



Lean Thinking: A Look Back And A Look Forward

By James P. Womack

It's now been fifteen years since the term *lean* was given its modern meaning, and more than a decade since my MIT colleagues and I published the book *The Machine That Changed the World* in an effort to describe lean production to a mass audience. What were we trying to say? What has happened in the interim? And what are the logical next steps? Let's start with what we mean by *lean*.

What does lean mean?

Although there are instances of rigorous process thinking in manufacturing all the way back to the Arsenal in Venice in the 1450s, the first person to truly integrate an entire production process was Henry Ford. At Highland Park, MI in 1913 he married consistently interchangeable parts with standard work and moving conveyance to create what he called flow production. The public grasped this in the dramatic form of the moving assembly line, but from the standpoint of the manufacturing engineer the breakthroughs actually went much further.

Ford lined up fabrication steps in process sequence wherever possible using special-purpose machines and go/no-go gages to fabricate and assemble the components going into the vehicle within a few minutes, and deliver perfectly fitting components directly to line-side. This was a truly revolutionary break from the shop practices of the American System that consisted of general-purpose machines grouped by process, which made parts that eventually found their way into finished products after a good bit of tinkering (fitting) in subassembly and final assembly.

The problem with Ford's system was not the flow: He was able to turn the inventories of the entire company every few days. Rather it was his inability to provide variety. The Model T was not just limited to one color. It was also limited to one specification so that all Model T chassis were essentially identical up through the end of production in 1926. (The customer did have a choice of four or five body styles, a drop-on feature from outside suppliers added at the very end of the production line.) Indeed, it appears that practically every machine in the Ford Motor Company worked on a single part number, and there were essentially no changeovers.

When the world wanted variety, including model cycles shorter than the 19 years for the Model T, Ford seemed to lose his way. Other automakers responded to the need for many models, each with many options, but with production systems whose design and fabrication steps regressed toward process areas with much longer throughput times. Over time they populated their fabrication shops with larger and larger machines that ran faster and faster, apparently lowering costs per process step, but continually increasing throughput times and inventories except in the rare case--like engine machining lines--where all of the process steps could be linked and automated. Even worse, the long time lags between process steps and the complex part routings required ever more sophisticated information management systems culminating in computerized Materials Requirements Planning systems (MRP).

As Kiichiro Toyoda, Taiichi Ohno, and others at Toyota looked at this situation in the 1930s, and more intensely just after World War II, it occurred to them that a series of simple innovations might make it possible to provide both continuity in process flow and a wide variety in product



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offerings. They therefore revisited Ford's original thinking, and invented the Toyota Production System.

This system in essence shifted the focus of the manufacturing engineer from individual machines and their utilization, to the flow of the product through the total process. Toyota concluded that by right-sizing machines for the actual volume needed, introducing self-monitoring machines to ensure quality, lining the machines up in process sequence, pioneering quick setups so each machine could make small volumes of many part numbers, and having each process step notify the previous step of its current needs for materials, it would be possible to obtain low cost, high variety, high quality, and very rapid throughput times to respond to changing customer desires. Also, information management could be made much simpler and more accurate.

We described this thought process in *The Machine That Changed the World* (1990). In a subsequent volume, *Lean Thinking* (1996), Dan Jones and I distilled these lean principles even further to five:

- Specify the value desired by the customer.
- Identify the value stream for each product providing that value and challenge all of the wasted steps (generally nine out of ten) currently necessary to provide it.
- Make the product flow continuously through the remaining, value-creating steps.
- Introduce pull between all steps where continuous flow is impossible.
- Manage toward perfection so that the number of steps and the amount of time and information needed to serve the customer continually falls.

Value, the value stream, flow, pull, and perfection are simple ideas, and are generally accepted by the manufacturing community today. This is not, of course, because of anything I've done, but because the ideas are right and because the manufacturing firm best exemplifying them--Toyota--continues to march from victory to victory. But how lean is manufacturing today? How far have we gotten beyond accepting lean in theory?

