will be produced in a single day to customer demand and pull. This expectation was well within the plant capabilities for cycle times. The team also studied demand patterns compared to the demonstrated capacity. Once this relationship was understood and lead times were reduced, the plant could successfully be level loaded, thus further solidifying delivery reliability to levels above 99 percent on time. This percentage was well above historic levels. The improved product flow quickly identified quality issues that were previously hidden by excess work in process. In the weeks that followed, a number of other enhancements were included such as improved equipment maintenance to assure reliability, mistake proofing methods, *kanbans* for supply replenishment, and a focus on faster changeovers. During the time the physical changes were occurring, another important transformation took place—the culture slowly changed. The plant began running differently. Employees knew what the customer needed by the hour and produced accordingly. Orders moved seamlessly through the operations without heroic efforts, making work life easier and, more importantly, safer.

Within weeks, the customers began to see and feel the changes. The new Hebron customer complaints turned to customer compliments. Overall demand steadily increased as past customers lost due to service issues began to return and new customers began to come to Hebron for their glass needs. The financial results followed as Hebron experienced a turn around in profitability. Commenting on profitability, Jerry Hackler, Hebron's Operations Manager remarked, "The effect of the bottom line came quickly. Even in the early months the facility generated more operating income on fewer sales, a clear indication of the cost improvement impact."

History of Lean

The history of manufacturing and the introduction of Lean are summarized in Figure 11.1. The Lean mission is to have the following throughout the entire supply chain to win the marketplace:

- Shortest possible lead time
- Optimum level of strategic inventory
- Highest practical customer service levels
- Highest possible quality (low defect rate)
- Lowest possible waste (low cost of poor quality)

This is accomplished by synchronizing the flow of work (both internal and external to the organization) to the "drumbeat" of the customer's requirements. All kinds of waste are driven out (time, material, labor, space, and motion). The overall intent is to reduce variation and drive out waste by letting customers pull value through the entire value stream (or supply chain).

In their book Lean Thinking, Womack and Jones state that the key principles of Lean are to

- Specify value in the eyes of the customer; the voice of the customer
- Identify the value stream for each product
- Make value flow without interruptions
- Reduce defects in products and deficiencies in processes
- Let customers pull value
- Pursue perfection—Six Sigma levels
- Drive out variation (short and long term)

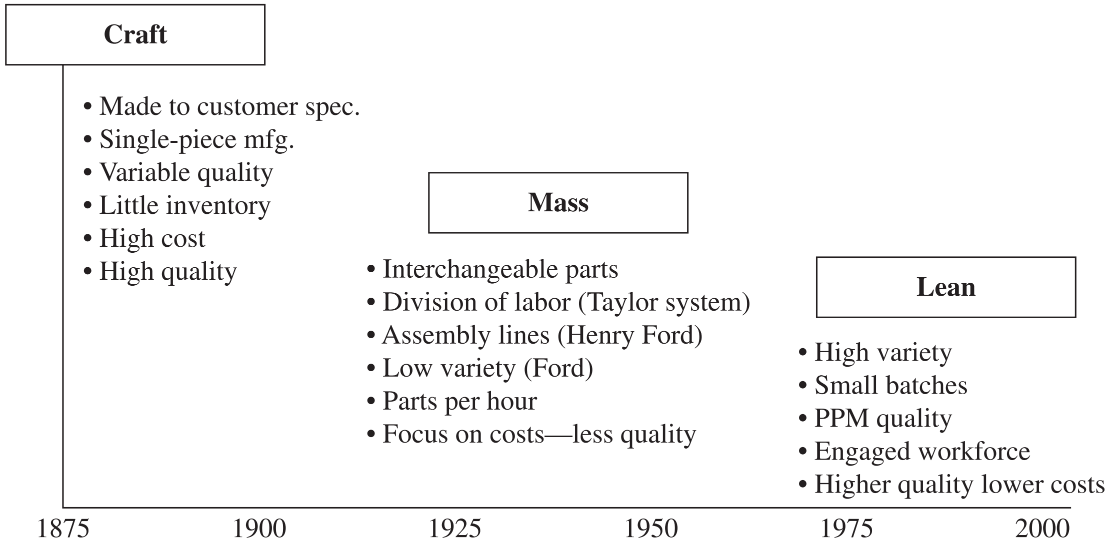


Figure 11.1 History of manufacturing.

The Relationship of Lean to Managing for Quality

One key component of being a Lean organization is the need to create "value" as seen from the eyes of the customers. The operational definition of value is the benefit the customer gains from using the product or service. Value is created by the customer. Providing value to the customer is why the producer exists. Lean starts with defining value in terms of products/services and benefits provided to the customer at the right time at an appropriate price. Anything that does not provide value to the customer can be considered waste (see Figure 11.2).

If we review the Juran Trilogy® in Figure 11.3, we can see that Lean supports the definition of quality in that all products and services must be "fit for purpose." Customers define quality as both the features and freedom from failures. Therefore, because Lean is about creating value by eliminating nonvalue, it is important to include in Lean the management of quality. Lean is used in quality control because it enables work to be standardized, leading to better compliance. Lean is used in improvement to decrease the costs of nonperforming processes in the form of waste reduction. Most recently, Lean methods are being used in quality planning to design for Lean. Designing for Lean is similar to designing for quality. An organization now must design a product or service so that it can flow easily with little disruption from customer need to customer use.

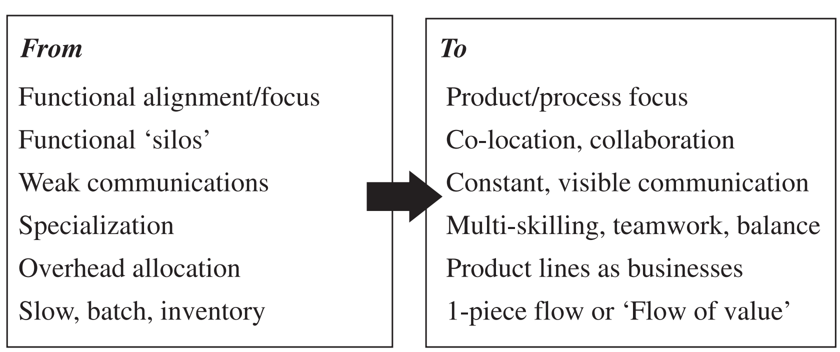


Figure 11.2 Lean characteristics.

