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LEAN PRODUCTION PRINCIPLES

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LEAN PRODUCTION PRINCIPLES

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EXECUTIVE SUMMARY

This project examines the lessons learned in other industries (non-construction) in applying the concepts of Lean Thinking. The objective was to determine how Lean has helped make companies in those industries more successful and to determine which Lean applications can be most easily implemented in construction. To accomplish this, the project concentrated on:

- Identifying the Lean principles used successfully in such industries as automotive, information technology, defense and aerospace.
- Identifying what "Lean" means in the sheet metal and HVAC construction industry.
- Determining how Lean can be transferred and implemented in the construction industry and which techniques are most applicable.
- Comparing and reviewing sheet metal and HVAC construction companies that are successfully applying the lean principles discussed in this study.

Although this study explored the application of Lean principles in the sheet metal and HVAC industry, it was impossible to do so without also examining the overall principles of the Lean model. For that reason, discussion is included on principles and concepts of Lean Thinking to assist contractors in examining their entire businesses.

What does Lean look like?

- Fast, uninterrupted flow of construction
- Elimination of waste
- Flexible planning process effective responding to changes
- Design process supports the "Pull" of construction
- Low inventories and no stashes of materials on site
- Frequent replenishment of materials
- Safe work environments
- Empowered and engaged workers
- Organized yards, shops and offices
- Rapid response to problems

Why do Lean? Because the application of Lean will:

- Reduce waste (costs) in the office, yard and fabrication areas
- Reduce waste in the field by eliminating double handling, crews waiting, inventories of material and treasure hunts (time spent searching for materials or tools)
- Maximize company resources
- Reduce losses from accidents
- Maximize productivity

The conclusion of this research is: **The Lean principles that have led the non-construction industries to higher profitability and lower costs are easily applicable to the sheet metal and HVAC industry.**

1 INTRODUCTION

Government census data continue to indicate increasing productivity trends within the nation as a whole. National productivity grew 2.7% annually from 1987-1996, resulting in a 27% increase over that time period. In addition, growth further increased by 3.9% annually from 1996-2000. During the same period, the construction industry's productivity, which is included in the national productivity numbers, grew by 0.2% and then fell by 1.0%, respectively (see Figure 1). In other words, the construction industry's productivity is lagging that of other industries 10-fold.

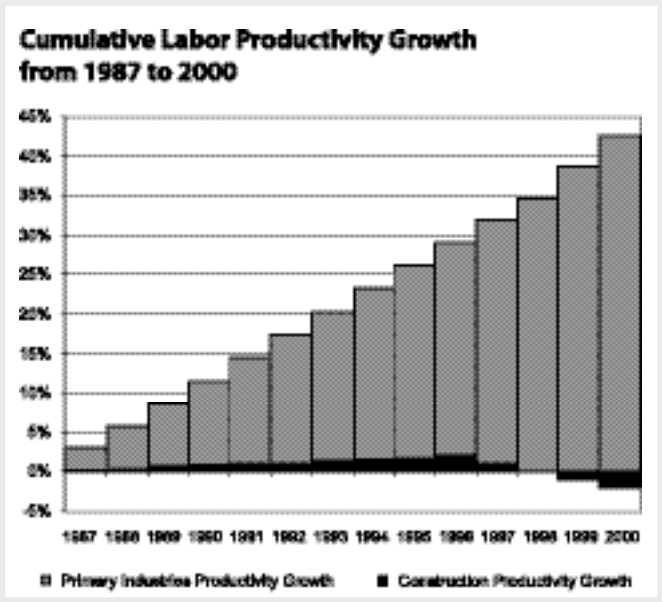


Figure 1: Annual labor productivity growth nationally and for the construction industry from 1987 to 2000.[1]

Productivity in the manufacturing segment of the economy has made major gains in the past 10 years. Many factors have contributed to this productivity improvement. Lean manufacturing has played a role in some of these gains. The Lean principles were mostly developed and refined by Toyota and are sometimes called Kaizen or the Toyota Production System. While most leaders give Toyota's Taiichi Ohno the credit for developing the Lean approach, the term "Lean" was first used by Jim Womack and Daniel Jones to describe Toyota methods.[2] Ohno claims to have based much of his initial efforts on the works and ideas of Henry Ford.[3] The Lean approach grew out of many years of trial and testing to continuously improve methods and results. Ideas and techniques still are being refined and advanced.

Regardless of its origin, American and international manufacturers have embraced Lean and achieved remarkable results. Companies have seen improvements in the following areas:

- Manufacturing Lead Time – less than 1 day
- Delivered Quality – 3 PPM (Parts Per Million so 3 PPM means three defective parts in a million parts – this is operating at a Six SIGMA level)
- Delivery Performance – 99+%
- Inventory Turns – Greater than 50 turns per year
- Conversion Costs (materials to finished goods)- 25-40% less than mass producers
- Manufacturing space – reduced 35-50% less than mass producers
- New product development – less than 6 months[4]

(Examples of manufacturing companies that have been recognized for successfully implementing Lean are provided in Appendix A.)

By using Lean operating principles, many industries have contributed to improvements in the overall national productivity. Manufacturing output in the United States has increased 180% over the past 50 years. Dell uses a "build-to-ship" philosophy in which production of a computer does not begin until after the customer's order is received. This operational model reduced Dell's inventory from six weeks to 3.8 days.[5]

Peter Drucker, the father of modern-day management thinking says:

"What has changed manufacturing, and sharply pushed up productivity, are new concepts. Information and automation are less important than new theories of manufacturing, which are an advance comparable to the arrival of mass production 80 years ago. Indeed, some of these theories, such as Toyota's "lean manufacturing", do away with robots, computers and automation."[6]

The manufacturing industry has realized these benefits from Lean. However, construction is not manufacturing and is unique in many facets. Can the same Lean techniques work in a construction environment? The answer is yes! While still relatively infant in its application to construction, there are sufficient examples of contractors who have successfully applied Lean concepts and techniques to validate Lean's applicability to the sheet metal and HVAC industry. The research used to answer the question of applicability consisted of the following methods:

- Literature reviews
- Industry interviews
- Industry survey
- Review of historical data gathered by observation

2 WHAT IS LEAN?

Toyota's goal is to "Give customers what they want, deliver it instantly, with no waste." This may seem impossible, but over the past 30 years Toyota has made great progress. The essence of Lean is covered in Toyota's goal. Lean is first about giving the customer value and always working to add value. Lean is about only building what the customer needs and delivering the product or service (almost) instantly. Finally, Lean is about driving out waste. In fact, waste is defined as the opposite of value, as *anything that does not add value to the customer.*

Value is what the customer is actually willing to pay for. The economist defines value as the ratio of the usefulness to the customer to the cost. Value includes the product's functions and features and relates to the whole product and/or service. Cost includes the price paid and also the cost in terms of time and hassle in obtaining and using the product/service. In today's fast-paced world, customers often place greater value on experiencing less hassle than on price.

A Lean company views the waste and non-value-added activities from the customer's perspective and is dedicated to driving out waste. Ohno categorized seven types of waste. Some Lean leaders have added two more. The seven basic kinds of waste are:

- Waste of DEFECTS: This is work that contains errors or rework or does not function as designed or intended. Waste includes wrong installation, defects in production, punch lists and change orders. Misunderstanding the customer's requirements or expectations can cause defective waste. Waste also includes code compliance issues. Waste often stems from lack of having and using standard processes.
- Waste of TRANSPORTATION OF GOODS: This is the movement of material or goods. Though necessary, any movement of a product does not add value. Unless one fabricates while transporting the product, nothing is changed to add value. Sometimes during transporting, damage occurs causing more waste. For construction, waste occurs when moving material around the shop by hand or on carts, loading it on the truck or trailer, hauling it to the work site, unloading the material from the truck, and moving the material around the job site from the lay-down area to the point of installation. This type of waste is caused by poor site or yard layout, by lack of an organized system for materials placement or

staging, by poor logistics planning and/or by receiving material too early to use or install.

- Waste of OVER-PRODUCTION OF GOODS: Producing more than the customer needs or more than is needed at that time is waste. Examples include fabricating material to keep the shop busy, stockpiles either in the warehouse or at the job site, printing more blueprints or marketing report copies than needed. Estimating jobs that are not won is a waste of over-production as well.
- Waste of WAITING BY EMPLOYEES or EQUIPMENT for processes, equipment to finish work or for an upstream activity to be completed. Examples are idle time in which workers are waiting for instruction or materials, a fabrication machine waiting for material or when payroll is waiting for late time sheets. Waiting is caused by poor communication between the field, support functions and/or suppliers; when people are unsure what is to be done; and/or because of poor coordination between trades.
- Waste in OVER-PROCESSING: Unnecessary or extra steps in the process or any steps that do not create value from the customer's viewpoint are waste. Over-processing includes writing too many purchase orders, over-engineering, multiple handling of timesheets, too many signature steps, duplicate entry on a

Picture 1: Sheet Metal waiting to be processed

Picture 2: Finished duct waiting to be shipped

form or in data-entry fields, inspections, getting double and triple estimates from suppliers and providing more polish or "a professional look" than is needed. Over-processing is caused by a lack of standard methods, poor communication or poor planning. Waste often occurs when a process slowly changes over time and no regular examination is conducted to assess whether the process meets current requirements.

- Waste of MOTION: Movement of people that does not add value such as storing material away from installation; treasure hunts by workers looking for tools, material or information; or searches in the office for contracts, files or vendor catalogues. Waste of motion is caused by poor planning and organization and/or by a lack of standard methods.
- Waste of INVENTORY: Any material or parts not being used by the customer is waste. This includes raw material, work in process and final fabrications. Regardless of whether the material is called "inventory" or is job costed, if the material is not yet installed, it is in reality inventory, and thus is waste. This type of waste includes parts, excess space and unused tools, copies and reports. Stashes and personal stockpiles are waste, too. While inventory may be needed to ensure that the work is performed in a timely manner, Lean organizations consider any type of inventory to be waste. Inventory is an especially costly and usually overlooked waste because inventory ties up working capital and space, requires controls to

ensure security, must be continually monitored and leads to additional handling.

Companies have traditionally accumulated inventory because of unreliable support from the shop, suppliers or delivery function or because of efforts to save money through a bulk buy. Usually the money saved in bulk buys is spent by the hidden, but real, costs of holding inventory. Inventory sometimes results from free shop time used to fabricate ahead of schedule or as a just-in-case contingency. Lean Thinking considers inventory as waste that produces or hides other wastes.

Two other types of waste that have been identified are:

- The waste of NOT BEING USED OR NOT MEETING THE CUSTOMER'S NEEDS: This includes designs, installations and reports that may be perfectly sound and functioning but do not meet the need defined by the customer. A system that does not provide the proper heating or cooling needed for a facility is waste.
- Waste of NOT UTILIZING TALENT AND KNOWLEDGE OF HUMAN RESOURCES: Not asking for, involving, following up and/or implementing the ideas and suggestions of employees is waste. The front-line workers are closest to the action and see more problems than management may ever identify. Waste results when workers' ideas are ignored. Waste happens when field or shop supervision is not involved in reviewing design drawings for constructability. Waste also occurs when lessons learned and best practices are not shared or replicated from one project or work team to another or across the company.

The Japanese call waste "Muda," an ugly sounding word in English and Japanese. Lean champions are waste-busters.