How lean are we now?

One of the occupational hazards in my line of work, as the head of a nonprofit organization dedicated to promoting lean thinking, is the invitation to visit a lean producer that isn't lean. It goes something like this:

I get a call from the CEO asking me to visit and hoping I will commend their progress in implementing a truly lean product development and production system. To reach a verdict, I take a walk along the value stream for a product family and the value stream for a product design in development. (I hope you take similar walks frequently along the value stream for your own products.)

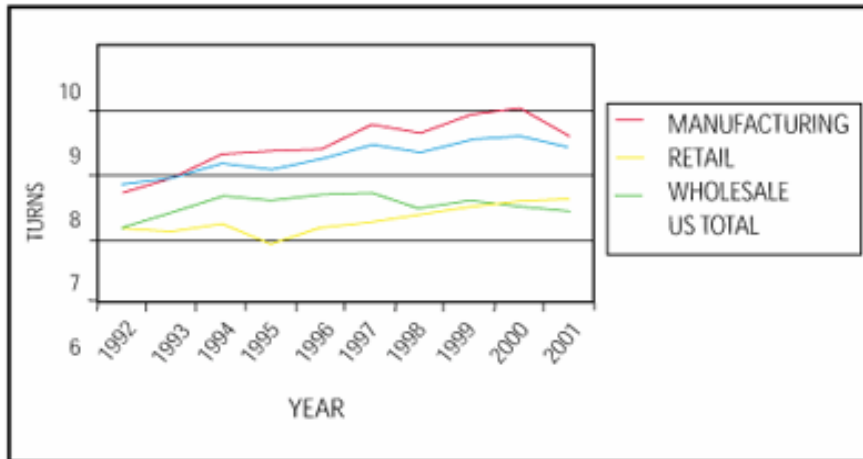
As I walk along--counting the steps and asking how many are value-creating, calculating throughput time, and asking how much is value-creating time, assessing the trend in quality and its cost, and looking at the information management system--I'm often directed to specific instances of "leanness:" the Five S program, the ISO certifications, the quick-change tools, the fabrication and assembly cells that have replaced process areas and rigid moving assembly lines, the pull systems that have replaced the MRP, the visual-management techniques from storyboards to the andon signaling lights that indicate process status, the self-directed work teams, the simultaneous-engineering process, and the kaizen teams from the process improvement group leading the charge on all of these initiatives.



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These are very interesting, but they are all inputs. What about the outputs? So I ask: 'What has happened to your total throughput time and inventories? What has happened to your cost of quality? What has happened to your manufacturing costs for your products? What has happened to your design costs for a product of given complexity?'

Usually the answer is either, "we don't know," or "not much." But I already knew this because the Five-S program was clearly not being sustained. ISO certification was really just a box-checking exercise; the quick changeovers could only be achieved during a special show for visitors, and the fabrication and assembly cells were really just collections of adjacent machines with inventory between each step. Output was very erratic (as clearly shown on the whiteboard next to the cell). The pull system was actually a mix of MRP, shop-floor expediting, and kanban that couldn't be maintained, and the visual management techniques, self-directed work teams on the shop floor, and simultaneous engineering in the product-development department were really new labels for old practices. What's more, the kaizen team often seemed to be fixing the same problem over and over.



Extremely modest growth in inventory turns has been produced by American manufacturers since 1992. This indicates that less inventory is required over time to sustain a given level of sales.

The best summary of this firm's progress toward lean production is "not much" and the great bulk of the potential for a lean leap is being lost. This is painful to hear, of course, and the CEO may wish I never made the visit, but it's hardly a matter of shame *because this performance is typical across the manufacturing economy in recent years*. The one indicator of lean that can't lie is the amount of inventory needed to support a given level of sales. And when we plot this trend (expressed as inventory turns, that is annual sales divided by the cost of raw materials, work in process, and finished goods still in the possession of manufacturing firm) for American manufacturing as a whole since 1992, we see just what I've been describing: There is a steady, but extremely modest growth in turns, indicating that less inventory is required over time to sustain a given level of sales. To give due credit to the manufacturing community, we should note that manufacturing turns have increased more rapidly than those in retail or wholesale.

