Lean Manufacturing Principles Guide

Version 0.5

June 26, 2000

Maritech ASE Project #10
Technology Investment Agreement (TIA) 20000214

Develop and Implement a 'World Class' Manufacturing Model for U.S. Commercial and Naval Ship Construction

Deliverable 2.2

Submitted by
National Steel & Shipbuilding Co.
On behalf of the
Project Team Members
Prepared by
The University of Michigan

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **26 JUN 2000**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Lean Manufacturing Principles Guide**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230-Design Integration Tools Bldg 192, Room 128 9500 MacArthur Blvd, Bethesda, MD 20817-5700**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**48**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

A Guide To Lean Shipbuilding

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DRAFT, Version 0.5

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Introduction

A shift is occurring in manufacturing around the world. Manufacturers throughout industries from automotive to aircraft to paint to computers to furniture and on and on are moving to a different system of production called Lean Manufacturing. We are not talking about adding some new techniques onto how we now build products, but actually changing the way we think about manufacturing. That can be a tough shift to make. The best way to understand lean manufacturing is to start with its roots in the Toyota Production System. Toyota started by following the basic principles set out by Henry Ford with the moving assembly line. Ford preached the importance of creating continuous material flow, standardizing processes, and eliminating waste. While Ford preached this, his company turned out millions of black Model-Ts and evolved to wasteful batch production methods of building up huge banks of work-in-process inventory throughout the value chain and *pushing* product onto the next stage of production. Toyota did not have this luxury, lacking space, money, and the large volumes of one type of vehicle and the it had to develop a system that flexibly responded to customer demand and was efficient at the same time.

Shipbuilding is clearly different from automobiles. One does not see a ship coming off the assembly line every minute with relatively standard configurations. Ships are built to order, one or a few at a time over weeks or months and are often highly customized. So is the model of "lean manufacturing" worth considering? The answer is clearly yes. First, the basic principles of giving customers what they want with shortened lead times by eliminating waste apply to any process, high volume or low volume, customized or standardized. While the particulars of how Toyota applies lean solutions in their circumstances may not all fit, the philosophy and principles have been fine tuned to a high art form by Toyota. Second, when world class shipbuilding models are examined we see much of the same underlying philosophy of the Toyota Production System at work in building ships. For example, Japanese shipyards are among the most efficient and have used relatively standardized, modular designs to create what some call ship factories—factories in which there is a constant flow of basic and intermediate products, built in most cases on moving lines, and material is carefully sequenced and shifted through the yard in a carefully orchestrated flowing pattern—Just-In-Time. Quality is built in at the source, rather than inspected in. Processes are highly standardized and timed. It is the responsibility of each worker, not just a select few inspectors. Raw material, such as steel plates, is not brought into the yard months in advance to sit and wait but brought in on a JIT basis.

American shipyards have not competed on the world market, instead serving a highly protected U.S. defense market. As American shipyards recreate themselves to become more competitive they need to rationalize manufacturing and draw on world class manufacturing philosophies and techniques. It is becoming accepted that the Toyota Production System and the lean principles that have been derived from this system, in combination with the best examples of world class techniques that build on this philosophy, will provide a sound foundation for the resurgence of American shipyards.

This document lays out a framework and some principles for the design of a lean shipbuilding process. The application of these principles depend heavily on how the ship is designed. They assume the ship is designed to be manufacturable and is based on relatively standardized modules. While each module will not be identical, modules as much as possible should be designed to go through common processes and facilitate flow through the yard within predictable times.

First, the general philosophies of lean manufacturing will be described, specifically focusing on the Toyota Production System. This philosophy and system has been translated into a lean shipbuilding model which we will then present. The model provides a framework and the rest of the guide will be organized around elements of this framework, wherever possible illustrating the elements with world class shipbuilding examples.

What is Lean Manufacturing?

The Goal

The Toyota Production System (TPS) was developed to become competitive on world markets, particularly competing with Henry Ford, while addressing the particular circumstances Toyota faced in Japan. Through years of trial and error on the shopfloor Toyota discovered that they could simultaneously achieve high quality, low cost, and just-in-time delivery by "shortening the production flow by eliminating waste." This simple concept is at the heart of the TPS and what distinguishes it from the older mass production paradigm it supplants. The focus is always on shortening the production flow and waste is anything that gets in the way of a smooth flow. The theoretical ideal is continuous one-by-one piece flow. While this ideal is rarely realized, practitioners of TPS understand directionally that performance of the system will improve if the *system* is moving toward continuous flow by eliminating waste.

To understand what this new paradigm of manufacturing of "lean manufacturing" is, it helps to briefly consider the history of mass production in America and how Toyota's path deviated from that trajectory.

1900 to WWII

Henry Ford broke the tradition of craft production by devising mass production…to fill the needs of early 1900's society. A key enabler of mass production was the development of precision machine tools and interchangeable parts. Frederick Taylor's time and motion studies, in concert with the division of labor into specialized skill groups, led to huge productivity increases.

The turn of the century was a time of massive growth and movement in the USA. From 1860 to 1920 our population more than tripled (31 million to 105 million people). We were experiencing massive immigration and migration westward. And many of these people needed a way to move around. They needed vehicles at a low cost, not vehicles for rich people. There was a big market with unlimited demand. Ford's response to this situation was to take advantage of "Economies of Scale" and create the Model T—the car for the masses. Ford's main innovation was the moving assembly line, which in combination with interchangeable parts and time and motion studies revolutionized manufacturing. The cost of the Model T dropped from $850 in 1908 to $290 in 1925. An amazing 15 million were sold. The rest is history.

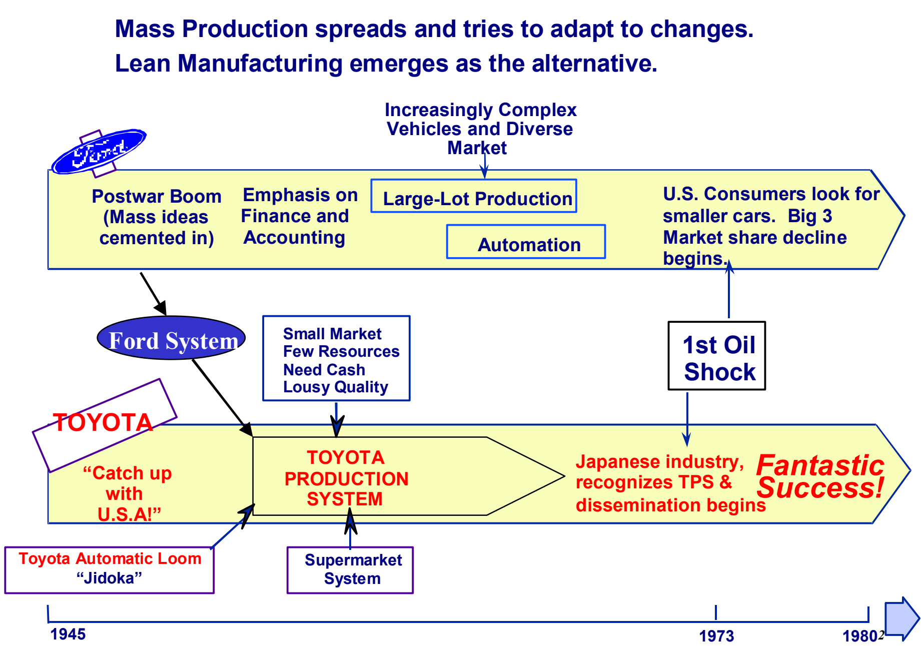
In the meantime, over in Japan, the Toyoda family was making automatic weaving looms. Toyoda's inventions included special mechanisms to automatically stop a loom whenever a thread broke. Toyoda sold these patent rights to the Platt Brothers in England for 100,000 English pounds, and in 1930 used that capital to start building the Toyota Motor Corporation. Toyota Motor Corporation started out primarily making simple trucks, and struggled for most of the pre-WWII period. Toyota produced poor vehicles and had little success. (e.g.: hammering body panels over logs)

However, Toyota did visit Ford and GM in 1930, to study their assembly lines. Toyota managers carefully read Henry Ford's books, and tested the conveyor system, precision machine tools, and the economies of scale idea in their loom production. Toyota realized early on that the Japanese market was too small and fragmented to support the high production volumes we had in the USA. (A U.S. auto line might produce 9,000 units per month, while Toyota would produce only about 900 units per month.) Toyota knew they would have to alter the mass production approach for the Japanese market.