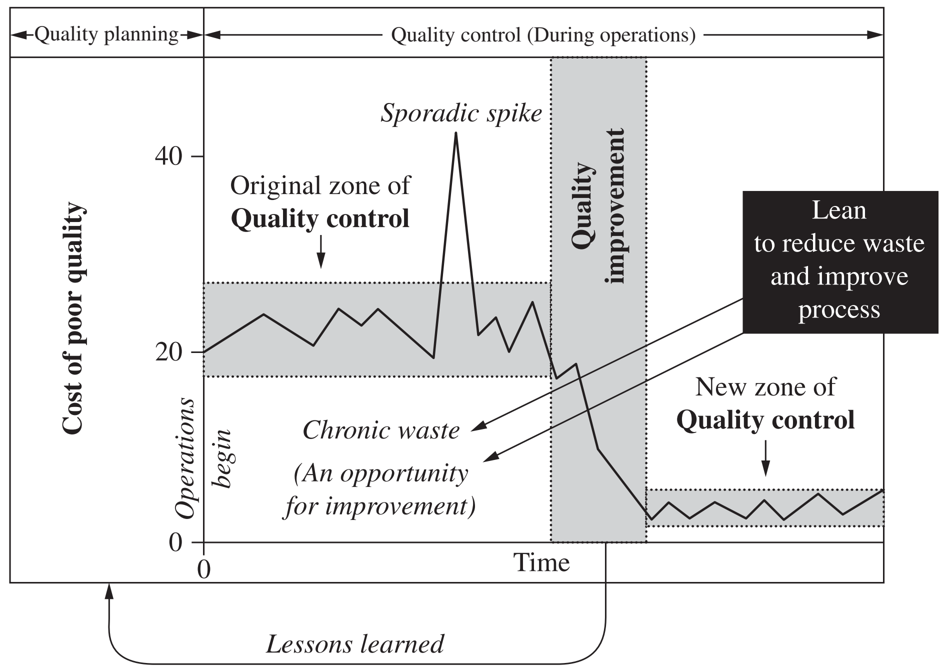


Figure 11.3 Lean and the Juran Trilogy®. (*Juran Institute, Inc., Southbury, CT.*)

The Eight Wastes

Taiischi Ohno (1988) identified seven types of waste that exist in most processes and organizational systems. These identifiable wastes lead to the cost of poor quality if they are not dealt with and removed. Lean practitioners and experts must focus on reducing or eliminating these wastes, part of a *kaizen* or Rapid Improvement Event.

The following includes Ohno's seven types of waste, which were focused on production in addition to the eighth waste (which seems to have no origin) directed at all processes.

1. *Overproduction*—making or doing more than is required or earlier than needed
2. *Waiting*—for information, materials, people, and maintenance
3. *Transport*—moving people or goods around or between sites
4. *Poor process design*—too many/too few steps, nonstandardization, and inspection rather than prevention
5. *Inventory*—raw materials, work in progress, finished goods, papers, and electronic files
6. *Motion*—inefficient layouts at workstations, in offices, poor ergonomics
7. *Defects*—errors, scrap, rework, nonconformance
8. *Underutilized personnel resources and creativity*—ideas that are not listened to, skills that are not used

The Lean Roadmap and Rapid Improvement Events

Six Sigma and Lean have both evolved over decades as part of the continuing revolution of quality, excellence, and breakthrough performance. Motorola created the term "Six Sigma" as it worked to raise the standard for improvement to new heights. Lean grew out of the experiences of the TPS.

Now Lean and Six Sigma have evolved to reflect today's core business challenges: the challenge to execute and to maximize value, as well as respond to "nanosecond customer" needs. Joe De Feo of Juran, refers to the speed at which today's demanding customers expect results. Lean and Six Sigma are now used for sustainable competitive advantage across all industries and cultures.

Every organization wants to be Lean and have

- The shortest possible process lead times for providing products and services
- The optimum level of strategic inventory and human resources
- The highest practical customer service level
- The highest possible quality (low defect rate)
- The lowest possible waste (low COPQ, cost of poor quality) . . . throughout the entire value chain

Although there have been numerous techniques and tools utilized in Lean implementation, most Lean practitioners did not have a Lean model until the collaboration with Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control). The Juran Lean Roadmap in Figure 11.4

Define value

1. Define stakeholder value and critical to quality (CTQ).
2. Map high-level process.
3. Assess for 6S.

Measure value

1. Measure customer demand.
2. Plan for data collection.
3. Create a value stream attribute map.
4. Determine pace, Takt Time and manpower.
5. Identify replenishment and capacity constraints.
6. Implement 6S (S1–S3).

Analyze process—flow

1. Analyze the value stream attribute map.
2. Analyze the process load and capacity.
3. Perform value added/non-value added analysis.
4. Apply Lean problem-solving.

Improve process—pull

1. Conduct rapid improvement events (RIE).
2. Design the process changes and flow.
3. Feed, balance, and load the process.
4. Standardize work tasks.
5. Implement new process.

Maintain control

1. Stabilize and refine value stream.
2. Complete process and visual controls.
3. Identify mistake-proofing opportunities.
4. Implement 6S (S4–S6).
5. Monitor results and close out project.

Figure 11.4 Lean Six Sigma roadmap and substeps.

is an example of a model designed to carryout "Lean projects or events." It provides the five DMAIC steps as in Six Sigma and includes the lean tasks. This set of steps provides a Lean or "Lean Six Sigma" practitioner with a reminder to focus both on efficiency and effectiveness.

Figure 11.5 provides a tool grid to demonstrate tools that can be used at every step in the method. Each of the tools in this grid can be found in this chapter as well as in Chapter 18, Core Tools to Design, Control, and Improve Performance and Chapter 19, Accurate and Reliable Measurement Systems and Advanced Tools.

Rapid Improvement Events or *Kaizens*

Rapid Improvement Events (RIE) or *kaizens* are typically one-week focused efforts that are facilitated and conducted by Lean Experts or Black Belts to enable Lean teams to analyze the value streams and quickly develop/implement solutions in a short time-frame. These events have application in offices, service organizations, health care arenas, and manufacturing operations and consistently yield tremendous, real-time improvement. *Kaizen* is the Japanese word for incremental improvement. It has become associated with the use of small teams carrying out improvements on a regular basis. It is often used as a name for all encompassing continuous improvement methods. We have chosen to use it as it is defined: a small improvement that is made on a regular basis. RIE or *kaizen* teams are multifunctional so that all aspects of the process and problems associated with them are considered and soutions developed will be understood and accepted by all. Rapid improvement teams are fast because Lean is easier than, say, Six Sigma. Rapid improvement teams are fast because they tackle focused projects bit by bit. They also tackle problems where the data are typically readily available.

This technique is a good tool to involve all levels of the workforce. It can help build an empowered and engaged workforce. RIEs can be used to identify and solve departmental problems as well.

What Do RIE and *Kaizen* Teams Do

A Lean Expert or a Black Belt works with management to select the area to focus the improvement on. They then carryout the following preparations for the events.

1. One to three weeks prior to conducting the event the expert assembles the team, facilitates development of a charter and gathers as much data as possible surrounding the area to be improved. The type of data depends on the area selected but typically includes a manufacturing area of focus:
   a. Process flow diagrams for each product or product family (if available)
   b. Yields by operation
   c. Setup time by operation
   d. Changeover time by operation
   e. Average WIP (work in progress) inventory levels between operations
   f. Average materials inventory
   g. Average finished goods inventory
   h. Cycle times by operation
   i. Average daily customer demand by end item
   j. Monthly customer demand by end item