My sum-up after walking through my sample company is the same as for the whole economy: "You're trying hard and you are making some progress. Congratulations! But you really ought to be doing much better." Here's how.



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First, let me insist that lean is here to stay. Programs and management fads come and go, but the need to provide the customer more value with less waste is a constant for any firm wanting to stay in business. And this is what lean thinking is all about. What's more, other manufacturing philosophies--Six Sigma, agile--turn out upon examination to be the same thing with a different entry point. The quality movement started with defects and process capability, but soon discovered that analyzing the entire value stream was essential to success. The flexible manufacturing movement started with the need to respond to rapidly changing customer demand, but soon discovered that high process capability and truly lean value streams are critical components of successful response. At the end of the day, all of these approaches are focused on creating a perfect process of value creation in product development and operations, along with the supporting processes within firms.

So the problem is not disagreement on the objective, but confusion about the means. And here we are poorly served by the typical management practice of solving every problem by launching a new program. In the lean movement, this has often meant creating a revitalized process improvement group--usually the old industrial engineers--and targeting the least lean aspects of the manufacturing or design process. It's amazing what can be accomplished in only a few days with a kaizen blitz of the defective process, and equally amazing how quickly performance regresses toward the mean once the lean team moves on. Soon, many companies--like my sample company above--are counting kaizens (another input) rather than showing sustainable improvements in their total design or production process. Yet the latter is the only important output.

The remedies are simple, but they are more difficult than just overlaying initiatives on the pre-existing mass-production organization. And it's a general rule of life that we will try anything easy that doesn't work before we will embrace anything hard that does. So let me list the next five steps, concluding with a key task for manufacturing engineers:

1. Embrace *value-stream management* by giving someone the responsibility to look at the entire value stream for a given product. This doesn't mean adding a new layer of management. Someone with another task in one of the functional areas like operations or engineering will be fine. Tell this person to form a team from the relevant departments and functions supporting the product on its path from concept to launch and from order to delivery. Then draw a simple map of the current state of the value stream, showing every step, and envision a future state with more rapid throughput, less waste, fewer defects, and more agility to changing customer desires. Finally, give this responsible person the task of implementing and sustaining the Future State, judged by the key metrics of increased margins and increased market share for the product.

2. Give this person the appropriate financial tools. One of the legacies of Frederick Taylor's Scientific Management is a focus on individual machines, their utilization and labor hours--through the mechanism of Standard Cost accounting. The lean thinker and value-stream manager would rather optimize the whole and account for the entire value-stream rather than individual machines and processing steps.

3. Implement truly continuous flow and rigorous, but simple, pull systems in every value stream. The problem here is not so much the lack of knowledge; rather it's the lack of collaboration between value-stream managers, manufacturing engineers, industrial engineers, and information managers in production control and logistics functions that bring all four



perspectives together to truly support every value stream.

4. Once value streams are managed and on the road to improvement at the facility level, expand the scope of value-stream management to the larger value stream running from raw materials to customer. Focus in particular on reducing the costs that loom large in today's manufacturing world, where fabrication and assembly steps are spread across the globe without managers' understanding the full consequences.

5. Value-stream managers need to consult with manufacturing engineers to rethink process machinery. The engineering community has been occupied for a century with building machines that are larger and run faster with more features, in hopes of reducing costs per fabrication step. There have been many brilliant achievements (for example look at the Hauni-Blohm blade-grinding sidebar *The Lean Machine*), but the overall effect has been to optimize the points rather than the whole.

What's needed today are right-sized machines that are highly capable, highly maintainable, and highly movable, with no more features than necessary, which can be inserted in value streams rather than requiring the value stream to come to them. (Henry Ford noted by 1914 that the process should go to the product rather than the reverse.) These machines should permit both capital and labor linearity so that small amounts of incremental capacity can be added or subtracted as customer needs change, but without changing capital costs and labor content per unit of output over a wide range of demand.