POST-WWII

WWII and its aftermath brought auto production at Toyota to a near standstill, but brought boom times again in the USA. Plants were running at capacity…almost a repeat of the earlier big market & big demand! Mass ideas became cemented due to great financial success. Mass production techniques introduced by Ford became universally used across U.S. and Europe. This is illustrated in Figure 1.

Figure 1: Post-War History of TPS



Henry Ford was clearly a manufacturing genius and in fact his early writings (for example, Today and Tomorrow, published in 1926) clearly laid out all the basic concepts of lean manufacturing. The famous River Rouge complex in Dearborn was designed to flow materials from iron ore to finished vehicles and Henry Ford wrote that large batch production with lots of inventory everywhere is waste. Yet, batch production was exactly what was practiced at the River Rouge, and despite the waste the huge demand and large volumes made Ford profitable despite all the waste.

> "Ford made a dramatic wrong turn at his new Rouge complex. He maintained the assembly track but rearranged his fabrication machinery into process villages. He proceeded to run a push schedule in which growing fluctuations in end-customer demand and persistent hiccups in upstream production were buffered by a vast bank of finished units forced on the dealer network and equally vast buffers of parts at every stage of production upstream from assembly. Thus "flow" production (as Ford termed it in 1914) became "mass production".
>
> James P. Womack, 1997. Foreword to: *Becoming Lean*, edited by Jeffrey Liker (Portland, Oregon: Productivity press).

But Henry Ford died in 1947, and American industry began to move away from his philosophy. While the rest of the industrialized world was struggling to rebuild, American companies were able to sell everything they produced…and a kind of "good old days mentality" seemed to set in. Henry Ford II, who was not a manufacturing man like his father, began to place a growing emphasis on finance and accounting and to neglect the manufacturing side of the business. Factories deteriorated.

At the same time, the automobile marketplace began to change. Vehicles were getting much more complex, and there was growing variety of vehicle type to serve different customers. In the early days the Model T joke was: "You can have any color, as long as it's black." Now, with several different models being produced (called "product proliferation"), it was getting more difficult to keep production flowing in a coordinated manner. On top of that the number of parts in a typical car shot up from 6,000 in the Model T to the 15,000 we have today. This made it even harder to coordinate the flow of parts.

American companies continued to stray from Henry Ford's original philosophy of continuously flowing materials. Due to the great success we had with mass production and economies of scale, we tried to adapt mass production to fit a changing situation, rather than to re-evaluate our fundamental approach. We adopted large-lot production and faster automation, to try to maintain economies of scale. The result was the scheduling nightmare and accumulation of inventories throughout the system that we know today. We thought we needed to stick with mass production because we had made a fortune with it!!??

Meanwhile at Toyota…

Toyota tried exporting cars to the U.S., but failed miserably. They had 1/10 the productivity of American auto manufacturers, so it was a constant struggle to build vehicles. Toyota's management was given the edict to "catch up with USA", or the company will fail. Toyota's situation after WWII was the opposite of ours. They faced a small market and diverse products. Low volumes meant that Toyota had to make more than one model on the same assembly line. With few resources and capital, Toyota needed to turn cash around quickly (from order to getting paid). They simply could not let material set in large piles of inventory on the shopfloor.

So Toyota's Goals were different. Instead of economies of scale, they had to find a way to simultaneously achieve high quality, low cost, short lead-time, and flexibility. Toyota assigned Taiichi Ohno, a production manager, to find a way to catch up with the West. Ohno began with an intense focus on the shop floor, just as we began to ignore it. In 1950, Toyota visited U.S. plants again on a 12-week study tour. They expected to be dazzled by our manufacturing progress, but were surprised that development here had nearly stopped and saw their opportunity to catch up.

From 1952-1962, the Toyota Production System (TPS) was developed by Taiichi Ohno on the shop floor to meet the goals mentioned above. This was the first lean manufacturing system, incorporating a new philosophy with ideas mostly taken from America. These included a supermarket system, that is the concept of pulling materials from the customer backward to production. They also built on Deming's preachings that the next process is our customer, learned from U.S. Quality and Productivity seminars offered in Japan. They also religiously read Henry Ford's Today and Tomorrow. From 1962-1972, Toyota rolled TPS out to 40 key suppliers and the lean manufacturing plant became the lean extended enterprise.

The First Oil Shock to Today

Then came the first oil shock in 1973. While it certainly hit the U.S. hard, as fuel prices soared and the small, fuel-efficient Japanese cars suddenly looked very attractive, it hit Japan at least as hard. Japanese manufacturing went into a recession and companies almost uniformly went into the red. However for some reason Toyota recovered much more quickly than their competitors. For the first time, Japanese industry took notice of TPS, and dissemination of TPS began throughout Japan.

American automakers became aware of Japanese manufacturing in the late 1970s, but it was not until Toyota's joint venture with GM in Fremont, California (NUMMI in 1984) and "The Machine that Changed the World" by Womack, Jones, and Roos in 1990 that we began to understand there was a new system of production that went beyond quality methods. The Toyota Production System was dubbed by Womack and associates "lean manufacturing" and is now sweeping the West as modern manufacturing—the next paradigm beyond mass production.

In sum, the characteristics of the U.S. market at the turn of the century led to the development of our mass production approach. But that market is now gone. Mass production worked well with a simple vehicle & single model for a high market demand. In that situation you can keep on running individual production areas very fast and at high volume. When we produce a variety of more complex products, it becomes a scheduling nightmare to get all the thousands of parts together at the right time. So we build up big inventories, which lead to waste and hidden quality problems. Mass production simply does not provide the flexibility we need today.

Japanese Shipbuilding as Lean Manufacturing

When the Japanese restarted shipbuilding after World War II they were not as productive as the world leading shipyards in Britain and Northern Europe. They also had a reputation of lacking innovation/creativeness and delivering poor quality products. While the impetus for improvement resulted from a unique government/industry relationship, it was the individual shipbuilding groups that brought it about. From 1960 to 1965 Japanese shipbuilders improved their productivity by 100%. They did this by further developing the structural block construction approach and pre-outfitting that was started in the U.S. and Europe during World War II.

From 1965 to 1995 they improved their productivity by 150%. This was accomplished by perfecting the structural block construction approach and developing advanced and zone outfitting. This was further aided by their excruciating attention to every detail in design and construction to eliminate waste.

A major factor was their involvement of all employees in the continuous improvement effort, not just management and some technical employees. Other important factors (now lean manufacturing principles) were standardization, one piece flow, flow smoothing, focus on elimination of waste, group technology and part families, dedicated interim product lines, continuous improvement, and multi-task assignment for employees. They have also applied 5S to some level.

It is safe to say that although different from the automotive industry and Toyota, Japanese shipbuilders were developing some of the lean principles at the same time as Toyota, and they probably learned from each other. More recently they have adapted some of the lean principles to suit their unique situation, such as JIT.

It is not possible to say how much lean principles helped them to achieve their exceptional productivity gains, as they applied other aspects of Japanese manufacturing technology at the same time. In fact lean manufacturing blurs with Total Quality Management and other Japanese developments to provide their unique and successful shipbuilding production model.

Why Change to Lean Shipbuilding?

Change is not a natural state for most people, even though it is prevalent in the environment surrounding them. Most people prefer stability. In fact the Scientific Management School is based on the concept that it is management's task to protect workers from such change and provide a stable environment in which they can work. Today that approach is doomed to failure. Change touches us all in many ways.

There is a minority that finds change exciting and invigorating. The change adverse majority often designates them as foot loose or unstable. Therefore change is often difficult to accomplish as there is always a strong inertia resisting it. Because of this, countries, industries, companies and even individuals only undertake change when they face a crisis and change is the only hope for survival. Unfortunately, for many, it is too late! In the case of shipbuilding the British experience is proof of this fact.

The U.S. shipbuilding industry is almost at, and may even have already past, the critical stage. U.S. Navy orders are dwindling and the major shipyards are incapable, at this time, of winning new build orders for commercial ships at world competitive prices. Most of the U.S. shipyards have made improvements to facilities and processes over the years, but the results have been marginal compared to Japan and even Korea. Productivity in U.S. shipyards is half that of Europe and third of the Japanese shipbuilding productivity, and this is for an apple to apple comparison based on the internationally accepted productivity metric based on Compensated Gross Tonnage (CGT), that accounts for differences in size and complexity of the ships involved. In addition to the productivity problem, U.S. shipyards also take twice as long, or more, to build ships. An extreme example is a comparison between Newport News Shipbuilding and Hyundai in Korea. Both have approximately the same number of employees. Hyundai delivers 74 ships a year (ULCC, VLCC, LNG, Car Carrier, Container and Bulk Carriers). Newport News delivers one aircraft carrier every 5 years! Of course an aircraft carrier is significantly different and more complex than commercial ships, but "that much?"