LEAN	LEAN TOOLS																																			
	6S	Basic Statistics/Graphs	Brainstorming/Affinity	Cause-Effect Diagram/5 WHYS	Control Plans	CTQ Matrix	Data Collection	FMEA	Kanban Calculator	Load Charting	Mistake Proofing	MSA	Pareto Analysis	Poka Yoke	Process Load Calculator	Process Modeling	Production Control Board	Product Quantity Analysis	Product Routing Analysis	Project Charter	Reliability Centered Maintenance	Rapid Improvement Events	S1-S3 Planning Document	Selection Matrix	SIPOC	SMED	Sort Sheet	SPC/Control Charts	Standard Work Diagrams	Stratification	Supermarket	Takt Time	Theory of Constraints	TPM	VNVA	Value Stream Mapping
Select Projects		X	X										X					X	X					X				X		X						
Define Demand																				X																
a. Verify/ Refine Project Charter			X				X																	X						X						
b. Confirm the Value Stream Improvement Focus																		X	X																	
c. Determine Stakeholder Value & CTQs						X	X						X																							
d. Map High-Level Process																									X											
Measure Value Stream																																				
a. Define Customer Demand							X																							X		X				
b. Plan for Data Collection							X																							X						
c. Validate Measurement System		X										X																								
d. Create a Value Stream Map																									X											X
e. Identify Replenishment and Capacity Constraints							X			X					X														X				X			
f. Implement 6S (S1-S3)																							X				X									
Analyze Process – Flow																																				
a. Analyze the Value Stream Attribute Map																																				X
b. Analyze the Load Chart							X			X																						X				
c. Analyze Capacity							X								X	X																				X
d. Perform VA/NA Decomposition Analysis							X																												X	
e. Apply Lean Problem Solving to Special Cause				X																																
Improve Process – Pull																																				
a. Conduct the RIE								X														X														
b. Design the Process Changes and Flow																																				X
c. Feed, Balance, Load the Process									X	X																X					X					
d. Standardize Work Tasks																													X							
e. Implement New Processes																	X				X													X		
Maintain Control																																				
a. Stabilize and Refine Value Stream																	X				X													X		
b. Complete Process and Visual Controls					X			X																				X	X							
c. Identify Mistake-proofing Opportunities											X			X	X																					
d. Implement S4-S6	X																																			
e. Monitor Results & Closeout Project																												X								

FIGURE 11.5 Lean methods and tools.

k. List of suppliers including items supplied, amounts, annual dollar value, and delivery frequency
l. Material move/store times
m. Material move distances
n. Inspection frequencies and sample sizes
o. DPMO (Defects per Million Opportunities) or Sigma levels of each process

2. One week prior to the event, the team is trained in basic methods and tools of Lean.
3. Event week—the team begins by validating the current state Value Stream Maps and develop "Future State" maps, define customer demand, pace, balance the work, define standard work, and implement improvements.
4. After Event—ensure controls are in place; monitor progress.

During the event the teams may conduct multiple small assignments. Some of the more important ones are

- Begin current state Value Stream Map
- Understand the data that is available and collect as much needed data as possible.
- Ensure the availability of equipment
- Implement S1, S2, and S3 of 6S (sort, set in order, shine, standardize, sustain, and safety)
- Validate value stream maps—understand the "before" values
- Study current conditions
- Complete the following:
  - VA/NVA Decomposition Analysis
  - Current State Load Charts, Spaghetti Diagrams, Standard Worksheets
  - Review Current State Analyses
  - Design the Future State and design control sheets
- Develop Future State Standard Work
- Implement changes (big moves)
- Implement Control Boards
- Review standard work, standard work-in-process, needed fixtures, etc
- Finalize flow, procedures, standard work, and Production Control Board
- Present results to management and celebrate

Pull versus Push Systems

Traditional operations have worked within a push system. A push system computes start times and then pushes products into operations based on demand. This approach ignores constraints or bottlenecks within the process and can cause unbalanced flow and excess WIP inventories. A pull system, by contrast, only produces when authorized to do so and based on the process status.

Pull systems produce faster than push systems, and, by nature, pull production controls and enhances flow. The goal should always be to pull to customer demand.

Lean Value Stream Management

Lean focuses on finding value streams. These value streams consist of all activities required to bring a product from conception to commercialization. They can include all key business processes such as design, order taking, scheduling, production, sales, marketing, and delivery. Understanding the value stream allows one to see value-added steps, non-value-added but needed steps, and non-value-added steps. Value-added activities *transform* or shape material or information into something that meets customer requirements. Non-value-added activities take time or resources, but they do not add value to the customer's requirement (but they may meet the organization's requirements). The value stream improvement journey typically starts with training the team on key concepts of Lean and mapping the *current state* using value stream maps that document materials and information flow as well as any pertinent information on the process (such as cycle times, downtime, capacity, wait times, yield, and inventory levels).The goal is to identify all the necessary components to bring a product to commercialization, as well as all waste inherent in the process. Improvements are identified from here. The desired future state is then documented as a *future state value stream map*, and the improvements are implemented to drive toward the desired future state goal.

Value streams can be mapped for a single product or service but, more often, a process supports more than one single-ended item. When products share the same design and fabrication processes, they are called a *product family*. In practice, value stream maps are frequently developed around a product family. It is not uncommon for maps to commingle with other product families as they progress through the process.

As mentioned above, a value stream comprises all the tasks currently required to move the product family though its process. There are three typically mapped cycles: Concept to launch (the design cycle), raw materials to customer (the build cycle), and delivery to recycling (the sustain cycle). The build cycle is the most commonly mapped.

An example of a value stream map for a paint line showing both the current state and future state are shown in Figures 11.6 and 11.7. There are a number of excellent sources for the techniques of mapping the value stream such as Learning to See (Rother and Shook 2003), Value Stream Management (Tapping, Luyster, and Shuker 2002), and Creating Mixed Model Value Streams (Duggan 2002). To be most effective, mapping should include all process steps involved, including suppliers and customers. Specific attributes, including information flow, for each step should be well documented and verified. These data should be as realistic as possible and show variation within the attributes if it exists. These data will be the starting point developing the future state map, which incorporates improvements and waste reduction.

Impact of Demand

The impact of demand on an operation cannot be understated. A key component to satisfying the customer is understanding their demands of the product. This is one of the single most important elements within the value stream. It is important to understand the pattern of demand as well, whether growing or declining, seasonal, or stationary. The producer must react quickly and effectively to changing demand to assure delivery reliability and cost effective operations. Demand variability can be mix driven, quantity driven, or as often the case, both. Demand variability can adversely affect delivery reliability, product quality, inventory costs, and total cost, among others, all with negative consequence to the customer. Demand is also utilized to determine Takt Time (from the German *Taktzeit*), the rate at which customers buy a single unit. Takt Time is discussed later in the chapter. Changing demand causes changes in Takt Time, which causes changes to required resources. If this flux is not understood and managed correctly, many of the adverse effects mentioned will quickly become a reality. It is recommended that if demand varies significantly, multiple Value