Looking at the cost categories of contracting, opportunities for waste-busting can be found in:

- Labor
- Material
- Equipment and tools
- Overhead
- Margin

The biggest opportunities for reducing waste typically are found in labor, material and equipment and tools – areas in which Lean concentrates on improving. Lean or Lean Thinking is focusing on delivering value (as seen by the customer) and eliminating waste. Lean is not Total Quality Management (TQM) but is one approach of continuous improvement, which is an element of TQM. Lean is not Six Sigma. Lean focuses on driving out waste in the process, while Six Sigma focuses on measurable problem solving to make the process capable. Some companies are now practicing what is called Lean – Six Sigma. Six Sigma methods are used to solve problems that surfaced in Lean activities. Lean Construction is the term used to reference the application of Lean Thinking to construction.

3 THE LEAN APPROACH

James Womack defines the approach to Lean as:

- Understanding Value vs. Waste
- Value Stream Analysis
- Making the Process Flow
- Pull
- Continuous Improvement toward Perfection

Understanding Value vs. Waste

To fully understand Lean requires an understanding of value and waste as defined previously. Womack describes how a homebuilder in Texas (Doyle Wilson, Austin, Texas) redefined his business based on learning more about how

the customer sees value. Doyle had been successfully building homes since the mid 1970s. In the early 1990s Doyle started a TQM initiative that allowed him to increase customer satisfaction and sales. He did this in a flat market by outperforming his competition. He even won the National Housing Quality Award in 1995. But in looking at his customers and markets, Doyle realized that new-home building was only 22% of the total home-buying market. Even if he were to capture all of the new-home market he was still not touching the used-home buying market, which was 78%! Doyle listened to what the homebuyers of older homes thought was value. They bought used homes because they wanted a no-hassle factor in negotiating a contract, a short lead time to get into the house and did not want the inevitable punch list after moving in. Doyle decided to create a hassle-free home buying experience to draw these homebuyers into the new-home market. This led him to make major changes in his processes and operations. He had to shrink the industry average time to build a house from six months to 30 days.[2] Focusing on value as seen by the customer can change how we deliver our services in any industry.

To better understand the concept of value requires an understanding of the nature of quality. In its most simple definition, quality is meeting the customer's needs. W.E. Deming and Ron Moen, leaders in quality improvement, define quality as: "Translating needs of the customer into measurable characteristics."[7] Put into sheet metal and HVAC contracting terms, this means that a contractor needs to understand the customer's needs and translate these needs into measurable work for which the contractor can be paid.

David Garvin proposed eight dimensions of quality. These dimensions help translate production quality into the value perceived by the customer. The following list is an expansion of his eight dimensions:[8]

Performance	Primary operating characteristics
Features	Secondary operating characteristics; added touches
Time	Time waiting in line, time from concept to production of new product, time to complete a service
Reliability	Extent of failure-free operation
Durability	Amount of use until replacement is preferable to repair
Uniformity	Low variation among repeated outcomes of a process
Consistency	Match with documentation, advertising, deadlines or industry standards
Serviceability	Resolution of problems and complaints
Aesthetics	Characteristics that relate to the senses
Personal Interface	Characteristics such as punctuality, courtesy and professionalism
Harmlessness	Characteristics relating to safety, health or the environment
Perceived quality	Indirect measures or inferences about one or more of the dimensions; reputation

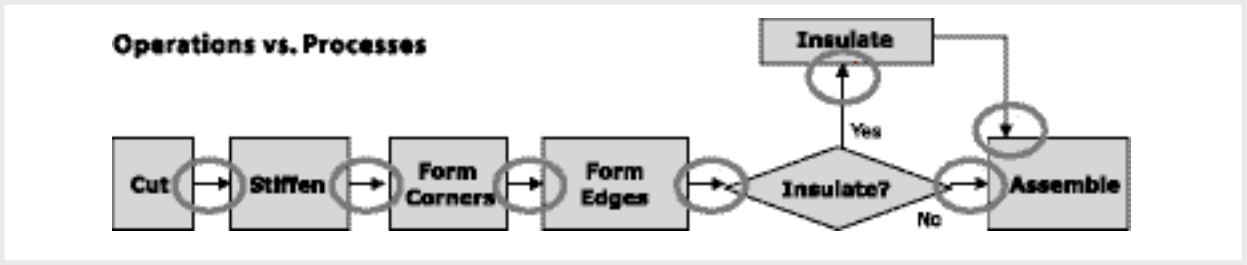


Figure 2: Lean focuses on the handoffs

The more a company works to distinguish the quality of its products and services using these dimensions, the greater the competitive advantage. Listening to the customer means producing *what* the customer wants, *when* the customer wants, and *how* the customer *wants*. The facets listed above can be used as guidelines to understand how the customer perceives quality.

Value Stream Analysis

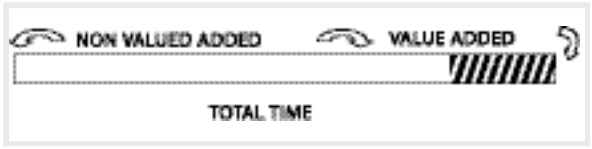
The Value Stream includes all the processes and activities used to design, produce and deliver the product or service to the customer.[2] A process is a series of operations or steps that creates a deliverable. All work is a process. In analyzing the Value Stream there are three possible steps, those that:

1. Add value

2. Do not add value but are necessary

3. Do not add value and are not necessary

Typically, only 3% of process steps add value; the rest fall into the two non-value-added steps.



Many productivity improvement efforts focus on the value-added operations or on all the steps to try to improve efficiency. A common cause of increased waste and costs are problems and/or lack of clarity that occur in the handoffs between operations within a process. Lean looks at the non-valued-added operations and at the handoffs (space) between the steps as illustrated in Figure 2.

To be Lean, a company optimizes the entire work system. Sub-optimization leads to waste. A Value Stream Analysis looks at the whole system to avoid sub-optimization. An example of sub-optimization in construction is where a shop fabricates duct to level its workload and not to meet the time requirements of the field. The fabricated duct is delivered to the field early requiring time to unload, store and control. Or the duct is stored in trailers or in a warehouse until it is needed. While the shop optimized its workload, the net results to the company can be increased cost, reduced cash flow and the risk of rework due to damage or field changes. Value Stream Analysis begins with mapping the Value Stream from start to finish or in major segments.

Making the Process Flow

When a piece of metal flows through the typical fabrication, the piece starts, stops, waits and starts again as it moves through the process. The same can be said for a materials request for a purchase order or for a check request. Most of the work we do and experience is done in a batch and queue method. Waste occurs when work is done in a batch mode, as there is much time lost when material is waiting. In Lean, the objective is to make value flow. The ideal batch size is one piece.

While it seems efficient to do all parts or pieces at the same operation and then move the batch to the next operation, Lean has shown that single-piece flow is more efficient. Consider an insulation process. If it takes one minute to cut the sheet metal, one minute to glue the sheet metal and one more minute to pin the sheet metal, it will take a total of three minutes to complete the insulation on the piece of sheet metal. Now imagine there are two other pieces waiting to be cut, two other pieces waiting to be glued, and still two other pieces waiting to be pinned. The total time it will take to insulate the sheet metal is now nine minutes by the batch mode. Only three of the nine minutes would be spent actually working on the designated piece of sheet metal. Remember, this is only for the insulation procedure. Similar backups cause delays at every step in sheet metal fabrication.

Like snow skiing, where weight is placed in a position that at first feels opposite of how we balance ourselves, flow is counterintuitive. A good indication of the lack of Flow is wherever the product or inventory is piled up between operations and/or departments. Working to improve Flow led Toyota to develop the Just-in-Time (JIT) approach employed by many progressive manufacturers today.

Pull

In Lean, the product is not worked on until it is pulled from the previous step upstream in the process. This is the opposite from a push approach. Lean companies don't want to make anything until it is needed, and then they make it very quickly. In Pull the internal customer (the foreman) or external customer (the general contractor or the user) pulls the products. The product is not fabricated until it is ordered from the field. Material is not delivered from a supplier until it is needed.

Why Pull? The concept of Pull gives the company the ability to respond almost instantly to customer orders and frees up cash by reducing in-process and finished-goods inventory. By not fabricating until product is needed, the waste of overproduction is avoided and the risk is reduced of making something that is later changed. In many fast-moving design/build projects involving many trades, there is a high risk when something is fabricated too early. Changes happen in construction. But regardless of who caused the changes, waste is created. If another trade beat the company to the intended route or the customer made a design change, waste still occurs when the product is fabricated too soon. Even when the contractor is paid for the change, the fact remains that there is a wasted product.

To Pull, the process must flow first; batches must be small; and quality needs to be high. Pull requires accurate and ongoing communication between those ordering the product (field) and those in fabrication.

Pull is easier to understand in a shop environment because it is similar to manufacturing. But Pull also applies to the field. Waste occurs when a rental crane is on site days before it is needed or when an air balance technician is called in before duct installation is finished. In some ways Pull seems to be common sense, but there is more to be learned to successfully apply this concept in construction.

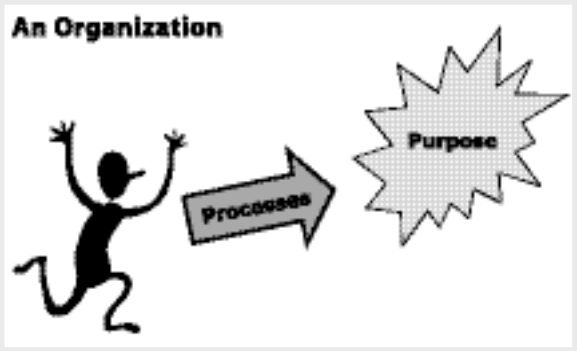
Continuous Improvement to Perfection

The Lean goal is perfection and the total elimination of every kind of waste. The paradox is that perfection can never be achieved, but must be pursued. Lean offers another way to work toward perfection. An example occurs in the way most contractors bid work. Typically, contractors bid work based on estimates of direct costs. Cost take-offs are developed from the plans and by the particulars of the job. This becomes the base direct cost. The profit margin is added, resulting in the bid price.

Lean contractors start with the target market price needed to get the job. From that market price, the profit margin is subtracted, resulting in the targeted direct job cost. The targeted direct job cost is lower, even much lower, than the base direct cost typically used to bid work. Someone always points out that it is impossible to really know the market price needed to win the job! But most experienced estimators know the ballpark price for the job. The quest for perfection becomes more than just talk when contractors use the targeted cost to drive operations. What would a 15% reduction in the direct cost do for a contractor? Manufacturing companies applying Lean have experienced cost reductions in the 30-40% range.

4 LEAN CONCEPTS – THE CONTEXT

All organizations, including contractors, consist of the three "Ps": *People* who work on *Processes* to achieve the organization's *Purpose*.



Lean concepts that form the context or fiber of all improvement efforts are tied to these three "Ps." These include having engaged employees, standard processes and leadership by top management.

Engaged Employees

People make work (and profits) happen. No Lean effort has been successful over the long term without the support of the company's front-line employees. Engaged employees have been shown to support Lean because Lean operates at the front lines of the workplace, not in the executive offices. Union craftsmen find the Lean technique of 5S's (discussed below) especially appealing because it reflects their pride of workmanship.