If the U.S. major shipyards are all to survive they must change enough to be competitive enough to entice U.S. ship owners to begin to replace the aging and time restricted Jones Act fleet. This would keep them busy for the next 10 years. But what about after that? It is unlikely the U.S. Navy will be able to fill the demand gap. To continue to survive the U.S. shipbuilders must be able to win international commercial ship orders. So effectively, U.S. shipbuilders have 5 years to become internationally competitive. How can they do it?

There are many things that could and should be done, but one way that could significantly help, is to adopt the lean manufacturing principles. Of course the major requirements is adequate throughput to which the new approach can be applied. It is recognized that this is a "chicken and egg" situation. The desired productivity cannot be achieved without adequate throughput and new orders cannot be achieved unless the productivity is improved.

It is anticipated that implementing lean manufacturing principles in shipbuilding could improve productivity by at least 50% and shorten build time by 100%. Such achievements would certainly assist U.S. shipbuilders to improve their prospects for the future.

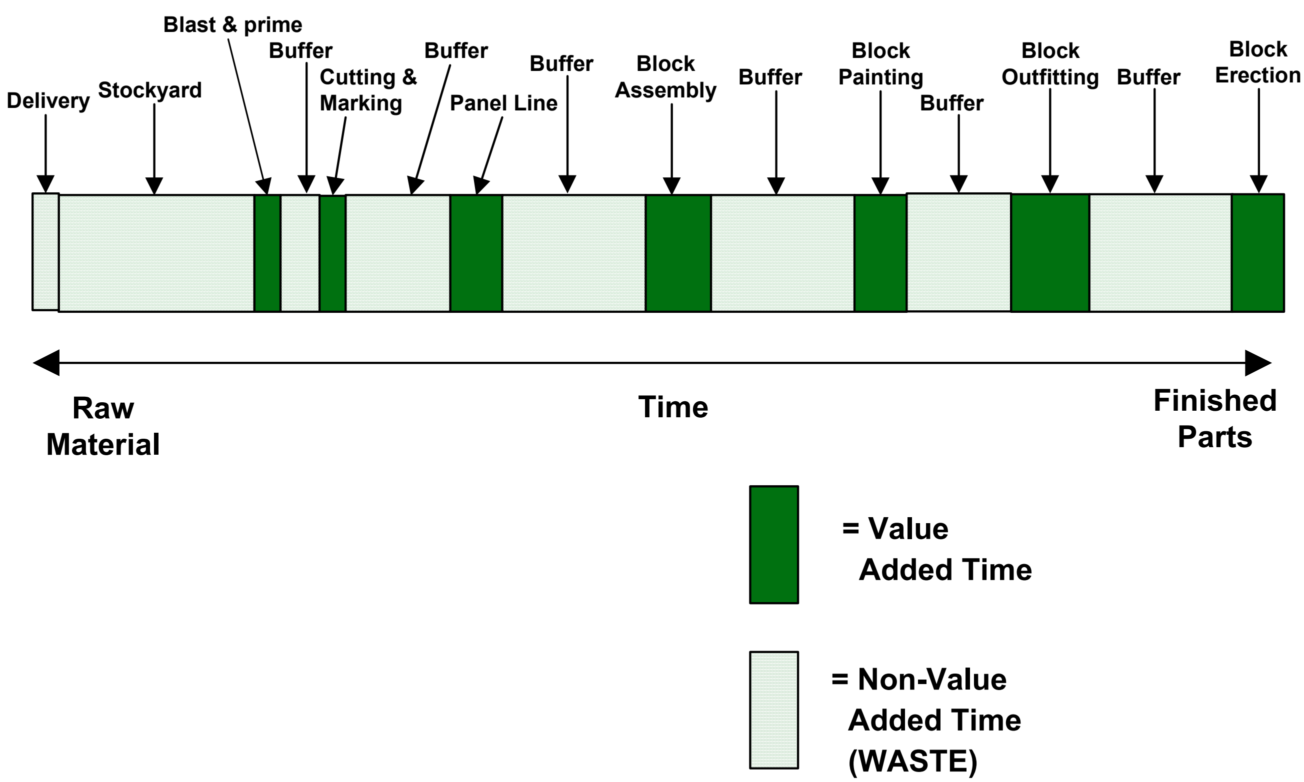
This Lean Shipbuilding Guide presents the lean manufacturing principles and gives examples of how they are, either, currently applied in some shipyards or how they could be implemented.

The Lean Focus: Reducing Lead Time by Eliminating Waste

What is waste?

In lean manufacturing waste is anything that adds to the time and cost of making a product but does not add value to the product from the customer's point of view. Value-added activities transform the product into something the customer wants. In manufacturing this is generally a physical transformation of the product to make it to conform to customer expectations. Figure 2 shows a simplified version of the steps required to make a steel subassembly. Only the activities shown in green add value. By add value we mean that they transform the product physically toward something the customer wants. The gray activities are waste—they do not add value from the customer's perspective.

Figure 2: Elements of Product Leadtime



Mass Production Thinking

Mass production is a way of thinking that starts with the principle of economies of scale. Bigger is better and making large batches of parts makes more efficient use of individual equipment than small batches with time consuming changeovers. The focus on mass production is individual efficiency – efficient use of individual machines and individual operators.

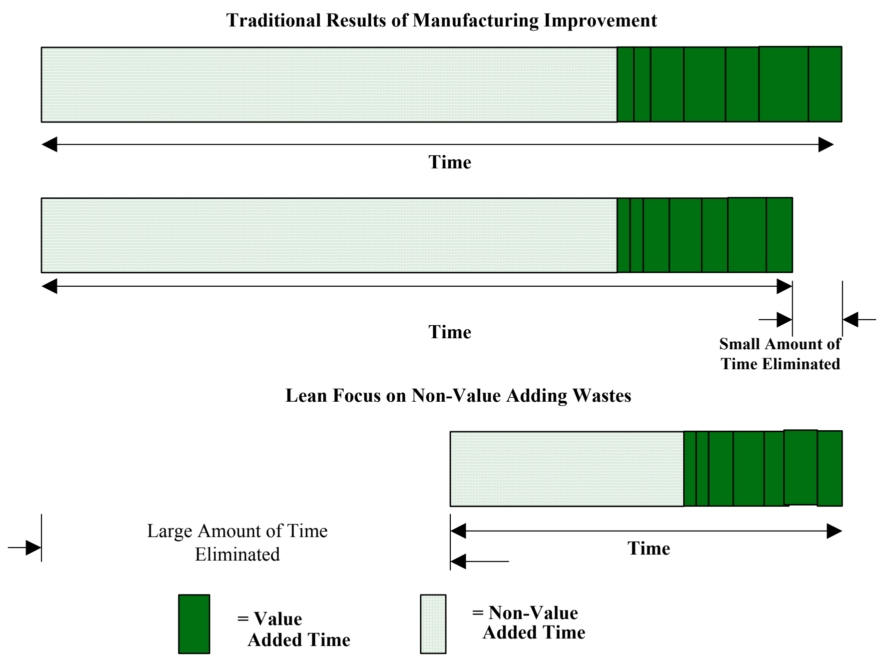
To make the overall system in Figure 2 more efficient mass production thinking attacks the efficiency of value-added activities. For example, one might reduce the cycle time needed cut the steel. We can see in Figure 2 that the total benefit of reducing the cycle time of value-added activities amounts to a small portion of overall lead time, because value-added time is a small portion of total lead-time.

Lean Thinking

Lean thinking focuses on value-added flow and the efficiency of the overall system. A part sitting in a pile of inventory is waste and the goal is to keep product flowing and add value as much as possible. The focus is on the overall system and synchronizing operations so they are aligned and producing at a steady pace.

Lean manufacturing is a manufacturing philosophy that shortens the time between the customer order and the product build/shipment by eliminating **sources** of waste. *Waste* is anything that does not contribute to transforming a part to your customer's needs. The results of the lean approach are illustrated in Figure 3 below. Lean manufacturing will take some waste out of the value-added activity shrinking it down as in the mass production approach, but more importantly, it reduces the pure non-valued added activities, which has the large impact on lead-time.