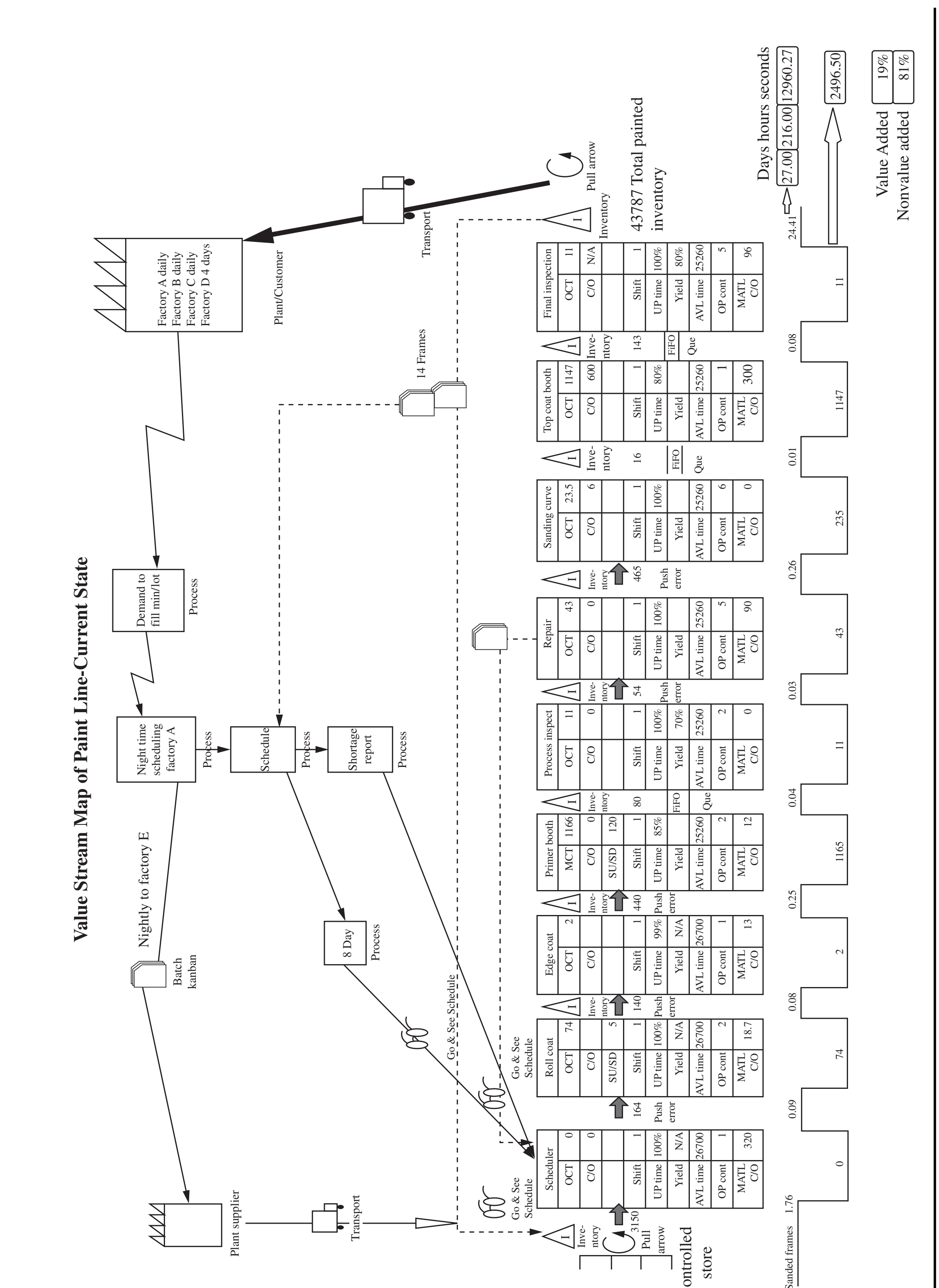


FIGURE 11.6 Value stream map for paint line—current state.

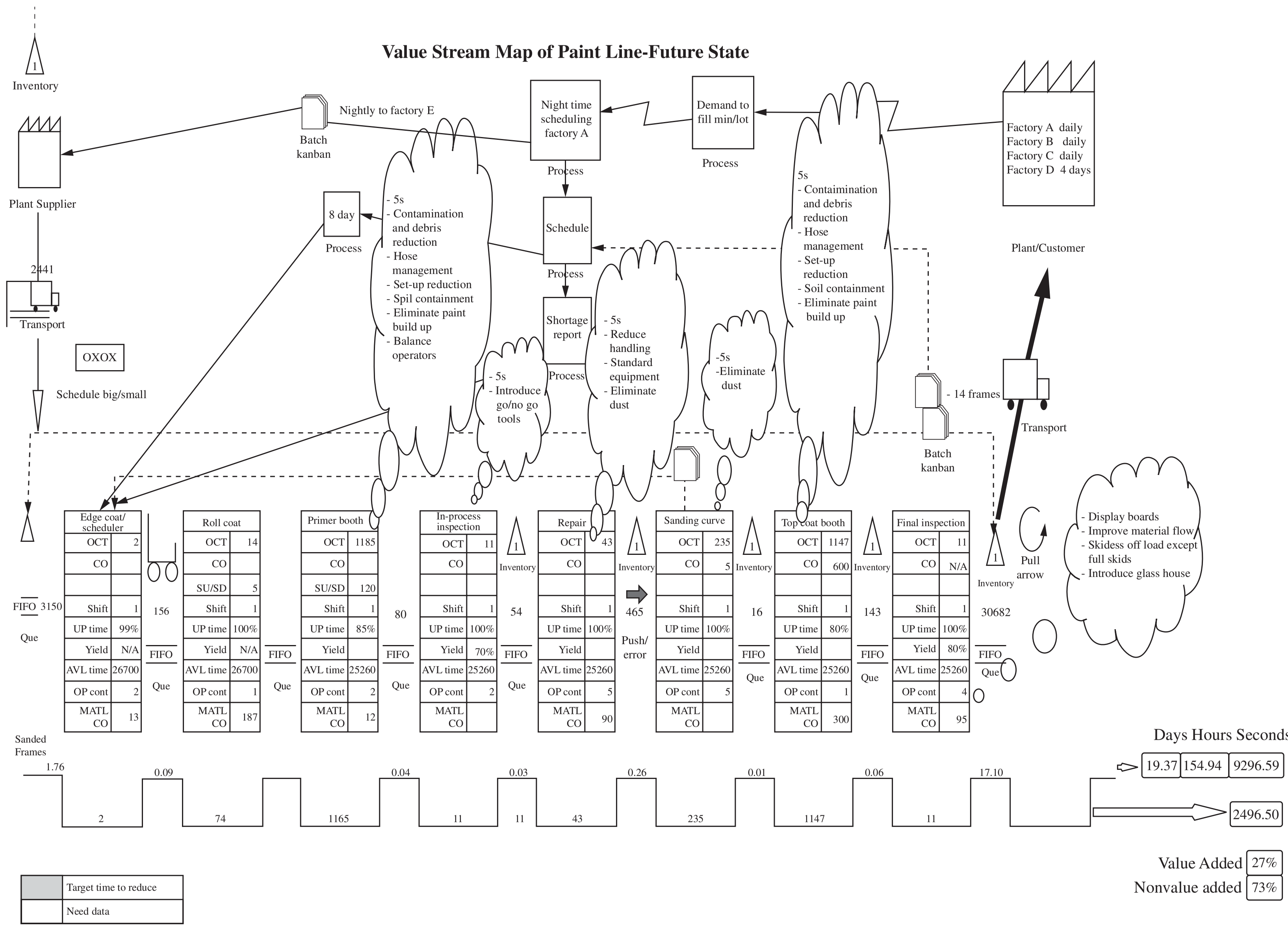


FIGURE 11.7 Value stream map for paint line—future state.

Streams be developed; each with the specific Takt Time and specific resources to match customer expectations.

Capacity and Demand

Capacity and demand must balance to ensure proper flow. With too little capacity, you have unhappy customers; with too much capacity, you have waste. Capacity is the amount of output that a system is capable of sustaining over a given time. It is loosely calculated as Available Time divided by the longest Cycle Time. Theoretical capacity (also called engineered capacity or maximum capacity) can be thought of as output at the ideal state. This may be nameplate output information of a machine. It operates under perfect conditions, which are not realized in most facilities. On the other hand, demonstrated capacity can be calculated based on current, real-life situations. The difference between theoretical capacity and demonstrated capacity is improvement opportunity.

Demand should not be confused with capacity. Demand is the customer's requirements and is independent of the producer's abilities.