The equation for having engaged employees is involvement plus communication. Employees see more problems and experience more workplace barriers than management. Companies involve employees by asking for their ideas and suggestions for improvement. In traditional American companies, the number of suggestions per employee per year averages 1:5 – one idea for every five employees. Lean companies in Japan and the US average more than 15 suggestions per employee per year. The difference in Lean applications and the traditional suggestion box system is that in Lean companies the supervisors work with the employees to share and implement their ideas. Outdated suggestion systems often bypassed front-line supervision and went to some designated suggestion coordinator. This bypass approach reinforces distrust and fear, encourages bureaucracy and slows the implementation process. Lean techniques do not require PhDs, complex IT systems or sophisticated mathematical models. However, Lean's success depends on people being engaged and involved in continuous improvement.

Lean companies realize the key role workers play and spend time communicating more with the workforce than may be customary in other organizations. What is communicated? Employees need to understand the why and how of Lean applications; where the company stands on safety, productivity, absenteeism, and

performance; and the company's vision and priorities. Failure to communicate results in mistakes, misunderstandings and a workforce that does not feel valued or trusted.

One of the hallmark characteristics of Toyota is that the employees are constantly encouraged and recognized by supervision to identify new ways of getting work done. Every suggestion is viewed as an experiment – a test. Tests sometimes fail, and making mistakes is acceptable and valued as part of efforts to improve processes. However, employees are expected to avoid making the same mistake twice. Lean companies do not punish employees for making mistakes but use errors as learning opportunities. *If the student hasn't learned, the teacher hasn't taught.*

The role of Lean in safety is critical. While Lean techniques can be applied to safety processes just like any other process, Lean does not focus specifically on safety. Lean processes incorporate safety. Where safety is a value, a company will find that Lean is in harmony with and supports good safety practices. Waste is any violation of sound safety requirements. Material can't flow when work is shut down while dealing with an accident. Lean encourages employees to find new and improved ways to be safe as well as productive.

Standard Processes and Operations

To continuously improve, each process or operation must first be defined. To have consistency in any process, there first must be a standard way of performing each step. The standard way should be the best method known. Good management and Lean require that processes be standardized first and then improved. Managers and supervisors should always ask these key questions:[10]

- Do we have the process defined?
- Is it standardized?
- Do we follow the standard?
- How can we improve the process?

Top Management Leadership

Nearly every new initiative ever started in any company required top management support to get under way and then to maintain the gains. Lean, too, requires top management leadership. Management needs to set the vision for Lean implementation. Employees, at all levels, want to know where the company is going and why. Creating the vision is not sufficient; management must communicate the vision with passion to every member of the workforce and instill enthusiasm for achieving the vision. One contractor created a "stump" speech of the vision for the company and why the organization had to become Lean. This compelling story drove the change actions throughout the company. If leaders aren't interested in being Lean, the workforce soon will recognize that commitment is lacking. A shop superintendent was dragging his feet in implementing Lean but his manager kept encouraging him. She let him know by word and action that they were going to implement the 5S's. After a few months, the shop superintendent saw the "light" and has now become one of the real champions for Lean in the company.

In any company the pathway to success includes a focus on the right priorities for how work is done. The role of leadership includes setting the right priorities for operations. The priorities for manufacturing are: 1.) making product as ordered, 2.) reducing inventory and 3.) reducing costs.[9] Many companies get these priorities backwards and are always downsizing or cutting costs at the expense of keeping product flowing out the door. Construction contractors do not make money

until the product is installed. In manufacturing the most expensive equipment is usually what everyone tries to keep operating. In construction the most expensive "machine" really is the field crew, and efforts are focused on keeping them productively installing. Thus, the logistical priorities for success and profitability in construction are:

- Keep the crews busy installing product
- Reduce inventory
- Reduce costs

These priorities form the basis for trade-offs in Lean applications. For example, inventory is waste and to be eliminated as much as possible, but it is better to keep some inventory on hand if that ensures that the crews keep installing. The trick is to know how much to keep and no more.

Continuous Learning

One other principle woven into the context of Lean is that of being a learning organization. Our research found that continuous learning and improvement is the focus point of perfection in Lean operations. In other words, the organization has the capability of learning from both its mistakes and its improvements and applying this learning to new projects to reduce cost and increase profits.

Dr. Deming taught the PDCA *(Plan, Do, Check, Act)* cycle of continuous improvement: *Plan* the improvement. Test or *Do* it. *Check* to see if the plan was followed and if it worked as an improvement. Then *Act* to make the new method the standard way to do that work if it proved to be a better way. Measures are used as a tool to determine whether improvement occurred. Wherever improvement is made, the Lean organization communicates the better methods to all areas of the company.

5 LEAN TOOLS AND TECHNIQUES

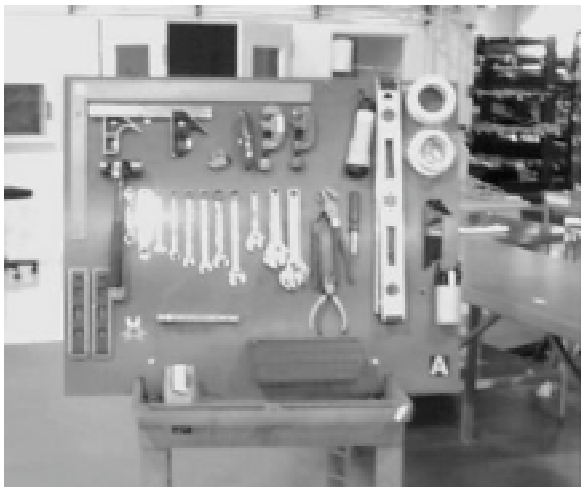
Five S's

The 5S's are fundamental to reducing waste in every shop, field and office operation and helping to improve productivity and actively engage employees in continuous improvement. The 5S's came from Toyota and are actually "S" words in Japanese. When these words were brought to America they were given English terms. While the words are at times translated slightly differently, the meanings remain the same. Here are the 5S's with the Japanese word given in parentheses:

- *Sorting* (Seiri) means to go through a designated work area and to sort out the necessary from the unnecessary. Necessary is defined by frequency of use. If an item isn't used at least annually, it is probably not necessary to the work. An item not used at least monthly probably doesn't need to be kept near operations. Items that are necessary are kept and all the rest are disposed, recycled or returned.

Picture 3: Areas ripe for sorting

Picture 4: Areas ripe for sorting



Picture 6: Shadow boards are examples of Simplifying

- *Simplifying (*Seiton*)* means to put everything (that we determined as necessary in Sorting) in a designated place and to mark them visually. Not only is a place established for every necessary item, but also the actual location is based on how often it is used. The items used most often are located closest to the person doing the work.

Picture 5: Foam cutouts are examples of Simplifying

- *Sweeping* (Seiso) means to physically clean up the work area and to deliberately pick up all parts and materials that are out of place and return each to the assigned places as defined in *Simplifying*.
- *Standardizing* (Seiketsu) means creating standard ways to keep the work areas organized, clean and orderly and to document agreements made during the 5S's process. Employees must understand the value of using and maintaining standard methods if this "S" is to be successful. Additionally, the first three Ss must be repeated frequently to achieve continuous improvement.
- *Self-Discipline* (Shitsuke) means to follow through with the 5S's agreements. Changes made using the 5S's must be maintained to reap full value.

Because the 5S's came out of a manufacturing shop environment, the practices are a natural for the sheet metal and HVAC fabrication shops. One shop was able to return over $5,000 in material that no longer was needed. A shop's management thought more space was needed to expand; instead, after doing the 5S's, enough

additional space was gained and costly expansion avoided. Shops have found that doing the 5S's led them to rearrange their shop material flow and move equipment closer together, reducing transportation waste. Tools have been color coded and assigned to pieces of equipment. Work areas are cleaner, and inventory is better organized. One shop rearranged its deliveries from a supplier so that all three semi-trucks did not arrive the first thing each Monday morning, relieving workers of a major unloading effort at the shop's busiest start-up time. Employees no longer had to find a place to put the new inventory until it could be moved in with the current inventory. The three trucks represented a weeks' worth of work. Now, the company keeps less inventory (two days' worth) and has the supplier deliver more often in smaller lots, saving space and time. Other successful ideas that companies have implemented include:

- Consolidating tooling into one location. In the past, tools were located around the shop.
- Sorting out all excess fittings by specification and placing spare valves into one segregated area.
- Sorting the bucket of hangers into the various sizes to avoid having to look through one bucket to get the correct size.
- Reducing the number of as-built drawings filed in binders and warehoused in document-control archives. The staff scanned all drawings onto their server and tossed the paper.
- Striping the walkways and labeling and color coding tools and parts.
- Devising standardized tool kits for each workstation.[11]

Jim Beaudet, shop manager for Miller Bonded Inc., says the biggest value he has seen from the 5S's is the organizing of shop tools so employees don't waste time looking for them. "We pay our employees to be productive; the 5S's is an investment to help them do that."

Ted Angelo of Grunau Company tells how they used the 5S's on their main yard. He said their yard, like those of most construction companies, was littered with stacks of material returned from jobs and saved for "just-in-case" situations. The yard also was crowded with equipment and material being made ready to go out to the job. After applying the 5S's, he reports, "it was like night and day to see the difference."

The 5S's work well in organizing offices. One company's purchasing department had problems finding partially issued purchase orders when a buyer was out for the day. They applied the 5S's and redesigned the buyers' work area so that all buyers had a designated tray for all unprocessed orders and another for those partially filled. This seems small, but time was saved for other buyers and for accounts payable staff when looking through stacks of orders.

Another office color coded reference binders using one-inch colored dots placed on the binder's backs. The dots were marked "1 of 5", "2 of 5", etc., enabling anyone passing by the shelf to see whether binders were missing or out of order.

In another office, the accounting department kept duplicate copies of all shop invoices. Over the past two years about 18,000 invoices had been accumulated. When the group decided this was no longer necessary, throwing the duplicates away freed up file space and administrative time.

Because of the changing nature of field construction, applying the 5S's presents unique challenges – and unique solutions. One site set up a rack and put names on it for the air balance crews to hang their harnesses. Less time was spent untangling and resizing the harnesses each morning. With 20 employees working the air balancing, this approach saved about 15 – 20 minutes each morning for each employee on a

three-week job. Organized gang boxes with the 5S's saves the crew's time looking for tools.

Yard lay-down areas are ripe for the 5S's. If the site has been around for any length of time, stashes of material are everywhere. One sustaining work site's crew found the same excess material stored in several different trailers, in boxes, behind the trailers and on top of shelves. Each foreman had his own stash. Foremen had come and gone, yet piles remained. The team consolidated all of the same material and reduced much of what was being stored. There was a lot of excess material to return or junk. Some very expensive parts were no longer in specification because they had sat out on a pallet for several years.

The 5S's apply to service processes as well. In addition to application to the parts storage area and office, the 5S's can be easily applied to vans or trucks driven by service technicians. Even when the fleet consists of different types of vehicles, having a common area designated for various parts makes it easier for technicians to find what they need. This is even more critical when the technician has to use a different vehicle. At Miller Bonded Inc., when they started the 5S's in Service, they found that *Sorting* through the vehicles resulted in getting rid of much material that was either used or not needed, a step the technicians welcomed.