Figure 3: Traditional vs Lean Approaches



Recognizing Waste

When we put on our lean thinking lenses and look at any manufacturing process the first question we should ask is: what does the customer want from this process? This then defines value. We then can ask what transformation steps are needed to turn materials entering the process into what the customer wants. Based on this we can observe a process and separate the value-added steps from the non-value added steps. As an example, we have done this for a generic manual assembly operation on truck chassis assembly line in Figure 4. If we watch an operator work there are many individual steps. But generally only a small number add value to the product. In this case only those steps highlighted in red add value. Some of the non-value added are necessary, for example, the operator has to do some walking and get the power tool. The point is to minimize the time spent on non-value added operations, for example, by positioning the material as close as possible to the point of assembly. Distinguishing value-added from non-value added and then identifying ways to reduce the non-value added time is an excellent exercise and one you can start on right now!

The Seven Wastes in Manufacturing

1. **Over production** – Producing more material than is needed before it is needed is the fundamental waste in lean manufacturing--Material stops flowing.
2. **Producing defective products** – Defective products impede flow and lead to wasteful handling, time, and effort.
3. **Inventories** – Material sits taking up space, costing money, and potentially being damaged. Problems are not visible.
4. **Motion** – Any motion that does not add value to the product is waste.
5. **Processing** – Extra processing not essential to value-added from the customer point of view is waste.
6. **Transportation** – Moving material does not enhance the value of the product to the customer.
7. **Waiting** – Material waiting is not material flowing through value-added operations.

Toyota made famous the seven wastes in manufacturing illustrated in Figure 5.

Figure 4: Waste in Truck Chassis Assembly

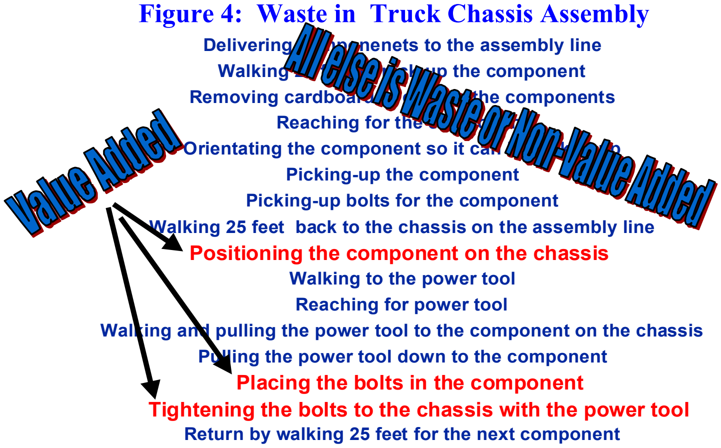
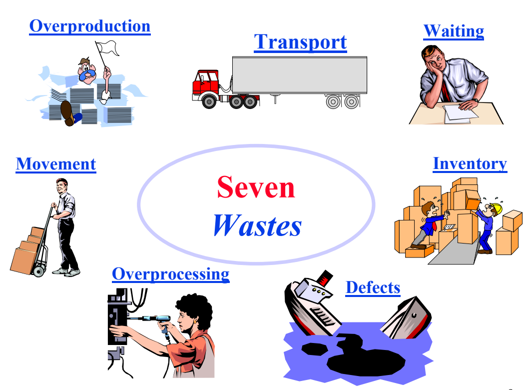


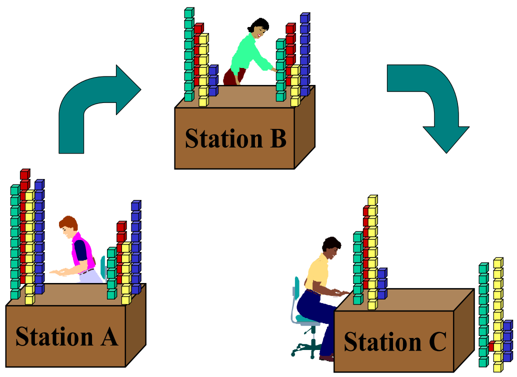
Figure 5: The Seven Wastes



Traditional batch manufacturing separates processes with buffers. Figure 6 presents three operations with plenty of inventory coming into the operation and leaving the operation. This buffers the operations so that each can all work at different pace and equipment breakdowns will not influence later operations until the inventory buffer is depleted. If the only goal was to keep everybody working as much as possible, this would seem to make sense.

Figure 6: Mass Versus Lean Flow

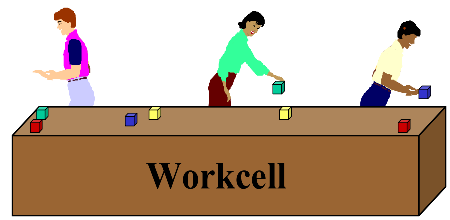
BATCH AND QUEUE PROCESSING



Inefficiencies:

- Long lead times due to inventory buffers.
- Imbalances in the timing of operations hidden—bottlenecks are hidden.
- Feedback from later operations (customers) to earlier operations is delayed. When a defect is discovered it is not clear when or why it was produced.
- Little motivation for improvement.
- When shifting to a new product (e.g., A to B) there is a large buffer of parts to be moved and handled.
- Extra handling is necessary (potential damage).
- Extra floor space is needed.
- Extra inventory costs money.

CONTINUOUS FLOW



Advantages: (over batch and queue)

- Production lead times are short.
- Imbalances in operation timing (bottlenecks) are apparent – improvement can focus on bottlenecks.
- Defects are immediately apparent and the underlying cause can be quickly determined.
- Constant motivation for improvement – problems have immediate production impact.
- Operations can quickly shift to a new product (e.g., A to B) without interrupting the flow, each operation makes just what is needed when it is needed.
- There is minimum part handling.
- Inventory holding costs are minimized.

So what is the problem? The problem is large batch manufacturing with big buffers leads to sub-optimal behavior. One operation may be greatly improved without improving the overall system performance. And it also reduces the motivation to improve. Why worry about preventative maintenance on equipment for blast and prime when shutdowns do not immediately effect steel cutting anyway? We can always work overtime cutting steel to make up for any lost production. How long does it take to discover a defect produced by steel cutting that is not noticeable until someone tries to assemble that piece? It can take weeks for the bad piece to work its way through the system to subassembly. By that time, there may be weeks of bad parts in process.

> "Ordinarily, money put into raw materials or into finished stock is thought of as live money. It is money in the business, it is true, but having a stock of raw material or finished goods in excess of requirements is waste - which, like every other waste, turns up in high prices and low wages."
>
> —**Henry Ford**, Today and Tomorrow, Productivity Press, 1926/1988, p. 103

Continuous flow processing is a much better approach for overall system performance. The ideal is a one piece flow which is best illustrated by Henry Ford's moving assembly line. In parts operations we talk about one-piece flow cells. With one-piece flow all operations are synchronized. It becomes immediately apparent where the bottleneck operation is and efforts can focus on that operation. The effects of poor preventative maintenance are felt immediately. Quality problems passed on to the next station are discovered immediately. Operators are linked together which enhances teamwork and problem solving.

If we take a broader view of the entire manufacturing system we can identify the major steps that add value from a customer's perspective. Look at the stamping and welding operation in Figure 6 depicting "Mass Production" and identify the value-added steps. There are only three in this process. If we timed these we would find they take minutes to perform. Yet, material can spend weeks or months in process before getting out the door to the customer. In a mass production setting, we seldom even know how far materials travel during a manufacturing process. How long does it stay in the plant? How much time is spent sitting in a large stack waiting to be moved? In many ways, mass production manufacturing is like a black box – the only thing that matters is putting new material in and getting finished product out. Imagine you are traveling with a part through a mass production plant. What percent of the time would you be going through a value-added operation as opposed to sitting, being moved or being repaired?