Value/Non-Value-Added Decomposition Analysis

The main goal of Lean is to identify and eliminate waste. This can be accomplished once we have a solid understanding of the process as it currently is. This is the first step to improvement; determine what is of value to the customer and what is not. As mentioned above, anything that does not provide value to the customer can be considered waste. If constructed carefully, the current state map will provide a wealth of opportunity for improvement. The basic premise of value/non-value-added decomposition analysis simply is to ask the question, is the customer willing to pay for this? This should be performed for each process step. If not, what can be done to reduce the waste or completely eliminate the waste all together? In some cases, due to the current capability of the process, a non-value-added activity is still required, at least for the time being. An example of a non-value-added, but necessary, task would include inspections or other quality checks. This activity will remain in place to ensure customer satisfaction until the process can be made robust enough not to require the non-value-added activity.

Flow and Takt Time

The concept of flow requires the rearrangement of mental thoughts regarding "typical" production processes. One must not think of just "functions" and "departments." We need to redefine how functions, departments, and organizations work to make a positive contribution to the value stream. Flow production requires that we produce at the customer's purchase rate and if necessary, make every product every day to meet customer's orders, i.e., to meet the pace or "drumbeat." The pace or drumbeat is determined by Takt Time. Takt Time comes from the German word for meter, as in music, which establishes the pace, or beat, of the music. It is the time that reflects the rate at which customers buy one unit.

$$\text{Takt Time} = \frac{\text{Available time (in a day)}}{\text{Average daily demand}}$$

For example, in Figure 11.8, the pace or Takt Time is calculated for the demand shown during a 10-day period.

Takt Time Calculation Example

To be practical, Takt Time may need to be modified, depending on the variability of the process. When modifying Takt Time beyond the simple equation, another name should be used,

Determine pace

Over 10 days	Demand
1	30
2	40
3	50
4	60
5	10
6	30
7	40
8	20
9	60
10	40
10	**380**

Per day:

$$\frac{\text{Time available in period (840 min.)}}{\text{Average demand (38)}} = \textbf{22.1 minutes}$$

Based on 2 shifts of 7 hours

Figure 11.8 Takt Time calculation example.

such as Cell Takt, Machine Takt, or Practical Takt. Although modifiers may be planned, they are still waste, or planned waste. Manpower staffing requirements can then be determined as follows:

$$\text{Minimum staffing required} = \frac{\text{Total labor time in process}}{\text{Takt Time}}$$

6S—A Plan for Neat and Clean Workplaces

Many workplace departments are dirty and disorganized. The benefits of an efficient and effective workplace include the means to prevent defects; accidents; and the elimination of time wasted searching for tools, documentation, and other important items to complete a work process. By focusing on the removal of the dirtiness and organizing the workplace departments, they will perform work safer, faster, and cheaper.

A simple tool called 6S now provides us with a framework to create a neat and clean workplace. Its steps are as follows:

- *Sort.* Remove all items from the workplace that are not needed for current operations.
- *Set in order.* Arrange workplace items so that they are easy to find, to use, and to put away.
- *Shine.* Sweep, wipe, and keep the workplace clean.
- *Standardize.* Make "shine" become a habit.
- *Sustain.* Create the conditions (e.g., time, resources, rewards) to maintain a commitment to the 6S approach.
- *Safety.*

Decades ago, industries producing critical items (e.g., health care, aerospace) learned that clean and neat workplaces are essential in achieving extremely low levels of defects. The quality levels demanded by the Six Sigma approach now provide the same impetus.

Perhaps the significance of the 6S approach is its simplicity. The benefits are obvious: The tools are the simplest work-simplification tools and are easy to understand and apply. Simple tools sometimes get dramatic results, and that is what has happened with 6S. For elaboration of the five steps (excluding safety), see The Productivity Press Development Team (1996); Figure 11.9.

6S should be implemented throughout the improvement process and sustained into the future, adjusting as needed. 6S provides a solid foundation for most all Lean tools and techniques.

A note on safety: Once the first 5Ss are firmly in place, a remarkable thing happens, the workplace becomes safer. Very often, no additional effect is required to achieve this benefit. With the work area sustaining organization and cleanliness, a 50 percent reduction in work related safety incidences can occur. Combining the 5S with a formal safety program can deliver amazing results, and it is called 6S for "success."

Inventory Analysis

Inventory is the amount of stock of any item or resource in an organization. In manufacturing inventory normally includes raw materials, finished goods, component parts, supplies, and Work in Progress (WIP). The purpose of inventory is to manage variation (demand, delivery, and the process itself), ease production scheduling, reduce setups, and balance the

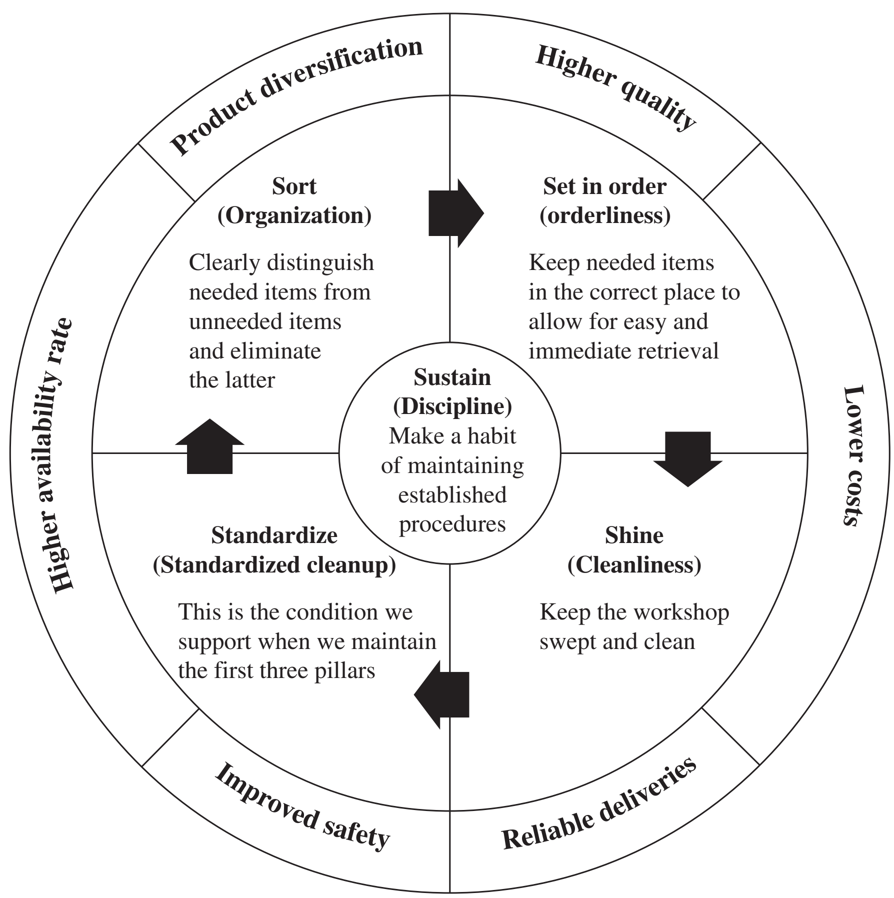


Figure 11.9 The 5S concept. (*The Productivity Press Development Team (1996). Reprinted with permission of Productivity Press.*)

quantity of the economic order. Although a certain volume of inventory can have strategic value, inventory is most often viewed as waste. Waste is the cash tied up in the materials and labor, and waste in storage and movement. Inventory is also open to damage, theft, and obsolescence. The aim of Lean is to reduce, if not eliminate, inventory.