Five simple steps to the future

If manufacturing management and the manufacturing engineering community can embrace these five simple--but difficult--steps in the years ahead, we can all make a true leap in serving the customer and sustaining our businesses. Call it lean, agile, Six Sigma, or whatever. The key is to creatively modify our inputs as managers and engineers so we maximize our outputs in support of our customers.

A Lean Layout

In 1988, Pratt & Whitney felt it had reached perfection in the blade grinding process for the turbine blades installed in its jet engines. Working with the German tool builder, Hauni-Blohm, Pratt engineers had devised a fully integrated and automated grinding system that reduced grinding time from 84 min through a series of nine grinding machines to 3 min in one massive machine. At the same time, expensive direct or "touch" labor was entirely eliminated.

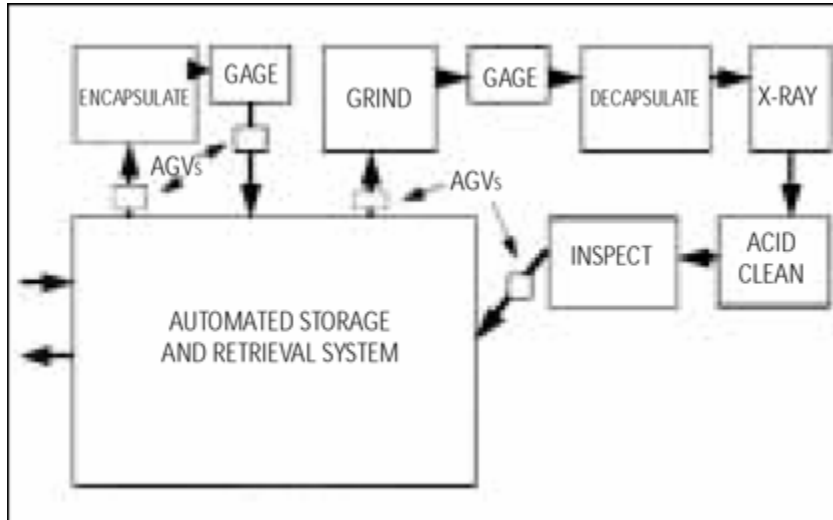
The new process was complicated because of the need to encapsulate the blades in a light alloy to fixture them in the grinder without overstressing them. And the computerized control systems with 2000 parameters of control were quite complicated as well, requiring substantial amounts of technical support. But the system was remarkably accurate, capable, and able to meet the envisioned need for thousands of blades per month for each of a few part numbers.

However, customers refused to cooperate with the logic of the new system. Instead of thousands of blades of a few types, they wanted hundreds or tens of blades of many different types. In addition, they wanted rapid response to changing orders and needed to dramatically change the total volume of blades requested from day to day and month to month. This created severe problems for the perfect grinding system. Changeovers were extremely complicated, taking eight hours, so it was hard to make a few parts at a time of a given part number. Also, time through the system--with the encapsulation and decapsulation steps--was ten days in



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addition to the three minutes of actual grinding time. This made it hard to react to sudden changes in demand. Finally, the system operated in an *all or nothing* mode. It was either running at full output or it was stopped, meaning that operating at any level below full volume carried significant cost penalties. Even worse, as demand approached the capacity of the system in the mid-1990s, Pratt faced the need to buy another massive module, which initially would be grossly underutilized.



Automated blade grinding center. Working with the German tool builder Hauni-Blohm, Pratt engineers had devised a fully integrated and automated grinding system that reduced grinding time from 84 minutes through a series of nine grinding machines to three minutes in one massive machine. At the same time, expensive direct or touch labor was entirely eliminated. But this process also posed problems.