Lean manufacturing is more than just a system for manufacturing. It is a philosophy – a state of mind! The focus is always on creating a value-added flow with as little waste as possible. In the new approach in Figure 7 all the operations have been lined up. Welding goes immediately to assembly in a continuous flow—like an assembly line. It is not practical to stamp one piece then weld that piece. There is some

Figure 7: Mass Production

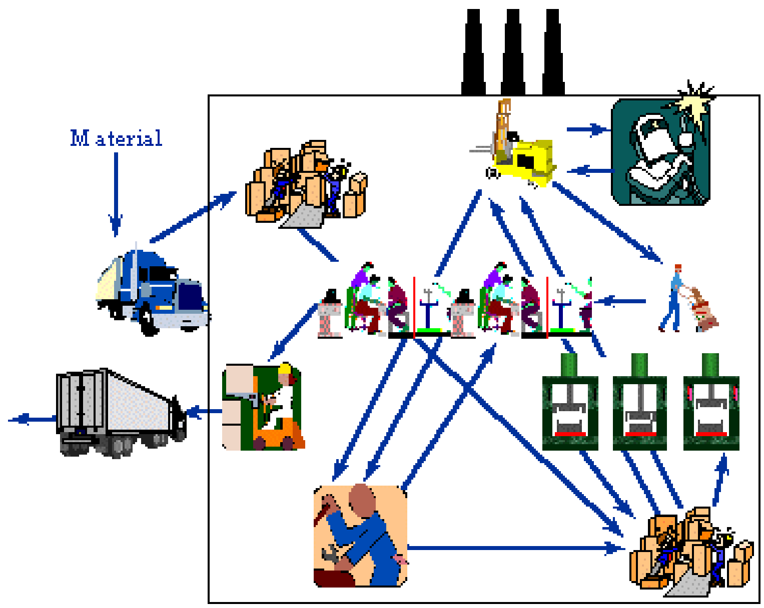
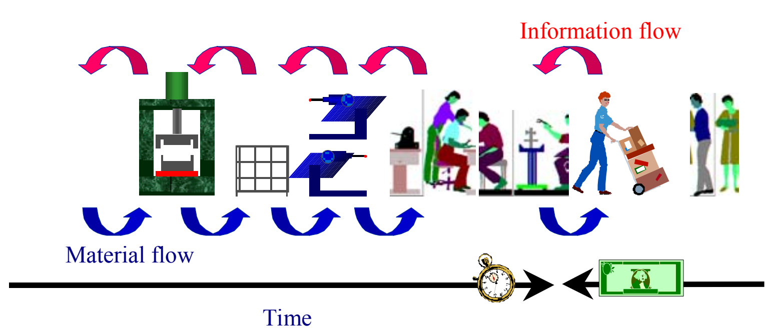


Figure 8: Lean Manufacturing

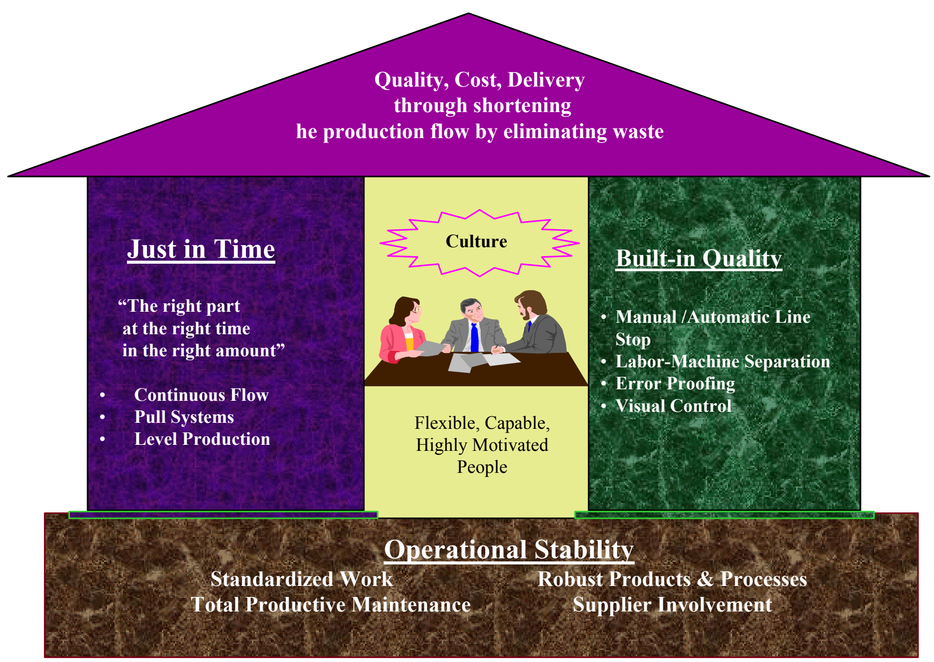


changeover time required and different parts are required for different products so a buffer is put in between stamping and assembly. We call this a marketplace, after the American supermarket, because it is a small inventory buffer with a small amount of each type of part needed by welding. Welding takes what they need and then stamping looks at what has been taken away, e.g., by getting a pull signal. Stamping then builds just what is needed to replenish the marketplace. In fact, each operation is responding to what their immediate customer needs—a pull system. In a pull system the flow of information works its way from the final customer backwards. Operations are not scheduled based on a centralized system but are responding to pull signals from their immediate customer. Focusing on the value-added flow and making just what is needed when it is needed leads to shortening lead-time and getting paid faster for what is built.

A Model of Lean Shipbuilding

The Toyota Production System (TPS) is depicted as a house as shown in Figure 9. The goals of TPS are illustrated in the roof—quality, cost, and delivery through shortening the production flow by eliminating waste. Traditional mass production focused primarily on cost—cost reductions through individual efficiency gains within individual operations. We learned later from quality gurus like Edward Deming that in fact by focusing on quality—doing it right the first time—we could simultaneously reduce cost and improve quality. That is, building in quality leads to significant cost reductions. Toyota found that by focusing on eliminating the wastes that cause lead time to expand, quality improved as everyone got quick feedback on quality problems and cost was reduced as inefficiencies were driven out of the *system.* The focus of TPS is on total system costs by taking a value stream perspective.

Figure 9: The Toyota Production System



The reason for the house metaphor is that a house is a kind of system. Without a strong foundation, as well as strong pillars, as well as a good roof, the house will fail. The two main pillars of TPS are Just-In-Time and Built-in Quality. As we have discussed, these are mutually reinforcing. Creating a JIT flow leads to increased quality. Without the inventory buffers of mass production, JIT systems will fail if there are frequent quality problems that interrupt the flow.

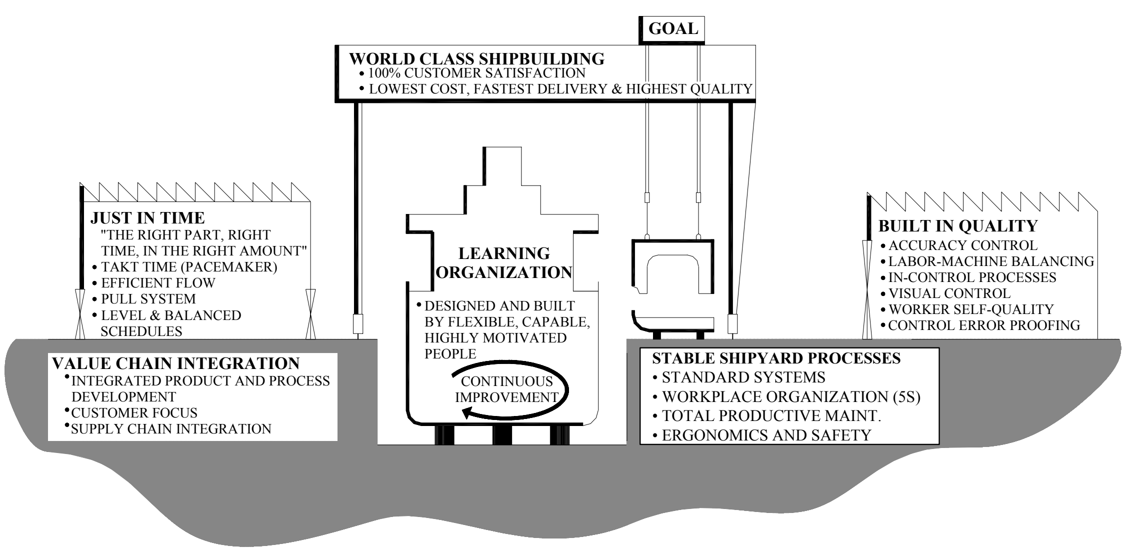
The TPS house must sit on a foundation of extreme stability. For example, machine downtime in one operation will quickly propagate through the whole value stream because the inventory buffers are so small. Products that are not well designed to be manufactured will hang up the system at troublesome operations and prevent a well-orchestrated flow.

At the center of lean manufacturing are people who must bring the system to life by continually improving it. The Japanese term *kaizen* literally means "change for the better." And without people who are committed to improving the process, and aligned with management's goals the discipline needed to run a lean manufacturing system will quickly falter.

We took the Toyota Production System house and translated it to a shipbuilding model shown in Figure 10. It includes all the elements of TPS but shown within a shipyard with a ship in dry-dock as the centerpiece. One strength of the house version compared to this ship building model is that the house clearly depicts a system—if any element is missing, the house will collapse. The shipyard figure does not reflect this as clearly. The rest of this guide goes through the model element by element based on ship building examples.. Note that lean is a system and the elements cannot be cherry picked one at a time.