There is a place for inventory besides in the hands of the customer. Inherent variation occurs in every process daily. Strategic inventories can compensate for process efficiencies and buffer customer demand fluctuations. Inventory is strategically placed and is set with calculated minimum-maximum stocking levels to ensure optimum flow through the process. When calculating stocking levels, one should consider customer demand (and variation), quantity consumed during replenishment, cycle time intervals for replacement, and impact of flow disruptions.

A regularly overlooked source of waste related to inventory is inventory inaccuracies. The differences between actual counts and recorded counts (commonly known as "book to actual") can be costly to both the producer and the customer. Measuring this difference can be the first step in improving accuracy. Another approach to improvement is cycle counting. Cycle counting is a physical inventory-taking task in which inventory is counted frequently rather than once or twice a year. Benefits of a more perpetual approach include more accurate inventory records, less overproduction, and less stock-outs and can be prioritized based on value.

Inventory in all its forms should be eliminated, or at least minimized. When developing the process improvements, the Lean practitioner should review each point of inventory and ensure continuous flow, and, if necessary, set a countermeasure inventory against variation. The educational society American Production & Inventory Control Society (APICS, now the Educational Society for Resource Management) provides an excellent source of information supporting resource management. Using the Lean Inventory Analysis Tool can reduce the inventory by matching it to the level of demand that occurs in your supply chain.

Little's Law

In our quest to achieve a Lean environment, we are fortunate to have a very simple, yet powerful, relationship known as Little's law. Simply stated, Little's law is a straightforward mathematical relationship among WIP, lead time, and the process' throughput. Little's, law:

$$\text{WIP} = \text{TP} \times \text{LT}$$

where WIP = work-in-process, TP = throughput, and LT = lead time.

Rewritten:

$$\text{LT} = \frac{\text{WIP}}{\text{TP}}$$

This relationship shows that by reducing WIP, we can directly improve time to the customer through reduce lead time. It also states that if WIP inventories are allowed to vary, so will lead times. In other words, if WIP is held constant. so will lead times (see Figure 11.10).

Managing and Eliminating Constraints

A constraint is anything that limits a system from achieving higher performance or throughput. Constraints can come in many forms, including:

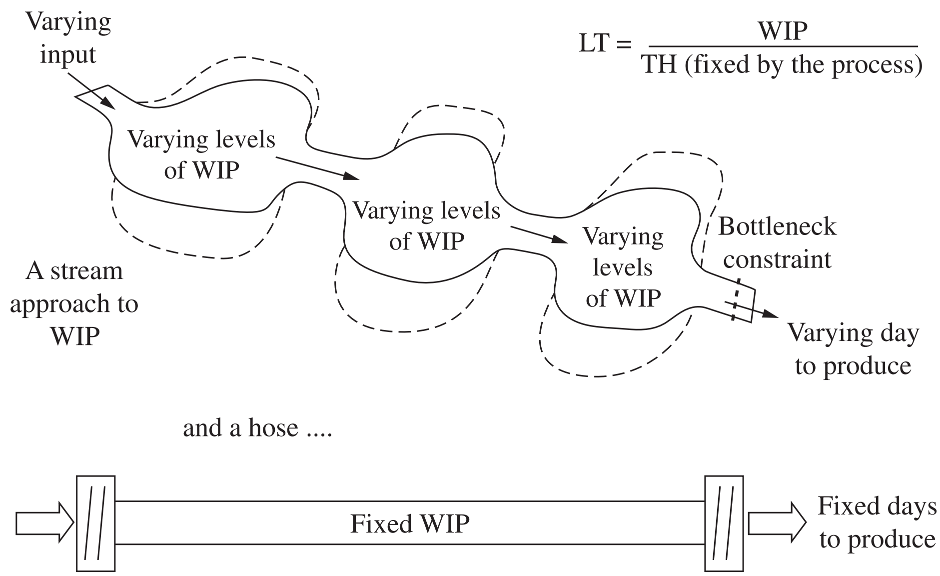


FIGURE 11.10 Little's law.

- *Equipment*. capacity, speed, capability
- *Labor*. supply, skills
- *Information*. speed, accuracy
- *Suppliers*. reliability, quality

This is an important concept when evaluating the current state value stream. When evaluating the value stream, special attention should be paid to the constraint. An improvement in any other area is, by definition, a waste; improvement should occur at the constraint. Once this resource is no longer a constraint, another resource will be the rate-limiting step. Focus should then move to the new constraint. The goal for a manufacturing organization is to drive the constraint to sales.

Goldratt's Theory of Constraints (Goldratt 1992) offered a five-step process for addressing constraints, involving the following:

- Identifying the constraint
- Deciding how to exploit the constraint
- Subordinating all else to the above decision
- Elevating the performance of the constraint
- Moving to the next constraint and go back to step 1

As we can see, this is an ongoing process to drive continuous improvement.

Improving the Process and Implementing Pull Systems

Once Takt Time has been calculated, each constraint (such as long setup times) should be identified and managed (or eliminated) to enable smaller batch sizes. Ideally, this leads to single-piece flow. If this reduction can be achieved, it will eliminate overproduction and excess inventories. Pull production scheduling techniques are used so that customer demand pulls demand through the value stream (from supplier to production to the customer). In pull production, materials are staged at the point of consumption. As they are consumed, a signal is sent back to previous steps in the production process to pull forward sufficient materials to replenish only what has been consumed.

The steps for improvement teams (or *kaizen* teams) to Lean out an operation are as follows:

- Determining the pace (Takt Time and manpower)
- Establishing sequence and replenishment (product family turnover and setup/changeover required)
- Designing the line or process (proximity, sequence, interdependence)
- Feeding the line or process (strategic inventory, standard WIP)
- Balancing the line or process (load, standard work)
- Stabilizing and refining (6S, continuous improvement)

Competitive pressures to reduce lead time are now a driving force to analyze processes for improvement. A flow diagram or preferably a Value Stream Map can reveal a wealth of sources for improvement such as:

- The number of functions and how they interact
- The extent to which the same macroprocess is used for the vital few customers and the useful many
- The existence of rework
- The extent and location of bottlenecks, such as numerous needs for signatures
- The location and amount of inventory

Numerous ways have been found to shorten the cycle time for processes. These include:

- Providing a simplified process for the useful many applications
- Reducing the number of steps and handoffs
- Eliminating wasteful "loops"
- Reducing changeover time
- Managing the constraint or bottleneck resource
- Reducing inventory

Physical Design and Proximity

As the Lean practitioner continues to evaluate the value stream for opportunities, it is not uncommon to find movement to be a waste. This is due to sequential operations not being in close physical proximity, as is often the case with departmentalized facilities. Simply moving processes closer together can improve flow and reduce waste of all types. When we expand this idea and group all the interdependent assets into a "cell," the benefits can be become even more significant. The cellular design will minimize space; a 50 percent reduction is common.

Cells should also be designed so that the steps are interdependent and run to the same Takt Time or pace. This approach will reduce inventory, reduce cycle times, and provide immediate quality feedback.

Another approach to aligning resources is the idea of group technology. Group technology is the process of examining all items produced by an organization to identify those with sufficient similarity that common design or manufacturing plans can be used. This would reduce the number of new designs or new manufacturing plans. In addition to the savings in resources, group technology can improve both the quality of design and the quality of conformance by using proven designs and manufacturing plans. In many companies, only 20 percent of the parts initially thought to require a new design actually need it; of the remaining new parts, 40 percent could be built from an existing design, and the other 40 percent could be created by modifying an existing design. Relocating production machines can also benefit from the group technology concept. Machines are grouped according to the parts they make and can be sorted into cells of machines, each cell producing one or several part families.