Instead, Pratt's manufacturing engineers pioneered a new approach to blade grinding. It consisted of a number of production cells consisting of small, easily movable machines handling parts in single-piece flow. By the late 1990s Pratt's manufacturing engineers, working with the same manufacturer who had created the massive automated system, switched both turbine blade and vane grinding to this new process. Blade grinding time in the four cells needed to meet demand that increased from 3 minutes to 25, but throughput time for the total process (which eliminated the costly and environmentally unsound steps of encapsulation and decapsulation) fell from 10 days to 75 min.

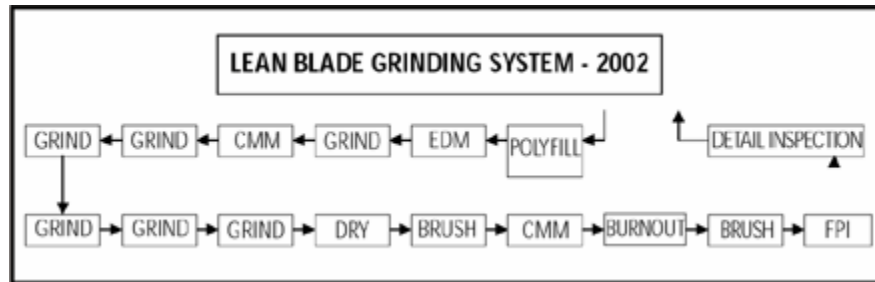
Pratt engineers then expanded the cells to include several subsequent processes including Fluorescent Penetrant Inspection (FPI) and Detail Inspection. Doing this replaced another large, automated, centralized monument system with in-line inspection stations in each cell. Changeover times were reduced from 8 hours to 100 seconds, so it was possible to run very small batches of a part number to meet changing customer needs. The overall leadtime for blade grinding through detail inspection fell from 12 to 14 days to 2 hours.

Finally, by using a small amount of touch labor to walk each blade through the cell, and adding or subtracting operators, it was possible to increase or decrease total output to meet gyrating demand, while maintaining near linearity in labor cost per blade. (This touch labor turned out to be more than offset by the reduction in indirect, technical labor needed to support the much more complicated automated grinding system.) Additionally, if rising demand called for output



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beyond the capacity of the four cells, a fifth cell could be added, preserving near-linearity in capital cost per blade at differing levels of output.



With the use of some touch labor and longer grinding times, the new lean blade-grinding system easily right-sized machines to slash throughput times, improve customer response, sustain the previous high level of quality, substantially reduce capital costs, and total cost per blade.

The perfect blade grinding process of 1988 gave way to a lean process in 2002 that uses some touch labor, longer grinding times, and easily moved right-sized machines to slash throughput times, improve customer response, sustain the previous high level of quality, substantially reduce capital costs, and total costs per blade. A truly lean leap.

How Lean Got Its Name

I was lucky early in my career to have the opportunity to manage a vast global project to understand and describe the new manufacturing system pioneered by Toyota. Our problem, in 1987, was that we were beginning to understand our subject but didn't have a label for the concept. We thought about Toyota-ism (after the car company) or Toyoda-ism after Kiichiro Toyoda, the company president who had many of the ideas for pull systems in the 1930s, or Ohno-ism after Taiichi Ohno, the legendary figure who pulled all the pieces of the system together immediately after World War II. But these sounded alien and connected a set of ideas pioneered by many individuals and firms to only one person or to one company.

One afternoon in my office, I asked our team to get serious about a name. John Krafcik, my young assistant studying at MIT's Sloan School after a stint as the first American engineer hired at NUMMI (the GM-Toyota joint venture to assemble cars in California), made a suggestion. He said we should simply ask what this new system could do that the predominant mass production systems couldn't. At a whiteboard, we all wrote down key performance advantages in both product development and production: less effort, less space, fewer defects, less throughput time, lower volume requirements, less capital for a given level of output, etc.

Standing back from this list, John (who is now the chief engineer for Ford's second-generation Expedition/Navigator SUVs) said very simply: "This new system needs less of everything to design and produce products economically at lower volumes with fewer errors. It's lean." And that was it. I knew immediately we had found our handle.