In 1999, SMACNA published "Sheet Metal Made Lean and Clean." This guide serves as a good reference for contractors wanting to start the 5S's.[12]

Last Planner System

The Last Planner System (LPS) is a Lean tool developed by the Lean Construction Institute and is a unique Lean application to project management. The LPS approach routinely gets better results than traditional project management – 30% better as a median.[13] LPS does this by:

- Reducing variability so the work flows from the completion of one task to another.
- Ongoing planning that moves to increasing levels of detail. The Last Planner is the field supervisor who assigns work to the crews. The Last Planner does a Weekly Work Plan and evaluates progress made the previous week.
- Making work ready so that when the crews start a task, they can finish it without interruption, rework or remobilization. A look-ahead plan is updated weekly to make the work ready to be performed.
- Creating a stable platform for coordination where people make commitments to each other in support of the schedule. In the Weekly Coordinating Meeting a review is made of each foreman's weekly work and look-ahead plans, constraints to performance and Percent of Planned work that was completed (PPC). The Last Planner makes the commitment on the work that is planned based on what is actually ready to be done.
- Controlling the project through monitoring the plan's completion rate (PPC) rather than the progress compared to schedule (effort). Learning occurs when investigating plan failures. Analyzing the PPC rate and the constraints that keep work from being performed as planned leads to problem analysis and preventive actions.

Many contractors are using the Last Planner System to improve performance. A recent article in the *Silicon Valley / San Jose Business Journal* reads "Sutter Health tells its builders: Make it lean. Hospital giant taking the lead in dictating new construction approach for its $6 billion project."[14] While learning how to implement the LPS is not complicated, explaining it is beyond the scope of this paper. However, consider the following case studies demonstrating the value of LPS:

Boldt is a fourth-generation, family owned construction services company doing business since 1889. The company completes $450-$500 million in projects annually. It is the largest constructor in Wisconsin and operates seven regional offices throughout the Midwest and

Southeast. Boldt has been using the Last Planner System on over 200 projects during the past five years. The contractor found that with LPS it had:

- Shorter schedules, up to a 20% reduction on some projects that fully committed to the process.
- Improved concrete productivity – up to 30%.
- Improved profitability due to shortened schedules (reduced general conditions) and improved productivity. (Much of Boldt's work is negotiated GMP so the savings go back to the customer in the form of growing contingencies).

In 2001 the Lean Construction Institute published its research that found, on projects where PPC was greater than 50%, companies averaged a productivity factor of 85% (15% under budget performance). Jobs with PPC less than 50% averaged a 1.15 productivity factor. While the statistics did not explain why the cut-off was 50%, the data support the logic that if more of the work is completed as planned, the crews will be more productive.

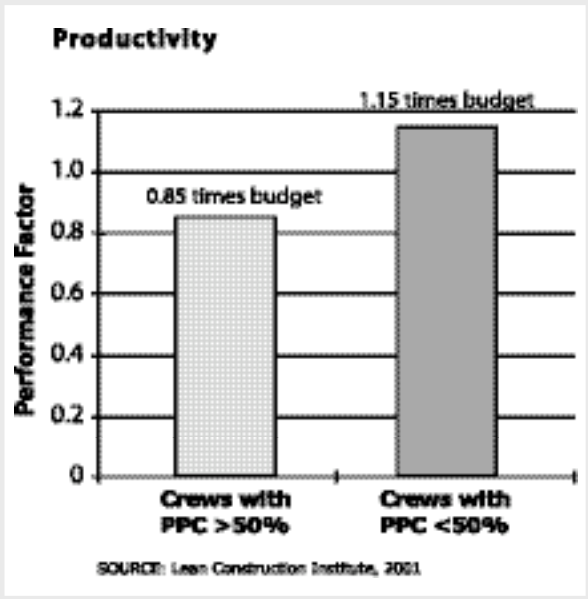


Figure 3: PPC and Productivity

A large mechanical contractor worked with a large computer chip manufacturer to do a pilot study for tool install using the LPS system. Two tools were installed from November 1999 to March 2000. The customer found that durations were reduced on major tool installs by 29% with an even greater potential.

The LPS is being used in other parts of the world with success, too. Rafael Simpson from Peru reports on a project to develop, design, finance, build, sell and deliver 420 low-cost apartments. He says, "At first we thought the constraint would be market demand. But the demand was huge shifting the constraint to production. We needed to produce four complete housing units a day to keep demand satisfied and not lose clients because we could not deliver quickly. The Last Planner System allowed us to deliver them as fast as was required. We not only reduced by more than half the time to make the profit (increasing the system throughput), but also increased the expected profit itself by 61% because of good work structuring, productivity, and other factors. Not only is there an increase in the absolute value of profit, but also in how fast you are producing it**.** Therefore we are making more profit per year, a greater present value or increased rate of return. Finally, there is also an opportunity because having the cash earlier makes it possible to make other investments with more returns."

Rafael's reported numbers for this project are:

	Original Business Plan	**Actual to Date** (95% complete)
Income:	US$ 9.75 M	US$ 10.4 M
Costs:	US$ 7.70 M	US$ 7.1 M
Profit:	**US$ 2.05 M**	**US$ 3.3 M**
Time to : complete	2 years	10 months

Stopping the Production Line

In manufacturing, Lean companies design into the process the ability for front-line workers to stop the production line when problems are observed with product quality or the process's operation. This approach is based on the principle that it is always less expensive to catch quality problems as early in the process as possible. Pull requires quality production. When the line is stopped, the line foreman works with the worker to identify and resolve the problem. The supervisor may involve other resources to develop a preventive cure for the problem. In a Lean operation line stoppages are not feared, but are seen as opportunities to improve the process and prevent quality problems downstream.

This technique has direct application in contractors' fabrication shops, though this research did not discover any actual usage. In construction fieldwork the concept is applied through the Last Planner System. In LPS the "Last Planner," who is the foreman, sets his/her weekly work plan and has the right to stop the line by not committing to do a task if the work is not ready to be done. This is different from the usual way that job-site tasks are assigned or handed to the foreman without an actual commitment by the foreman.

Kaizen Event (sometimes called a Kaizen Blitz)

The Kaizen Event is a quick-hit method for Lean process improvement. An event consists of several days of intense training combined with immediate application of the concepts just taught to identify and eliminate waste in the workplace. Manufacturing has been using Kaizen events since the early 1990s. Dana Corporation reports that using a Kaizen Blitz improved productivity by more than 400 percent in one plant alone. At its Whitman plant in Minneapolis, MN, the company achieved the following results:[15]

- 97 % reduction in parts traveled
- 94% reduction in floor space needed
- 75% reduction in work-in-process inventory
- 85% reduction in cycle time, and
- 83% reduction in set-up time.

The Grunau Company conducted a Kaizen Event applying the 5S's in its tool room. The company took a week to train and test the Lean concepts, resulting in a 50% reduction in the number of steps for scheduling tools.[11]

Kanban

Kanban is a communication tool or signal used in JIT production systems. The signal is used to tell workers to pull parts or refill material to a certain quantity used in production. One example is a two-bin system of consumable parts. When the first bin's materials are completely used, the bin is moved to a designated spot to signal the need to order more. Meanwhile, the operation continues production by drawing from the second bin. Instead of two bins, the signal may be a card on the side or inside a box of parts or materials. When consumption reaches the card or when the box with the card is depleted, the card goes to a person who replaces the lot. Another technique is painting a line on the side of a large bin. When the level in the bin reaches the line, an order is placed for a refill. Manufacturing has used Kanban-type signals to keep inventory at a minimum and still keep production going. Some construction companies are beginning to apply this simple technique in their shops. Kanban can also be used for consumables carried in service trucks and for consumables used in field installations.

Poka-Yoke

Poka-Yoke is a mistake-proofing method or device used to prevent an error or defect from happening or being passed on to the next

operation. A most common application is an electronic form that when not filled out correctly will signal an error immediately. A vacuum-cleaner manufacturer used the poka-yoke concept as a final check for errors. The company would weigh completed packaged boxes before shipping; an incorrect weight indicated something was left out or too much had been added. That detection method worked well, except the customers complained that the operating instructions were often missing. The first solution considered was to buy a more accurate scale. Instead a poka-yoke approach was used to alter the way they packaged the instructions in the box. Instead of drawing from a large stack of instructions, the packaging worker was trained to put one copy of the instructions on the floor of the assembly area each time he started to pack a box. If at the end of the packing the instructions were still on the floor, they were not in the box! This simple signal solved the problem and avoided spending $50,000 for a new scale. While there are numerous applications of poka-yoke in manufacturing, there is little evidence of its application in construction outside of electronic forms and data entry.

Process Mapping/Analysis

A process map is a flowchart identifying all the activities, operations, steps and work times for a process. The process is mapped and then analyzed to identify waste. Each step is categorized into "value added," "non-value added but necessary" or "non-value added and not necessary." Also, the maximum and minimum times to perform each operation are noted along with the distance traveled from operation to operations. Wait and delay steps are recorded. Improvements come by reducing the travel time or distance and by reducing or combining steps of operations. Any non-value-added and not-necessary steps should be stopped immediately. Process mapping is used in Kaizen events and with process improvement teams. One of the core benefits of doing process mapping is to get everyone to agree on what the process is and is not.

Most manufacturers report major reductions in cycle time, steps performed and space used when doing process mapping. An air strut assembly plant made major improvements using process mapping. For the dirt shield part alone they reduced:[16]

- The distance a dirt shield traveled from 4,300 to 75 feet.
- Dirt shield lead-time from 18 days to 39 seconds.
- Work-in-process from 9,078 dirt shields to 10.
- Steps in the process from 42 to 14.
- Inventory space required from 288 square feet to zero – no inventory.

One contractor mapped its tool repair process and was able to save eight to nine hours a week in the repair technician's time by rearranging where parts and tools were kept and the priority for repairing tools. Several steps were cut out as not needed and non-value-added.

Rules of Release

Lean concentrates on the hand-offs between operations. Rules of Release are established to ensure the hand-offs are done right the first time. These rules list the information and product quality required by the receiving side to be able to do the next operation correctly. See Figure 4 as an example of the Rules of Release for operations in a shop fabrication process. Defining these rules and then living by them help ensure the work is done correctly.