Balancing the Process

When designing improvements into a future state, smooth and sequenced flow is critical. The design should be balanced from step to step. Make process steps interdependent, and run to the same Takt Time with minimum inventory and the smallest lot sizes possible. In addition to reduced lead time as calculated by Little's law, this approach provides immediate quality feedback. As operations approach a continuous flow and single-piece processing, wastes will be quickly eliminated. Allocation of resources (people and equipment) to accomplish a series of tasks is minimized toward the idle point. Often, by combining work, the process can reduce the required resources by balancing new combined cycle times as close as possible to one another.

Kanbans: Signal to Produce

As mentioned earlier, nonstrategic inventory, excessive transporting, waiting, and overproduction are all forms of waste. An effective way to control these wastes is to use a signaling system to authorize production and motion within the value stream. This is sometimes, but not always, a card. The signaling device, whatever its type, is called a *kanban*. The device is used to conrol strategic inventory levels, standard WIP and is the trigger for a pull process. Some producers use marked-up floors to identify where the materials should be stored and in what quantity. When the space is empty, the supplying operation is approved to replenish the inventory. Containers can also be used as signaling tools; for example, when a container is empty, this triggers production of the upstream operation. Hopp and Spearman (2000) provide a detailed explanation of the design and applications of *kanban* systems.

Setup Reduction or SMED

In some processes, the waste associated with changeover from one product (process) type to the next scheduled can be sizeable. This was the case at Toyota, which promoted the work of Shigeo Shingo (1989) to reduce the changeover time for stamping presses from four hours to three minutes. The methods for reducing changeover were called "single minute exchange of die" (SMED). SMED is a set of techniques used to perform equipment setup and changeover operations in fewer than 10 minutes, or dramatically reduced from current levels. These principles can be applied to all types of changeovers.

The benefits of SMED include decreased inventory, improved capacity and throughput, and improved on-time delivery to the customer. The longer the setup time, the more likely the operation is to store inventory. Like equipment maintenance breakdowns, changeovers cost productivity which can not be recouped. Faster changeovers also improve flexibility to produce wider ranges of products at reduced costs (scrap, labor, and skills).

The primary steps to faster changeovers include:

- Moving as much of the work of change over from *internal* activity (which requires production to stop) to *external* activity (which can be completed without stopping production).
- Streamline the internal activity with the same principles as production: minimizing motion and travel, adjacency, and balancing. Then streamline external activity.
- Eliminate the need for adjustments and trial runs.
- Streamline external activity.

Although originally developed for changing capital equipment configurations for different product runs, the same principles have been applied to improving lead times for service and knowledge work—for example, staging the data for insurance underwriters so that they can began a new case immediately rather than having to retrieve the needed data, minimizing the time for a customer service representative to open a new case by prepopulating key fields in the case documentation, or organizing all audit data in a standard format to facilitate switching from one study to another.

Reliability and Maximizing Equipment Performance

Reliability is the ability to supply a product or service on or before it is promised. Within operations, this normally directly ties to a resource being able to consistently produce the quantity and quality demanded by the customer. To ensure quantity, the asset must be available when called upon. Maintenance excellence is the mindset to maximize resources through the highest levels of equipment consistency and dependability. Maintenance excellence is based on a sound philosophy of guiding performance, combined with a strong tactical approach for implementation. The overall philosophy is called total productive maintenance (TPM) and the tactical approach, reliability-centered maintenance (RCM).

Maintaining equipment is generally recognized as being essential, but pressures for production can result in delaying scheduled maintenance. Sometimes, the delay is indefinite, the equipment breaks down, and maintenance becomes reactive instead of preventive.

The planning should determine how often maintenance is necessary, what form it should take, and how processes should be audited to ensure that maintenance schedules are followed. Prioritizing maintenance activities is discussed as follows in RCM.

In the event of objections to the proposed plan for maintenance on the grounds of high cost, data on the cost of poor quality from the process can help to justify the maintenance plan.

Total Productive Maintenance (TPM)

Equipment maintenance used to be carried out by the operator. After work was organized and more specialized, maintenance was turned over to specialists. This was typically a small group of highly trained individuals who could fix nearly any problem with the equipment. It has become imperative to return as much of the routine maintenance responsibilities to operators. TPM looks into the value stream for improvements. TPM identifies the sources of losses and drives toward the elimination of all of them and focuses on zero losses (including quality losses) for productivity.

The operator forms the core of TPM and is the process expert. They are in the best position to help drive improvement in accidents, defects, and breakdowns. TPM is a philosophy based on total employee involvement, which is called autonomous maintenance. Operators are trained to stop abnormalities and other sources of accelerated deterioration. Operators will also perform daily checks for cleanliness, carry out routine lubrication, and tighten fasteners. Training is the key and should be incorporated with 6S mentioned earlier.

Reliability-Centered Maintenance (RCM)

TPM sets the overall philosophy and standards for maintenance. To complement this, a planning method is needed, a way to prioritize resources and actions. This is called reliability-centered maintenance (RCM). The goal of RCM is to ensure process reliability through data collection, analysis, and detailed planning. Like TPM, if properly deployed, RCM will drive down inventories, shorten lead times, provide more stable operations, and improve job satisfaction.

Prioritization is the foundation of RCM. The basic premise is to allocate resources as effectively as possible to eliminate unplanned downtime, reduce deteriorating quality, or ensure planned output. Assets are prioritized into one of three categories: reactive, preventive, and predictive. The reactive maintenance approach is to run to failure. These assets could include noncritical components, redundant equipment, small simple items, and assets with low failure rates. Examples would include electric solenoids, relay coils, lamps, and all breakdowns. The priority for this class is low; allow for running to failure. The next step is preventive maintenance. This set of assets has a known failure pattern and is often a time-based relationship. Consumables also fall into this group. Motor brushes, bearings and gears, filters, and most normal planned maintenance actions are some examples. Here, a planned schedule can be generated based on the number of cycles or a time interval, performing maintenance activities (hopefully) before failure. The final class is predictive maintenance. This category is the highest priority in terms of planning and assigning of resources. These resources are the most critical to the operations and the ones required to provide customer satisfaction. This group also includes assets with random failure patterns, assets not normally subject to wear, and replacement components with long lead times for replenishment. The group is analyzed based on condition. Methods such as vibration analysis, lubrication analysis, temperature, current signature, and high-speed videos can determine machine conditions. If successfully implemented, RCM can deliver significant business benefits. Experience with Juran's principles has shown that reactive maintenance costs are two to three times higher than preventative; and preventative is two to three times higher than predictive.

Measuring improvement in reliability should include several dimensions. The most encompassing is overall equipment effectiveness (OEE). This measures the cumulative effect of all losses due to equipment condition–machine availability, machine efficiency, and machine quality performance. Figure 11.11 shows a calculation OEE. Other measures for maximizing equipment performance include those found in Figure 11.12(a) and (b).