Figure 10

LEAN SHIPBUILDING



Just-In-Time and Shipbuilding

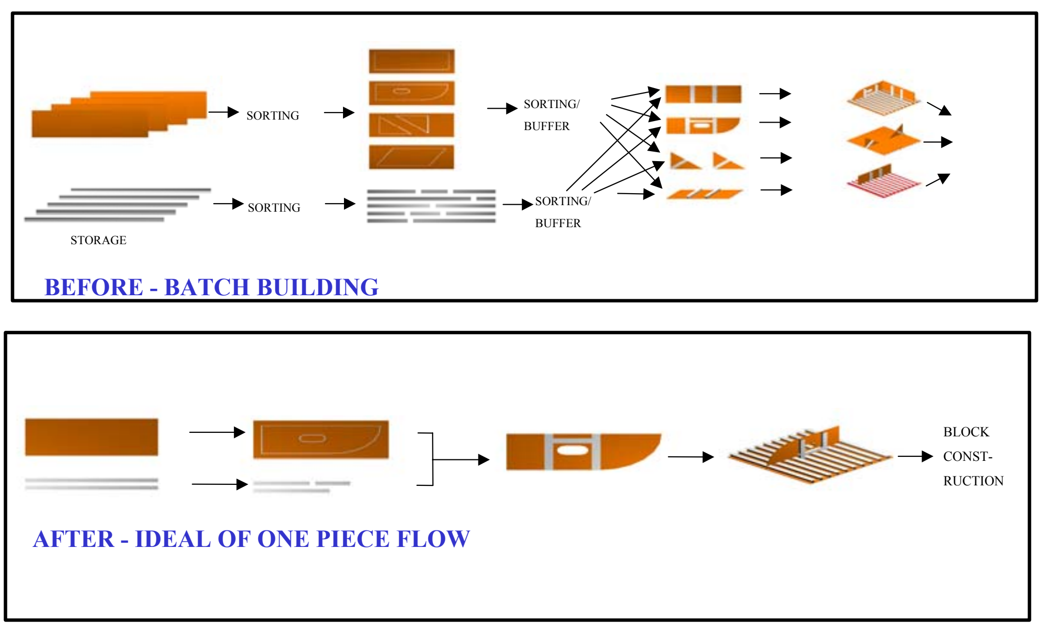
Continuous Flow

The ideal for JIT as we saw earlier is a one-piece flow. For many parts operations the main focus of lean manufacturing is creating one piece flow. This means identifying families of parts that go through the same set of processes and dedicating a production line to that product family. All products assigned to the cell will go through those operations one piece at a time. It is possible to have some parts skip a step so not every part must go through every single step. Typically, this approach has been used for large volume production, but it has been adapted by world class shipyards, particularly Japanese yards as we will explain later in this section.

Figure 11 gives a simple example of batch processing versus one-piece flow. In the batch processing case some rectangular steel shapes for a block are cut, along with some stiffeners. This is done in large batches which are moved as large batches to be cut into more specific shapes. These parts must be sorted before they are cut into the actual shapes needed. This batch cutting leads to a large pile of inventory which must be moved to another buffer and then sorted through to be subassembled, and finally the subassemblies are moved and sorted through to get the parts needed to construct the actual blocks. Notice how much non-value added work there is on this process—all of the moving and storing and sorting is **pure waste**.

The alternative ideal from a lean manufacturing point of view is a pure one-piece flow that is shown in the bottom of Figure 11. In this case you would cut just the material you need, pass it on do the final cutting, pass it on, do the subassembly, pass it on, and build up the block. While it may not be feasible to make one and move one, the smaller the batch size the better from a lean manufacturing point of view, **within feasible limits**.

Figure 11: Batch Processing versus One-Piece Flow



Another example is given in Figure 12. In the top portion we see traditional batch cutting. All the triangle shaped pieces are cut at once from a large piece of steel stock. In fact, for the next block only six triangle pieces are needed. But many more pieces are cut in advance of need in order to use up all the material in the steel stock and take advantage of a single set up to cut out all the triangles needed well into the future. This is an example of overproduction, one of the worst forms of waste. In the bottom panel we see that only the six required have been cut. By careful planning they could be cut from a smaller piece of steel stock just the right size to cut a larger piece and find areas from which to cut the triangles. Thus, only what is needed next is cut and the material is still efficiently utilized.

Figure 12: Batch Cutting versus Cutting as Needed

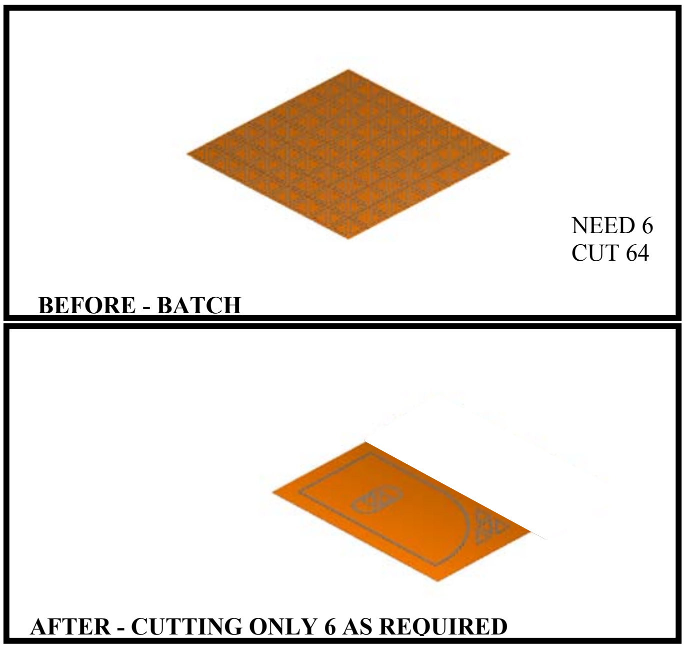


Figure 13 provides a bigger-picture view of the ship production process. Traditionally, U.S. shipyards have been organized by functions. For example all the plates are processed in one shop, whether curved or flat, and the profiles are processed in a separate shop, both straight and curved. Large batches of plates and profiles are processed and then pushed into storage. They are then pushed into subassembly where they need to be sorted as we saw in Figure 11. All parts must go through the same paint shop which often becomes a bottleneck.

The bottom part of Figure 13 shows a typical arrangement in Japanese shipyards. In this case the yard is organized by “product line.” Product line does not mean separate ships but rather similar part families, in this case flat blocks go through one set of processes and a separate set of processes are reserved for curved blocks. So for example all the flat plates are cut in process lanes, as are straight profiles, and then small batches are brought to the flat block line for assembly. Figure 13 shows a yard that actually segregated the paint shop into two shops, one for flat blocks and one for curved blocks. The flat blocks and curved blocks are then outfitted in separate areas and finally come together in grand block construction. Notice the convoluted paths materials take in the functional batch process and how clean and smooth the flow is in the product-flow process.