Reduced Setup Time

Setup time is wasted time that Lean companies work to reduce. The ideal setup time is zero. Many manufacturing companies have reduced their machine setup time by factors of 10. Much of the time in construction is non-productive time. Get-ready and clean-up times take a major

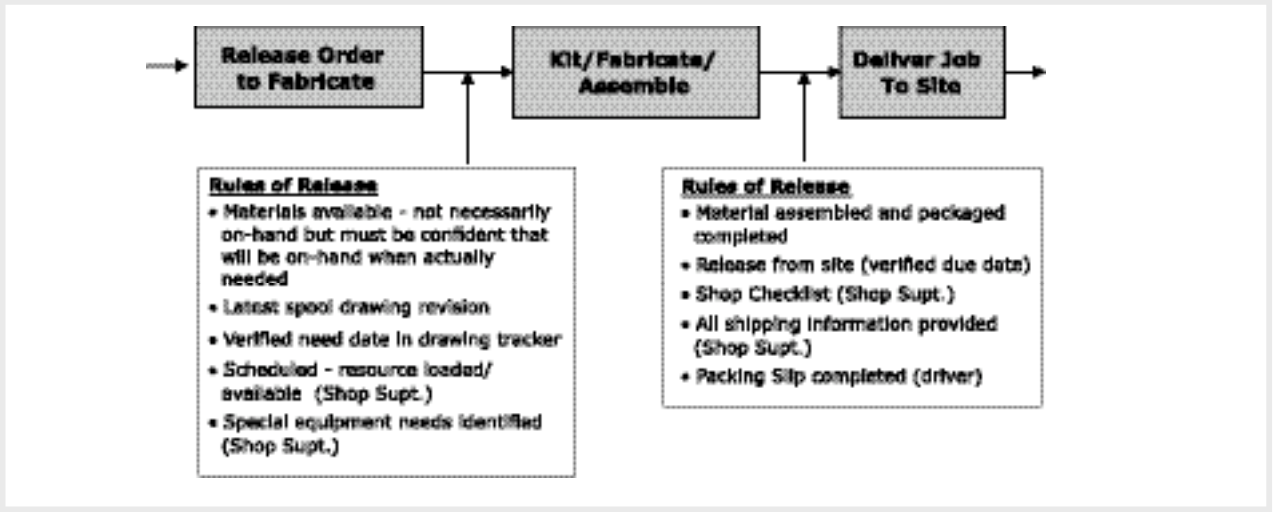


Figure 4: Sample Rules of Release for Shop Fabrication

bite out of the day. Contractors have done very little to systematically reduce setup time in the shop, service or field. The example given above, in which the 5S's were applied to an air balance job to reduce the time searching for harnesses, shows how setup time can be reduced in the field.

Mapping the steps can be helpful for attacking and reducing setup time. A useful approach often is to separate the steps into two groups: those that can be done while equipment is still running and those that must be done while equipment is stopped. The 5S's, base plates, markings for adjustments and standard parts all can help. In most cases once employees are involved and trained they can identify many opportunities to reduce setup time.

Spaghetti Chart

A useful and simple tool to see how a product flows or work is performed is the spaghetti chart. A physical map of the work area is drawn that shows the path taken by a specific product or a person who is being observed. A line is drawn

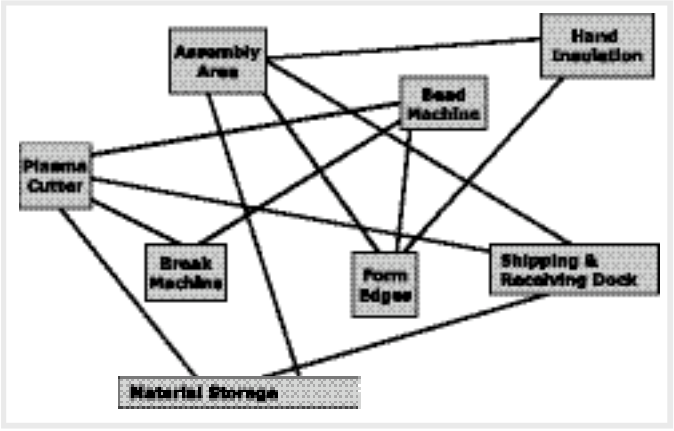


Figure 5: Spaghetti Chart

from start to end indicating the path moved by the product or person. A completed chart looks like a plate of spaghetti because the product or person typically moves all over the area being studied. In one sheet metal shop the spaghetti chart helped surface questions about how the various machines were located in relation to each other. This led to a closer and more logical relocation of several machines and substantially reduced the distance fittings traveled through the shop. See figure 5 for an example of a Spaghetti Chart.

Takt Time

The key to continuous flow in manufacturing is takt time, named by German manufacturers who used the rate of customer demand to set the pace of production. Takt time is the heartbeat of Lean production. Takt time is calculated by dividing the available production time by the rate of customer demand. For example, if the field asks for 100 pieces of duct per day and the fabrication shop is available 480 minutes per day, the takt time is 4.8 minutes. This means that the shop must produce a piece of duct every 4.8 minutes to meet customer demand without over- or under-producing (creating waste). The calculation of takt time only considers available production time and subtracts time taken for coffee breaks, lunch, etc.

While takt time can be calculated for any process, it is used in Lean operations to set the pace of the main production process. By setting and working to achieve a constant pace, the product flows more evenly through the process. Applying this idea to the example above, with 4.8 minutes takt time, pieces of duct would need to move from one station to the next every 4.8 minutes. When an operation takes more than 4.8 minutes, the team would work to split it into smaller components to balance the flow. When a process is started with a set takt time, flow roadblocks will become very evident. This method obviously works best in a plant with long productions runs of the same product; however, job shops are also learning to apply takt time. Research has not found any construction shops using takt time.

Total Preventive Maintenance (TMP)

Pioneered by Nippondenso, a member of the Toyota team that developed many of the Lean techniques, TMP is a set of methods used to ensure production equipment is always working properly and does not stop production.[17] Many manufacturing companies have applied TMP with great success, but this research did not find any applications in construction.

Visual Control

Sometimes called transparency, Visual Control is the displaying of tools, schedules and performance reports in full view of front-line workers so everyone can see the status of work and their unit's performance. Visual Control also includes marking the locations of equipment, tools, inventory parts, disposal cans, cabinets, etc., so that everyone knows where everything belongs. Using Visual Control helps eliminate waste and is a valuable part of any 5S's effort.

6 HOW TO BECOME LEAN

Lean is not one technique nor does there exist an exact recipe of steps to follow to become Lean. There are techniques that work in most companies and some that fit one firm better than others. Norman Bodek, who is considered the grandfather of the Lean movement outside of Japan, once said:[18]

"Ohno and Shingo both loved to say simply "do it!" and then leave you the challenge to figure it out for yourself. They rarely ever had a cookbook approach for you. In fact, Ohno would never let anything be written down on how to do Lean. He wanted it to be a system that allowed for constant change."

Such an approach actually holds well for contractors who are accustomed to trying whatever it takes to get the job done rather than using detailed research on the theory of construction. "Just try it" can be one tactic for getting started on improving a process. On the other hand, Lean is not a one-time test because Lean uses a PDCA approach with continuous efforts to improve. Contractors will only realize the success of Lean Construction when they stay the course and keep working on adapting the Lean techniques to their operations. The following are ways to implement Lean; use as best fits each company's unique situation.

Define Value

Lean is all about value as defined from the customer's point if view. Redefining or validating the value a customer is looking for in a project sounds a little academic. After all "we" already know what they need! Redefining value takes some discipline, but the process can also lead to new views on what is value to the customer and give those who make the investment in this examination a sizable competitive advantage.

Independent of the type of work, such as "design-build" or "hard-bid", or method of estimation, such as "sequential" or "follow the air," the final product's value to the customer is the perceived usefulness in exchange for cost invested. Regardless of whether a job is bid with the "pounds per hour" or "hours per unit" method, the customer ultimately determines the job's value. For example, construction is a nuisance to some customers until the building is occupied and sustains 72 degrees. To another customer the value is only realized when the plant is up and producing product.

How does one proceed in asking the customer to define value? Start by identifying the customer: Is the customer the mechanical contractor, the general contractor, or the owner/operator? (The customer can be all three, and maybe a few more!) Two approaches can be used once the customer is identified. Start at the micro level and work with the next-in-line customer to obtain his/her view of value. Or start with the end user and work backwards through the system.

Womack suggests that addressing the Lean Enterprise is the next frontier for manufacturers that have mastered many of the basic Lean techniques. By Lean Enterprise, Womack is referring to the entire value stream from raw material to the final customer such as the homeowner, building tenant or manufacturing workers. He suggests that as the entire value stream is viewed without regard to company boundaries and self-imposed walls, there will be many opportunities to streamline sub-processes and eliminate duplicate efforts. This undertaking is beyond the scope of this paper; however, the Lean Enterprise concept offers rich possibilities.

A more usable and practical approach is to try the *COPIS* method. COPIS stands for Customer – Output – Process – Input – Supplier.[19] Doing COPIS starts with identifying the customer requirements. There are multiple ways to reach out to customers to obtain their ideas on their current and future requirements. Customer surveys, focus groups, corrective-action systems all provide listening posts along with bid specifications. The dimensions of quality referenced earlier may be used to explore the details of quality requirements. Once the requirements are identified, then review the outputs that are needed to meet the requirements. Look too for the hassle-free requirements of the customer. Is there a match in outputs to needs? Are priorities aligned? What is missing? What outputs fail to meet the requirements?

Moving next to the process, examine all steps that produce the key outputs. Fully review those processes in which failure to meet requirements occurred. Where in the process flow does the failure start?

After examining the processes, next examine the inputs. "Garbage in, garbage out" is the rule. Failure may be due to bad inputs. Almost in sequence with examining the inputs is a review of the suppliers. The root cause of a failure to meet requirements may be a failure in the supplier's processes.

COPIS works backwards. The process starts with what the customer requires to avoid conducting an entire analysis based on misinterpretations of what is most important to the customer. Through this analysis, barriers and problems are uncovered, root causes discovered and preventive or corrective actions taken.

Organize the Workplace

Many manufacturing companies have found that doing the 5S's is a good place to start implementing Lean. Because it organizes the workplace, the 5S's are very acceptable to front-line workers. The 5S's help eliminate many of the treasure hunts that take the workers' time away from doing value-added work. Start with sorting, then simplify, then set up the sweeping methods and finally move to standardize. Doing the 5S's is not rocket science but does take self-discipline. The training required to do the 5S's is not great; a two-hour session is usually sufficient. Like learning to ride a bicycle, just start trying.

Like most Lean techniques, the 5S's are new to construction and not widely known in the field. There are a few consultants in the construction industry who can help with the 5S's, as well as consultants in every region who know Lean and the 5S's but don't know construction. There are advantages of using either type.

A contractor may also learn how to implement the 5S's on his or her own with a modest investment of time to ensure the approach realizes all the benefits. Boeing has a videotape that some contractors use to help explain the 5S's. The tape shows both shop and office examples. The tape can be purchased from Boeing.[20]

One problem some contractors have incurred in doing the 5S's is only doing the first "S". Many areas are ripe for sorting. Workers feel a sense of accomplishment when sorting through a yard, office, shop or even a service truck to get rid of excess materials and clutter. However, applying the four other S's is necessary to reap the full benefits.

Establish Standard Procedures and Processes

Some contractors have felt disdain for standard procedures and processes, believing the only path to effectively establishing standard operating procedures requires tedious writing and the creation of cumbersome documents. Once documented, many companies file the standard descriptions away and neglect what they see as the arduous task of continually updating the materials. Lean companies do not have time for wasted efforts but do need standard procedures and processes to be most effective.

The Lean contractor will review the overall processes for creating work and identify the key processes. These contractors only review the key processes and supporting procedures that create value to the customer. While documenting the process for distributing the mail at the office may meet ISO 9001 standards, this task has little value for getting product installed. During the initial evaluation, managers should focus on the consistency and correctness of their processes and procedures. They may need to write or rewrite the procedures. In a Lean organization every person performing the same procedure such as writing purchase orders will need to adhere to the same procedure.

Drafting processes and procedures need not be tedious. They don't have to look like a legal document! Processes and procedures drawn similar to flow charts or with pictures are easy to do and to use. Like any Lean approach, the descriptions need to provide value to the user, especially if that user is new or not experienced in doing the task. The documents or drawings should be located wherever they will be best used, such as displayed on a wall or on a laminated sheet hanging near or on the machines to be used in the step.