OEE calculation:

$$\text{Machine availability (MA)} = \frac{\text{Actual running time}}{\text{Planned running time}}$$

$$\text{Machine efficiency (ME)} = \frac{\text{Cycle time X units produced}}{\text{Uptime}}$$

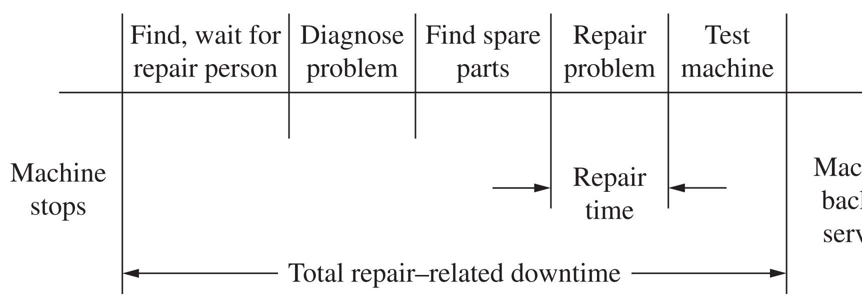
$$\text{Machine quality performance (MQ)} = \frac{\text{Number of good units}}{\text{Total units produced}}$$

$$\textbf{OEE = MA X ME X MQ}$$

Figure 11.11 Calculation of overall equipment effectiveness.

Maintainability – Mean time to repair (MTTR)

$$\text{MTTR} = \frac{\text{Sum of downtime for repair}}{\text{number of repairs}}$$



Reliability – Simple measures

$$\text{Machine availability (MA)} = \frac{\text{Actual running time}}{\text{planned running time}}$$

$$\text{Mean time between failure (MTBF)} = \frac{\text{Total running time}}{\text{Number of failures}}$$

Figure 11.12 (a) Maintainability: mean time to repair (MTTR), (b) Simple measures of reliability.

Mistake Proofing the Process

An important element of prevention is designing the process to be error free through "mistake proofing" (the Japanese call it *poka-yoke*).

A widely used form of mistake proofing is the design (or redesign of the machines and tools, the "hardware") to make human error improbable, or even impossible. For example,

Principle	Objective	Example
Elimination	Eliminating the possibility of error	Redesigning the process or product so that the task is no longer necessary
Replacement	Substituting a more reliable process for the work	Using robotics (e.g., in welding or painting)
Facilitation	Making the work easier to perform	Color coding parts
Detection	Detecting the error before further processing	Developing computer software that notifies the worker when a wrong type of keyboard entry is made (e.g., alpha versus numeric)
Mitigation	Minimizing the effect of the error	Using fuses for overload circuits

TABLE 11.1 Summary of Mistake-Proofing Principles

components and tools may be designed with lugs and notches to achieve a lock-and-key effect, which makes it impossible to misassemble them. Tools may be designed to sense the presence and correctness of prior operations automatically or to stop the process on sensing depletion of the material supply. For example, in the textile industry, a break in a thread releases a spring-loaded device that stops the machine. Protective systems (e.g., fire detection) can be designed to be "fail safe" and to sound alarms as well as all-clear signals.

In a classic study, Nakajo and Kume (1985) discuss five fundamental principles of mistake proofing developed from an analysis of about 1000 examples collected mainly from assembly lines: elimination, replacement, facilitation, detection, and mitigation (see Table 11.1).

Mistake proofing is both a proactive and reactive tool. As Figure 11.13 shows, the upper portion of the chart (prevent defects) highlights a proactive effort, whereas the lower part of the chart (mitigate errors) assumes a reactive effort because a problem already exists. It is better to use mistake proofing in a proactive mode. Stop defects from ever occurring by mistake-proofing products and processes at the design stage. However, the next best alternative is to prevent defects from passing along to the next operation, reactive mode.

Mistake proofing can, of course, result in defect-free work. The advantage can also include eliminating many inspection operations and requiring an immediate response when problems do arise. For more information on mistake proofing reference Mistake Proofing for Operators from The Productivity Press Development Team (1997).

Summary

Competitive pressures compounded with increased customer expectations with respect to quality, service, and price has prompted many businesses to seek creative solutions. These businesses are experiencing pressure to provide the lowest total cost of a product or a service with rapid order fulfillment in highly competitive markets. Lean implementation provides the tool kit and the methodology for organizations to focus on getting the right things, to the right place, at the right time, in the right quantity to achieve perfect work flow while minimizing waste and being flexible and being able to change. Value proposition from Lean implementation includes increases in customer satisfaction, cost reduction, and increase in shareholder value. Lean implementation increases operating profit and decreases inventory (a large draw on cash) and capital expenditures. In short, it is the right thing to do.

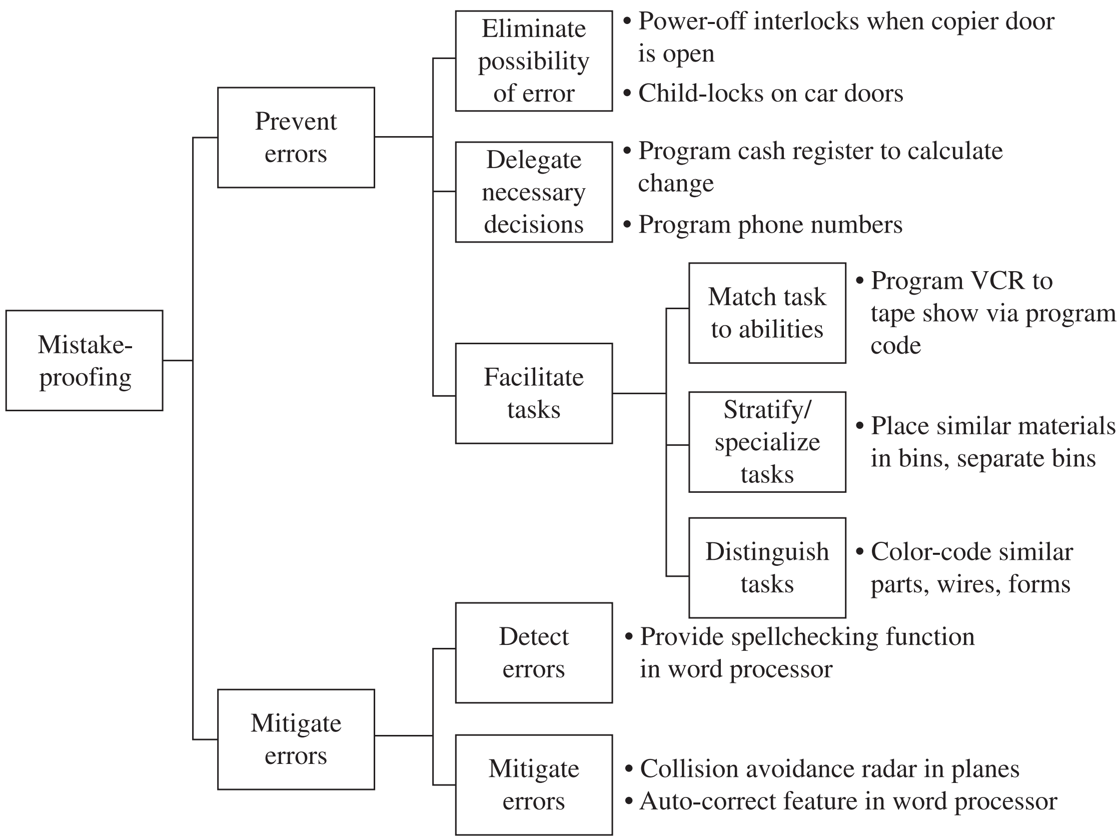


FIGURE 11.13 Mistake-proofing guidelines.

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