Figure 13: Functional-Batch versus Product-Flow Process

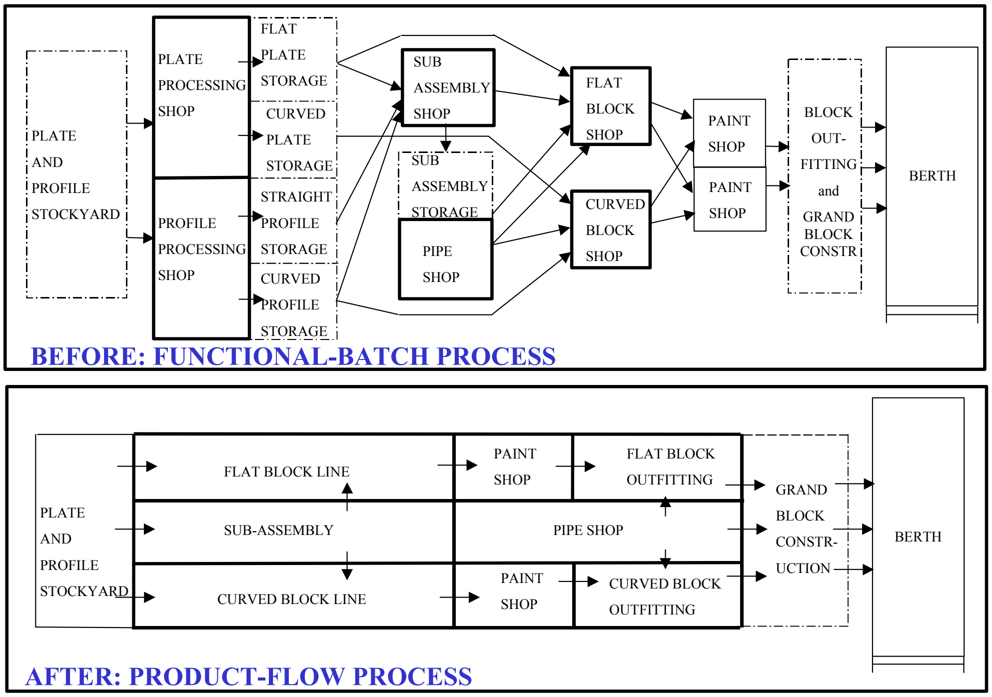
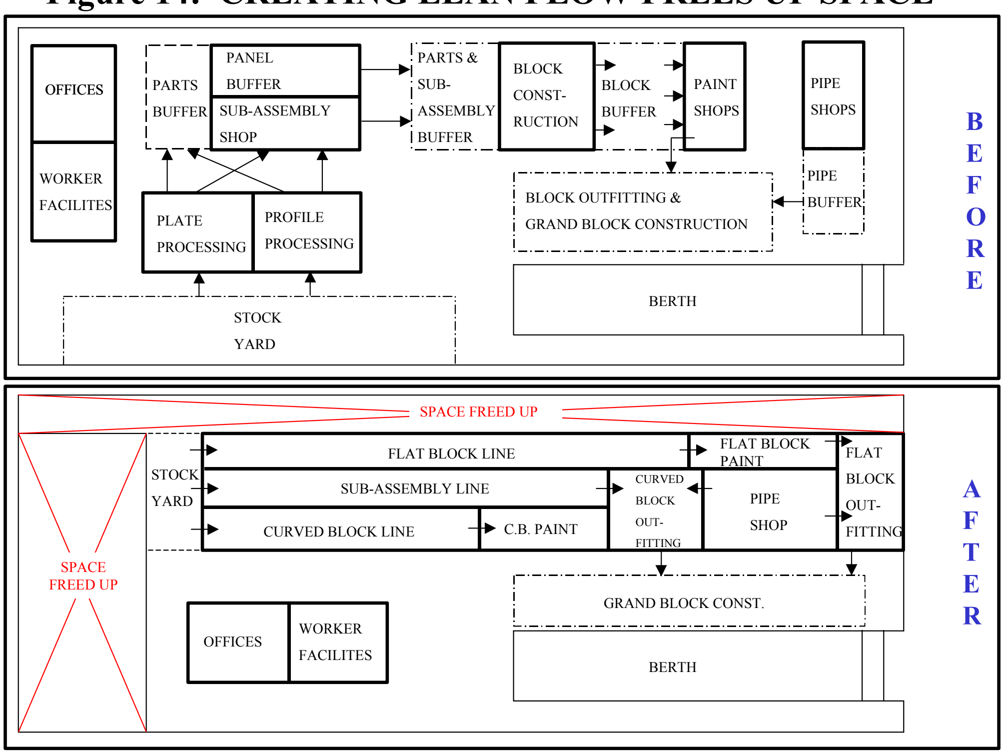


Figure 14 shows a layout of a traditional functional flow yard compared to that of a lean product-oriented yard and we see a real paradox. If would seem that if we segregate operations by product family and have to duplicate some resources, e.g., the paint booths, it would take more space. Yet the experiences of lean manufacturing have shown over and over that a great deal of space is actually freed up by becoming leaner. The main reason for this is the dramatic reduction in inventory when we move to a lean flow—inventory, the space needed to store it and move it, often takes as much space as our value adding processes.

Figure 14: CREATING LEAN FLOW FREES UP SPACE



Why disrupt your yard and move to a lean flow? The most obvious answer is that since lean flow reduces inventory we can save on the inventory carrying costs. Figure 15 suggests there are many other savings, perhaps more important than inventory carrying costs. One of the most important benefits, which we will discuss in more detail later, is improved quality. The quality benefit comes because of the shorter feedback loops when what we cut this morning is actually assembled into a block this afternoon, instead of weeks from now. With large batches of inventory many quality problems are hidden and only become visible when our downsteam customers (e.g., the block assemblers) try to use the material and it does not fit. By this time we may have made the same problem on many other plates or profiles and they are all somewhere in the pipeline. Productivity also improves simple as a result of reducing all the non-value added time spent handling and handling again materials. Productivity is also increase since identifying problems and solving them in real time takes less labor hours than finding and fixing problems that have accumulated over weeks. One of the largest benefits of continuous flow is shrunk lead times which allows you to quote shorter lead times to your customer and also to increase the utilization of your shipyard therefore generating more revenue in the same period of time. Your team members generally will have higher morale when they are spending more time doing value added work and will feel a much greater sense of accomplishment.

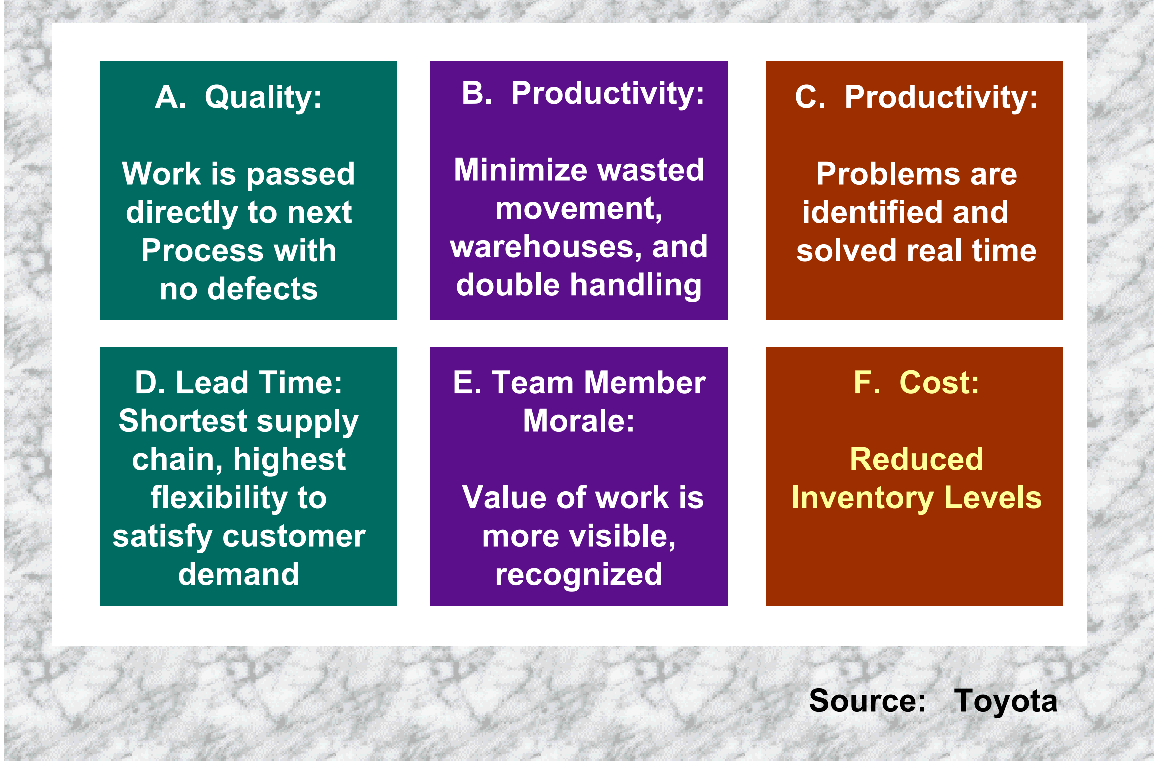


Figure 15: Benefits of Creating Flow

Actual examples of lean flow in shipbuilding from Japanese shipyards are shown in Photos 1-8. In photos 1 and 2 we see at IHI they burn and mark steel on continuous flow lines and then cut the steel on a flow line. Photo 3 shows flat bars have been kitted and are just what is needed for sub-assemblies. Notice the small amount of material that has been prepared for sub-assembly. Photo 4 shows a curved block moving along a process line. Workers stay in station and perform similar tasks on each of the curved blocks that come to their stations. The moving line helps imposed discipline as workers know how much time they have available to complete that block before it moves. Photo 5 shows another small buffer of kitted materials, in this case pipes. Again we see a very small amount of material. Photo shows an outfitted block flowing to the Grand Block assembly tables along side the dry dock. Photos 7 and 8 show material neatly staged for outfitting—just the amount of material needed.