Implement the Last Planner System

Given all the examples provided previously, a contractor who is serious about improving project management should seriously consider the Last Planner System (LPS). Research shows the benefits LPS brings to the field. This is the area of work that makes or breaks the company. Reviewing the constraints identified through research, shown in Figure 6, almost all of the constraints are eliminated with coordination and planning. The Last Planner System is very effective in forcing field supervision to do a better job of integrated and coordinated planning and of committing resources to work assignments ready to be done. Variance in the work can be reduced and plan reliability increased.

If a new estimating system were introduced into the industry that was proven to out-perform the current ones in use, most contractors are likely to invest time and money in training their people on the new system. LPS has proven to out-perform other project-management methods and demands serious consideration. To implement the Last Planner System will not need any investment in new software applications or IT equipment. Implementation does require:

- An investment in training project managers, superintendents and foremen on how to do the Look-Ahead and Weekly Plans, in making and keeping commitments and in understanding and using PPC and constraints analysis to improve the system. Four to eight hours of training is needed for field supervision.
- An investment in developing an individual or team in the company to champion and coach others on the Last Planner System and to maintain the momentum.
- Management leadership to maintain a focus on implementation and to encourage continued LPS use by supervision.

The details for implementing the Last Planner System are beyond this paper but can be gained through working with the Lean Construction Institute or its representatives and/or by serious study of the many papers published about Lean and learning from the companies that have implemented LPS.

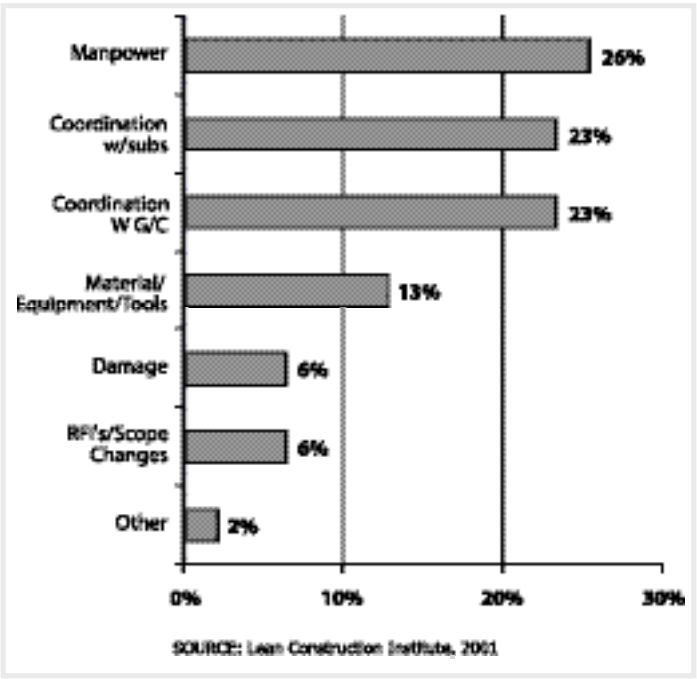


Figure 6: Constraints to completing work assignments

Reduce Batch Size and Make the Product Flow

To improve Flow, all workers must pass on only quality products and only accept correct work from the previous operation. The Japanese say, "Don't get it, don't make it, don't send it" regarding poor quality work.[10] To accomplish production of only quality work, everyone in the process must know what quality is so they can be sure they are receiving, producing and handing off quality to the next operation that is always right the first time. To ensure that the hand-offs between operations are done correctly the first time, Rules of Release are defined from the view of the next-in-line customer. These rules define what makes the handed-off product or information correct.

Product flow improves when all work is performed on a first-in first-out (FIFO) basis. In a batch mode it is often necessary to stop work and rush a job through the process. In one-piece flow a rush order can be inserted and fabricated in minimum time. In the transition to single-piece flow, look for all situations where FIFO is not working and eliminate any backlogs, barriers or stoppages. Because there are many barriers and flow blockages in batch systems, a process usually can not go from batch processing to single-piece flow at once without a disruption in the production rhythm. An initial step can be to reduce the batch size by moving smaller quantities of completed work to the next station and doing so more often. Work-flow diagrams (process maps) can help identify improvement opportunities. Root-cause analysis is needed to permanently eliminate problems.

Consider what happens when detailing sends a batch of drawings to the shop. Often the drawings represent several weeks of work but are all marked with the same need date. According to the shop superintendent these typically come in late in the week with the need date early the following week. A wild flurry of activities occurs, as well as overtime to meet the completion date. Even if all product is delivered on the need date, it won't likely be installed that fast and then must be stored on site. There are many wastes involved in this approach. If detailing issued drawings in smaller batches sufficient to match the shop's capacity and the field's actual installation need date, work would flow smoother and waste could be reduced. Look for batch operations in construction by considering the following:

- Designs passed on to detailing
- Detailed drawings passed on to the shop
- Fittings fabricated in groups and put on carts
- Fittings delivered to the field
- Material requests sent to a buyer
- Change orders given to the general contractor at the end of the job
- Packing slips for several weeks of deliveries given to accounting
- Work on reducing the batch size in any of these areas.

Another way to improve Flow is to move sequential activities adjacent to each other and as close as possible to reduce transportation waste and improve communication. This may require ignoring traditional functional boundaries. The best distance between operations is the shortest possible distance. While ample open space seems desirable, Lean seeks to keep the distance to the least possible that is still safe and functional.

Improving the workflow does not happen at once, and the manager must keep removing barriers as they become visible.

Remove Constraints in Product or Information Flow

Research for the construction industry reveals 10 causes of a contractor's wait time (see Figure 7). Material handling is the number-one cause of this waste. Keeping the crews installing steadily is the number-one priority. To improve material flow, conduct a Value Stream analysis of the material-handling delivery system from estimating take-offs to material being returned from the site or scrapped. Map the process and review the steps for value-added or non-valued-added work. Look at the barriers or constraints that keep the material from getting to the right site at the right time in the right quantity and with the right specifications.

One contractor performed this analysis and one of several improvements paid off quickly. The staff found that having the foreman review in detail the take-offs made by estimating at the time of a turnover meeting would be beneficial. The foreman would look at the work from a

constructability standpoint and compare the plan to the material take-off list. The foremen did not want to take the time upfront to do this level of review, but after the first test job identified more than $8,000 in savings in material, this step became standard practice. The group then defined several levels of turnover meetings and rules of release for each stage.

The 10 Most Costly Causes of Non-Productive "Wait Time"

1. Waiting for material – warehouse or offsite
2. Waiting for tools and equipment
3. Waiting for equipment breakdowns to be fixed
4. Rework due to design, prefabrication or field errors
5. Interface from other crews
6. Overcrowded work areas
7. Workplace changes
8. Waiting on permits
9. Waiting on instructions
10. Other delays, the common of which is waiting for scaffolding to be put or taken down

Figure 7: Main Causes of Labor Wastes

Another contractor solved the industry-wide problem of foremen filling out a material request by hand and not being clear on what is ordered. Foremen often use their own terms for parts. Buyers can make a mistake by assuming they know the right term or often they have to call the foreman to verify the correct part. All this is wasted time. This contractor developed an Excel™ spreadsheet with all the parts listed for that job. The parts were the correct specifications for that job. Staff were able to fax in the sheet with the correct parts marked by the quantity listed. The fax was much easier to read; later, the process was further improved by enabling the foreman to email the material request, saving more work.

Process mapping and examining the value stream can identify many opportunities to improve the information and the material flow.

Implement Pull

One area where the Pull delivery system can be applied is material handling on the jobsite. Figures 8 and 9 illustrate the difference between a Push delivery method and a Pull delivery method.

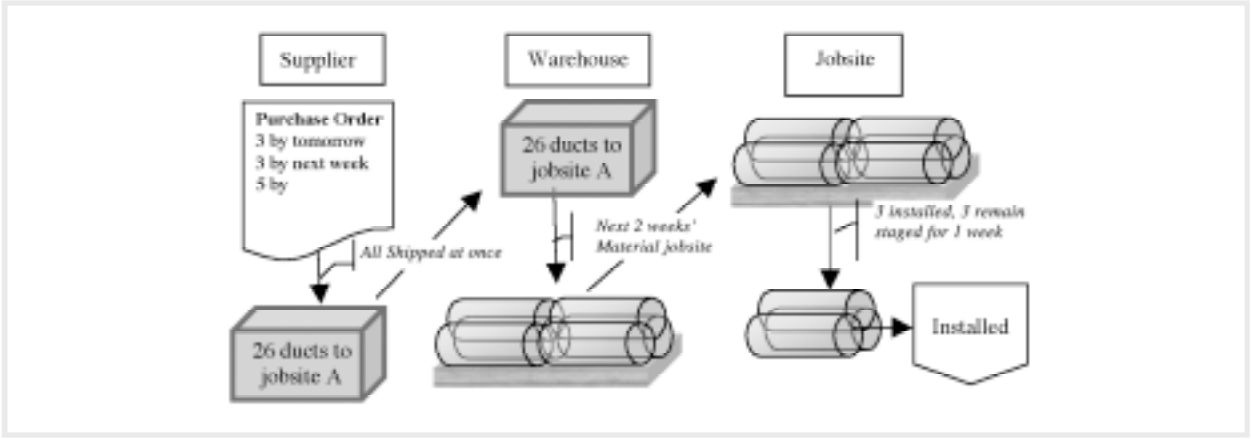


Figure 8: Typical 'Push' Material Handling Process

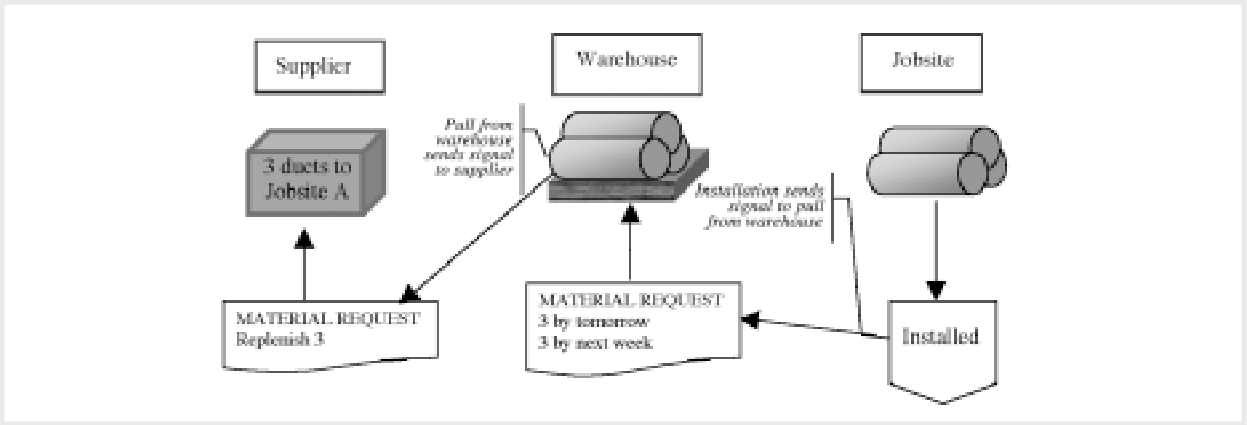


Figure 9: Lean 'Pull' Material Handling Process

Share Lessons Learned

In sheet metal and HVAC contracting, project learning is crucial. Figure 10 shows the results of a survey of over 300 sheet metal contractors asked about the meetings they hold. The purpose of these meetings is to support organizational learning. This research found that fewer than half of contractors surveyed hold regular meetings of any type. In today's dynamic business environment, communication is essential, especially to relay and receive clear requirements and commitments from all stakeholders. The absence of clear communication leads to a vacuum that also can impact the level of employee engagement.

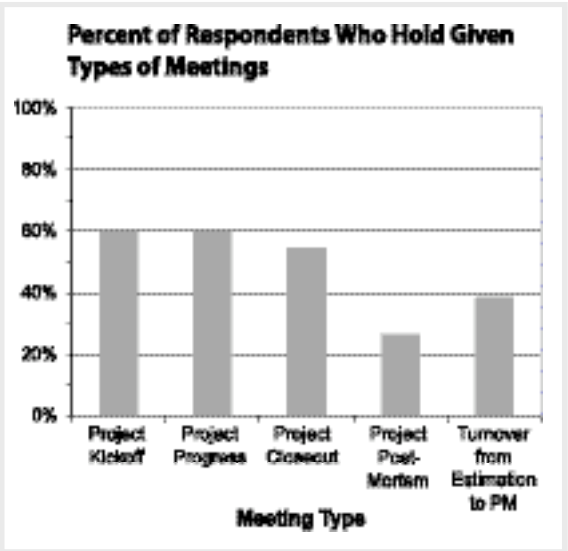


Figure 10: Meetings held by Contractors

Of critical importance are Project Review or post-mortem meetings. Less than half of those surveyed hold these meetings regularly. While holding an effective meeting is important, it is not enough to ensure that the company is learning and growing from the experience. Based on the surveys conducted in this research, of the companies that do hold project-review meetings, less than 40% disseminate the review meeting's information to anyone outside of the meeting. Project managers and foremen are not the only people who can learn from a project. Support functions also can benefit from feedback. Lean practitioners would also include the customer's feedback in the review meetings. Some contractors survey the customer prior to holding this meeting, using methods that include in-person discussions or written survey forms. Few contractors involve the customer directly in the project-review meetings, though this would allow for more meaningful learning about what the customer values.

A typical agenda for a project-review meeting could include:

- Review project purpose and scope
- Review project results:
  - Schedule
  - Budget
  - Quality – punch list and warranty issues

  - Change orders management
  - Customer's feedback and corrective action
- Review internal team's observations – what worked and what to do differently next time
  - Estimating
  - Support functions
  - Shop and fabrication
  - Field supervision
  - Project management
- Determine what key lessons can be learned
- Identify any problems to resolve and assign actions
- Determine how to communicate the lessons learned to the rest of the company.
  - How to replicate successes
  - How to prevent failures

7 WHO IS DOING LEAN?

This investigation of Lean principles practiced in the sheet metal and HVAC industry has led to several conclusions. Sheet metal contractors that have in-house fabrication and assembly operations are in general leading the industry in applying Lean applications. Next, Lean has been implemented in some support functions such as tool repair and material delivery. Some contractors have implemented the Last Planner System, others have used the 5S's and a few have started Six-Sigma initiatives. Fewer applications are seen in field or service operations. Even in the manufacturing world of Lean champions, Lean applications in the office are taking hold slowly.

The difficulty for the sheet metal, HVAC and many other industries lies in translating the applications of Lean from manufacturing to the softer, intangible business functions of the organization. To date, research has not revealed any contractor that has been able to apply the Lean principles and concepts to the degree that manufacturing has achieved.

There also have been some false starts. Some contractors have thought that doing Lean is an easy fix and have not given adequate attention, and Lean has failed. Contractors are learning, as have manufacturing organizations, that successful implementation of Lean practices requires the commitment of senior leaders discipline to continue moving forward with the new procedures, and a management style that invites workforce participation.

In many industries, the large leading companies who have mastered Lean themselves, have begun to require Lean practices of their suppliers. This has already started in the auto industry, with contractors, where Ford has introduced the Lean to Walbridger Alinger, a general contractor. If construction follows a pattern similar to manufacturing regarding Lean, in a few years the contractors who master Lean Thinking will out-perform their competition to the degree that they will capture their markets and be the low-cost and high-quality (value) providers. These Lean contractors will also start introducing Lean to their sub-contractors. Shea Homes in the Phoenix area has been teaching its key sub-contractors the basics of Lean and Six Sigma for several years with great success.

8 BARRIERS TO IMPLEMENTING LEAN

Change is never easy in a company or industry with long traditions. While Lean has proven successful in many industries including the construction industry, there is and will continue to be resistance. Three essential ingredients are required for lasting change: First, the leaders must see the need to change. Next, leaders must develop a vision of what the company is now striving to become. Finally, a plan or roadmap must be developed and shared with all stakeholders. The plan needs to detail how the company will achieve its vision.

Womack has said that health care and construction are highly complex industries and present great challenges to implementing Lean. This is because these industries consist of many crafts and have "secret processes" that the workforce believes are best methods for accomplishing work in a hectic environment. Both workers and managers believe that every job (or, in the case of healthcare, every patient) is unique and different and cannot be standardized. Indeed, in construction each job is unique, yet the various processes of construction are repeated over and over and, therefore, can be made Lean.

Lean has proven its value in manufacturing and service. The construction functions of purchasing, material management, payroll, billing and collections and fabrication are very similar to manufacturing. Consequently, these areas are the ones in which construction companies have first tried to implement Lean. The greatest challenge lies in the field and in project management. Can the Lean world of order, planning and organization fit into the construction environment of changing plans, fighting fires and contention? The problem and answer is not really in the nature of construction work but in how workers and managers have come to think about their work in order to cope with rapid change.

Lean applications in construction, including in the field, will not be sustained until the PMs and field supervision believe that their job is not firefighting but defining and improving processes that deliver value. These masters of work-arounds are being challenged to create consistency. Some people stay in the construction industry because they love the challenge of a hectic, contentious, deadline-driven and fire-filled atmosphere. How will they become comfortable in a Lean environment of a more reliable and orderly work system? When construction experiences – as has manufacturing – reduced stress and a more disciplined work environment under Lean, will workers and managers easily make the transition? It is always easier to apply techniques than to change behaviors. The role of leadership becomes twofold: champion the implementation of Lean techniques and help managers and the workforce adapt personally to a new style of working that focuses on planning, prevention and consistency.

Through research of many successful and failed change initiatives, John Kotter has identified eight reasons why change fails in organizations.[21] Contractor leaders and executives need to understand these potential causes of failure and design their Lean transformation to avoid them. The eight reasons are:

1. **Not creating a sense of urgency**: Leaders need to communicate to all employees the urgent need for becoming Lean. Over time, the construction industry has come to expect an amount of waste as inherent in sheet metal and HVAC work. The need to change must be clear.

2. **No leadership coalition**: While one very passionate leader can do wonders, most successful change efforts require the involvement and commitment of a team. Not all leaders have the title of manager, but in any company there needs to be a critical mass supporting Lean.

   The 20 – 60 – 20 rule fits when making change in contracting companies. Typically when a change is announced, 20% of the workforce is behind the change almost immediately. Another 20% is against it from the start. The remaining 60% is usually in a wait-and-see mode, wanting to know whether management is serious about this or if the change is the flavor of the month. Typically leaders spend most of their energy trying to win over the 20% that is against change. The research suggests that this 20% will probably never really buy into the change. It is much more effective to focus on convincing the neutral 60%. Once they are on board there is a critical mass (80%) ready to move forward. Womack goes so far as to say the sooner you "free up the future" of the

negative 20%, the better it is for the company and those individuals.

3. **Not creating a vision**: "Where there is no vision the people fail." Leaders need to know where Lean can take them, and they need to share that vision throughout the company.
4. **Under-communicating:** The research shows that managers under-communicate the vision, the sense of urgency and the passion for changing by a factor of 10. Contractors are among the weakest in communicating with their workforce.
5. **Not removing obstacles to the vision:** Two of the most common obstacles to implementing improvements are time and budget. "We must keep cutting, we don't have time to stop and sharpen the saw" is paraphrased every day in construction. Top management can remove these barriers by making Lean implementation a priority and providing the time and budget.
6. **Not creating short-term wins and celebrating***:* Continuous improvement is a journey that does not occur quickly. However, making note of and celebrating the wins along the way adds to momentum. Managers will do well to celebrate the small and big wins to demonstrate to employees their commitment to change.
7. **Declaring victory too early***:* Lean evolved at Toyota over 30 years of trials and improvement efforts. The traditional construction culture has been around even longer. There will be no quick, easy victory, and leaders must stay the course.
8. **Not anchoring changes**: To make the changes stick they must align with existing company polices and core values. Companies should avoid rewarding PMs who are not team players even if they do make money, allowing some workers to violate safety rules and expecting the rest to obey or putting processes in place and allowing worker variations. How the organization promotes, recognizes and rewards employees must complement and reinforce the Lean transformation. Leadership's role is to define, coach and ensure that the right behaviors are taking place to achieve the best results.

9 FUTURE POSSIBILITIES

Lean is still very young in its application to construction and especially to the sheet metal and HVAC industry. However, industry leaders are thinking beyond the immediate tools and techniques to what is next for Lean to explore. Consider the following:

Lean Enterprise

As mentioned previously, a Lean Enterprise looks at the whole process from raw material to end product. For the Sheet Metal and HVAC industry, this span would be from metal ore to a room or facility with proper heating and cooling and/or a facility with architectural sheet metal adding value. Possibilities for eliminating waste are even greater when the whole process is considered. Studying construction processes from the vantage point of Lean Enterprise has the potential to yield vast advances because so many trades are involved.

Submittal Day

One challenge faced by most contractors are delays in receiving approval for submittals. Lean would define most of the time and steps in the submittal review process as waste. Submittals review time includes the time traveling and waiting for someone to review the documents. This is waste. Additionally, Lean could improve the impact of decisions made by one discipline on the others involved in projects. Implementing Lean offers opportunities for reducing submittal cycles and adding value to the customer. An

alternative suggested by the Lean Construction Institute is to hold a submittal day. This event would bring all the engineering disciplines together with the general contractor, architect and facility owner to develop the detailed design and specifications together. Ways to make submittal day work should be explored.

Modularization/Kitting

There are some examples already in the industry of kitting, or doing work in modules at the shop, to reduce on-site challenges. There are many opportunities to apply Lean concepts and techniques to kitting or modular assembly. These methods and best practices should be identified and shared.

Zone Material Deliveries

One method that can pay good dividends is to eliminate the site yard for material deliveries. One study showed that delivering to zones closer to the actual installation areas reduces much material-handling travel (waste) between the yard and work area. That study showed a 2-4% reduction in the crew's time spent carrying material. With margins so tight in today's market, gaining additional crew installation time can add to profits. More research needs to be done on how to determine and arrange for JIT zone deliveries.

10 CONCLUSION

We investigated the application of Lean principles and found them to be transferable and applicable to the sheet metal and HVAC industry. We saw some islands of excellence; however, we did not find an organization that we can at this time declare the "Toyota of construction." While the principles are simple and contain large doses of common sense, it will take more time for Lean to be an industry-wide practice. As the larger and more progressive contractors embrace Lean principles, adaptation may gain greater speed.

The overall goal of Lean is to improve profitability through better management of the company's resources to add value and eliminate waste. Waste was once thought of as just rework and scrap. Lean brings a much broader definition of waste and expanded opportunities for reducing or eliminating the many forms of waste in the sheet metal and HVAC industry. Comparing Lean to traditional project management reveals the following differences:

Traditional Project Management	Lean
Perform work-arounds as needed	Perform job as defined with clear understanding of value
Add people to meet need dates when the job falls behind	Keep a constant workforce productive
Add equipment to rush to get the job done	Tools and equipment are sufficient and balanced in their use
Work longer hours when project falls behind	Project is not rushed and less overtime is needed
Every PM and field superintendent learns but does not share. Similar mistakes continue to occur.	Organized Lessons Learned process
Constant firefighting	A rhythm to the flow
Accept wastes as part of construction	Continuous efforts to reduce and eliminate waste

Although the construction industry continues to lag behind the national average for productivity improvement, it appears that solutions are readily available. By using and properly applying the principles of Lean that have proven effective in other industries, the sheet metal and HVAC contactor can significantly improve both productivity and profitability.

11 GLOSSARY OF TERMS

COPIS: Term stands for Customer – Output – Process – Input – Supplier and is a method for working backwards through the process to identify and validate requirements and possible errors.

5S's: The 5S's came from Toyota. The 5S's are used to organize and visually control the workplace to eliminate waste. The 5S's are Sorting, Simplifying, Sweeping, Standardizing and Self-Discipline.

Just-in-Time (JIT): A system for producing or delivering the right amount of parts or product at the time it is needed.

Kaizen: The Japanese word for continuous improvement. Kaizen has come to mean the philosophy of continuous improvement.

Kaizen Event: A quick-hit method for Lean process improvement, typically consisting of several days of intense training combined with immediate application of the concepts just taught to identify and eliminate waste. It takes place at the production work location.

Kanban: Japanese term meaning "a signboard." A communication tool used in JIT production systems. The signal tells workers to pull parts or refill material to a certain quantity used in production

Lean Thinking: Focusing on delivering value (as seen by the customer) and eliminating waste.

PDCA: Stands for Plan – Do – Check - Act. The cycle introduced by Dr. W.E. Deming as a method of continuous improvement.

Plus/Delta: A discussion done at the end of a meeting, project or event used to evaluate the session or activity. Two questions are asked and discussed: What worked? and What could we do different/better?

PPC–Percent of Planned Completed: The percent of planned work assignments (tasks) made at the beginning of the week that the crew completed by end of week. Partial completions do not count as completed. A key learning tool for project managers to help remove constraints that keep the crews from greater PPC.

Process Mapping: A flowchart identifying all the activities, operations, steps and work times for a process.

Poka-Yoke: A mistake-proofing method or device developed by Shigeo Shingo that is used to prevent an error or defect from happening or being passed on to the next operation.

Quality: Conformance to the customer's requirements.

Root-Cause Analysis: A systematic method of analyzing possible causes to determine the root cause of a problem.

Spaghetti Chart: A physical map of the work area that shows the path taken by the specific product or a person being observed. A line is drawn from start to end indicating the path moved by the product or person.

Standards: The set defined way to do the job. As used in this context it is assumed to be the best way to do the job or task.

Six Sigma: Technically, a statistical term meaning 3.4 defects per million opportunities. The term has come to mean a system of applying defined problem-solving techniques to improve performance. The method includes measuring performance before and after the problem-solving analysis. A Six-Sigma initiative includes systematic training to sustain the effort.

Takt Time: The time required to produce a piece of product ordered by the customer that is calculated by dividing the total production time by the number of units ordered. Takt is the German word for musical meter and the takt time is the drumbeat of production.

Total Quality Management (TQM) is organizing and operating all functions based on quality management principles and concepts to meet and exceed customers' needs and expectations. TQM is not quality control or quality assurance, but is much broader in scope. TQM has more to do with the quality of management than the management of quality. These quality management principles include:

- Having a shared vision
- Focusing on the customer's needs
- Maintaining the standard of zero defects
- Using prevention not inspection to work to zero defects
- Respecting people and involving them in the efforts to improve
- Continuous improvement of all processes and systems
- Managing by facts
- Constant learning of how to improve and
- Managing for results by managing the process

TQM is best seen and evaluated using the Malcolm Baldrige National Quality Award criteria.

Value Stream: Includes all the processes and activities used to design, produce and deliver the product or service to the customer

Waste: The opposite of value.

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13 APPENDIX I – EXAMPLES OF LEAN COMPANIES

The following are examples of Lean companies and their achievements. They are all recipients of the Shingo Prize for Excellence in Manufacturing. This award is named for Japanese industrial engineer Shigeo Shingo who distinguished himself as one of the world's leading experts in improving manufacturing processes. Dr. Shingo has been described as an "engineering genius" who helped create and wrote about many aspects of the revolutionary manufacturing practices that comprise the renowned Toyota Production System.

The Maytag Jackson Dishwashing Product

Jackson, Tennessee is the exclusive manufacturer of dishwashers for the Maytag Corporation. Here are a few of their recent accomplishments:

- 64% reduction in OSHA recordable injury rate
- 16% improvement in attendance to 99.1%
- Employee turnover improved by 50%
- Very flexible single assembly line with capability to produce "any model/any day" was transformed into eight single-piece flow assembly cells with capability to produce "any model/any hour."
- Improved labor hours to produce a unit by 29%
- Increased manufacturing floor space approximately 32%
- In 2003 alone, conducted over 2000 kaizen events and performed 53 Six Sigma projects to help generate several million dollars in cost reductions
- Consistently over 99% for machine uptime
- Scrap and rework costs have been reduced by 64%
- Improved first pass yield by 84% to 99.15%
- 2002 *Industry Week* Best Plant Finalist
- 2003 Shingo Award Finalist
- 2003 recipient of the first annual TBM Consulting Group's *Perfect Engine Award*

The **ArvinMeritor Gladstone** facility, located in Columbus, Indiana, was constructed in 1955 to produce light vehicle mufflers for the Ford Motor Company.

Achievements

Quality

- Decreased customer PPMs by 72% (since 2000)
- Decreased supplier PPMs by 99% (since 2000)
- Reduced scrap by 43% (since 2000)
- Decreased cost of non-quality by 54% (since 2000)

Productivity

- Increased finished goods inventory turns by 30% (since 2000)
- Averaged 36 total inventory turns
- On-time delivery average is 99.99% (since 1999)
- 100% of all work units have adopted cellular manufacturing
- Reduced MRO inventory by 73% (since 1993)
- Increased sales per employee by 12% (since 1999)

Employee Involvement

- 40 hours of annual training per employee (since 1997)
- Averaging 21 kaizen ideas submitted annually per employee (since 1997)

- Average annual savings per employee is $4,285; $204 per kaizen idea (since 1997)
- Idea implementation rate is 95%
- Safety incidents declined 86% (since 1999)
- Incident rate dropped 48% (since 2002)
- Lost-time rate dropped 60% (since 2002)

Plant Recognition

- Ford Q1
- Ford Full-Service Supplier Award
- Four-time recipient of the State of Indiana Quality Improvement Award
- State of Indiana Governor's Award for Excellence in Recycling
- Indiana Department of Environmental Management 100% Club Award
- Recipient of 11 ArvinMeritor corporate awards
- 2002 Shingo Prize Finalist

Raytheon Missile Systems

is the world leader in missile technology and production. The 10,000-employee Tucson, Arizona, site works to satisfy the numerous missile mission requirements of the United States military.

Delivery

- On-time delivery metric improved by over 38% since implementing lean

Quality

- Over 91% success rate on complex program flight tests
- First pass yield rates on highly technical products approaching 95%

Customer Satisfaction

- recent customer surveys indicate that customers would recommend Raytheon again

Cost

- Waste reduction efforts have contributed to significant program cost reductions
- Improvement projects focusing on waste elimination have saved $223 million over the past three years
- Inventory turns improved by 29%
- Cost reductions in other non-manufacturing areas (facilities, information technology, etc.) have been created by implementing Lean

Environment

- The employee work environment as well as the natural environment has been significantly improved as a result of the company's focus on people and process
- Safer workplace: 1.2 injuries per 100 employees per year following implementation of a culture of safety, 5S, and ergonomic workstations.
- Reduced hazardous waste byproducts and in 2003 recycled over 7,000 tons of solid waste.
- Volatile Organic Compounds (VOC) emissions were significantly reduced from 1997 to 2002.

Affordable Interior Systems

(AIS) Hudson, MA facility encompasses two factories. AIS produces high – quality, top-of-the-line systems furniture. AIS's 175 employees have driven these achievements:

- Productivity gains of up 88%
- 100% participation at Affordable Interior System (AIS) University where employees learn about Lean methodology and continuous improvement as way of life

- Average lead time of 8 days, a 33% reduction in two years
- Shipping 100% on-time for the past two years with a 97.9% completeness rate
- 76% reduction in panel WIP
- 62% reduction in PPM defects and 54% reduction in scrap over last three years
- More than 40,000 square feet of storage space was converted to production at two facilities
- Set-up reductions of more than 50% in several cells
- Rapid response and delivery to Pentagon for 2500 work stations to accommodate displaced workers after 9/11 attack

Source: www.Shingoprize.org

14 APPENDIX II - WHERE TO GET HELP?

The 5S's

- *Sheet Metal Made Lean and Clean,* by David Skinner**,** SMACNA Publication, Dec. 1999
- *5 Pillars of the Visual Workplace* by Hiroyuki Hirano, Productivity, Inc. Portland, OR, (1-800-394-6868) www.productivityinc.com
- **"**A Place for Everything and Everything In Its Place," by Katie Rotella, *PM Magazine*, February 2003, page 48.
- "5S's that would make any CEO Happy," by Dennis Sowards *Contractor Magazine*, May 2004.
- To order the "The 5S's at Boeing " video tape - contact Dan Kays at Boeing at (206) 662-0853 or go to *www.Boeingimages.com*

Lean Concepts

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- Lean Thinking: www.lean.org
- *Learning about Lean*: www.joeelylean.blogspot.com
- Lean Ideas on the Web: www.productivityinc.com

15 ABOUT THE AUTHOR

Dennis Sowards has more than eight years of experience in mechanical contracting and 25 years in helping companies improve the quality of how they manage. He was formerly with Kinetics Systems, where he was the manager of continuous improvement and communications. While at Kinetics, he led several successful projects that applied Lean Thinking techniques to construction. One of these, the implementation of 5S's, was featured in *PM Magazine* in February 2003. Dennis now consults with contractors helping them to achieve operational excellence. He provides training and coaching in Lean applications and total quality improvement. He has presented at SMACNA and MCAA national conventions and many local chapters. Dennis is an active member of the *Lean* Construction Institute and the American Society for Quality.

Prior to coming to Kinetics, Dennis was the quality manager for J. B. Rodgers Mechanical Contractors. He was the founding executive director of the Arizona Quality Alliance, the state's organization that helps companies become world-class. He has served as a judge for the Arizona State Quality Awards program. He has published articles in several national publications including *Contractor Magazine* and is the lead author of the SMACNA book – Creating the High-Performing Contracting Company. Dennis holds a BSE and MBA from Arizona State University. You can reach him at (480) 835-1185 and through www.YourQSS.com.