Photo 1: IHI Burning and Marking

Photo 2: IHI Cutting Line

Photo 3: Flat Bar Pallets for Sub-assembly Shop

Photo 4: Curved Block Moving Process Line

Photo 5: Small Pipe Kit Buffer Between Shops

Photo 6: Outfitted Block Flow to Grand Block Assembly Area beside Dock

Photo 7: Staged Material For Block Outfitting

Takt Time Planning: The Tempo of the Production System

In order to make material flow through manufacturing processes at the rate needed to match customer demand we need a pacing mechanism—the tempo at which product is made. Takt time is the German word for meter and in lean manufacturing is the targeted pace of production. Takt time is also referred to as the "Customer Demand Rate" and is measured as the total available production time/total customer demand for some period of time (see Figure 16). This leads to a calculated amount of time per piece. For example, one vehicle should come off the line every 60 seconds. Takt time is the target and should be the driver in developing the way the product is scheduled **and** the way material flows through the system.

Takt/Target time is not always the same as cycle time—the rate at which machines produce. For example, a car body may be welded every 45 seconds even though a car comes off the line every 60 seconds. One source of confusion is what happens when a batch of parts are all cycled simultaneously as in a heat treat oven. If 1000 parts are all heat treated in an oven and it takes 1 hour to heat treat this batch then one piece is available for subsequent operations every 3.6 seconds (1000/3600 seconds). If the takt time requires a part every 20 seconds clearly this would be much faster than the takt time.

Ideally, the cycle time should equal the takt time. Almost by definition, not to follow the takt time implies that **waste** will exist in the system. To run faster than takt time will generate inventory (something made today that the next process does not need today), somewhere in the system. Running slower than takt time will generate the need for accelerated production, overtime and/or excess inventory.

Applying takt time is a little less obvious in the case of building ships. First, the takt time is much longer for ships than it is for automobiles. While a typical takt time for cars coming off the assembly line is 60 seconds per car. On the other hand a ship may need to be completed once every six months or longer. A takt time of six months is so long it is difficult to use as a means of breaking up tasks to set the tempo of production.

Second, the takt time can vary considerably from ship to ship depending on the size and complexity of the ship. Similarly, each ship is made up of a large number of unique parts and each part can have a different takt time.

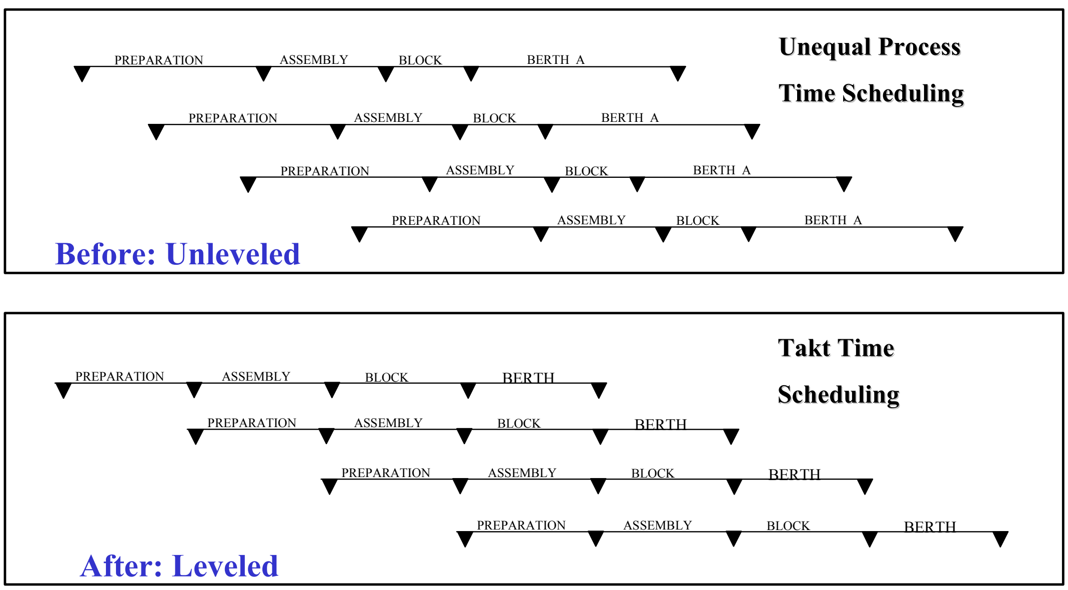
Nonetheless, to make the stages of ship production flow you need to define the takt time. That is, you need to know how often a part needs to be completed to fit the overall schedule for the final ship construction and ideally all parts of the shipbuilding process should move through the yard at the same tempo.

Thinking about takt time makes more sense when we conceive of the ship as a collection of smaller units. Consider the following thought process:

1. We can start with the ship delivery schedule. How often does a ship need to come out of dry-dock in order to meet this schedule.? If a ship comes out of dry dock every six months then all the components need to be built just-in-time for this to happen.
2. Next, identify when each of the parts need to be completed in order to meet this delivery schedule. For example, there are many blocks that make up a ship and they obviously need to be built in parallel and in a shorter time than the time it takes for final construction of the ship. Thus, a takt time for blocks can be defined working backwards from the ship delivery schedule and the time the ship will be in dry dock.

This is exactly what the most competitive Japanese shipyards do. Individual blocks are

Figure 17: Balancing Overall Shipyard Schedule to Takt Time



scheduled so that they will be complete just in time to construct grand blocks which will be complete just in time for final ship construction in dry dock. All individual components for the block are cut and shaped and welded in kits that arrive just in time for block construction. This is illustrated in Figure 17. The top portion shows unequal process time scheduling where none of the interim products are ready just when needed by later processes. This will lead to bottlenecks and queues of material waiting to be processed in later stages. In the bottom portion, through takt time planning, all parts of the process move in synch. This allows for flow production which as we discussed earlier makes optimum use of resources.

In Figure 18 we show the steps required to build up blocks starting with raw material. Takt time planning requires that all blocks have been designed and scheduled to be completed within the takt time. Photos 9 to 12 show various blocks and grand blocks that are being built to takt time in Japanese yards. Notice that in photo 10 the curved block is on a moving line. It is moved twice during each shift. The way that moving time was determined was by calculating takt times and then designing the blocks so they could be built within that takt time.

Figure 18: Block Construction To Takt Time

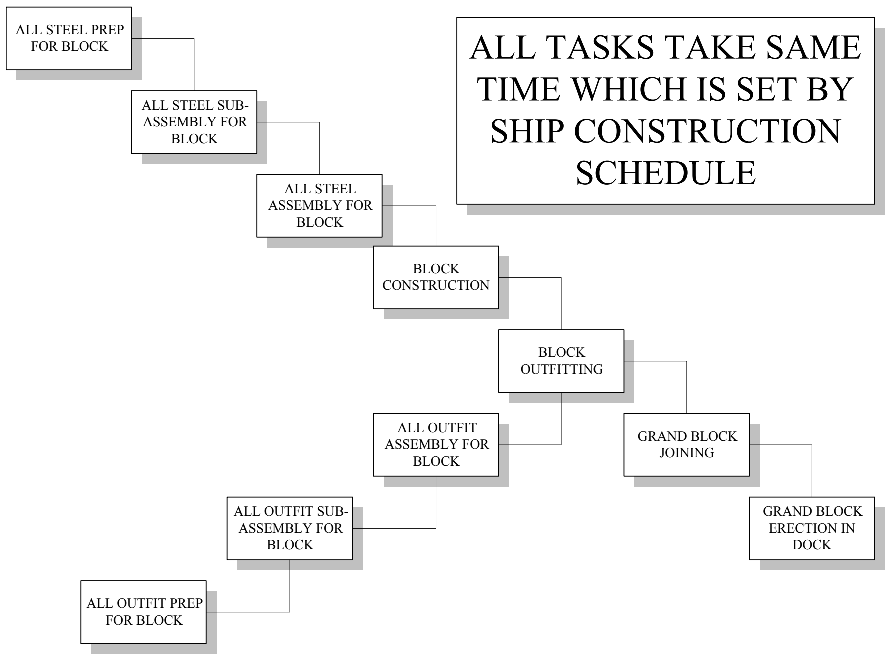


Photo 9: Block Construction Matches Takt Time

Photo 10: IHI Curved Block Moves to Takt Time

Photo 11: Different Grand Blocks Must Match Takt Time

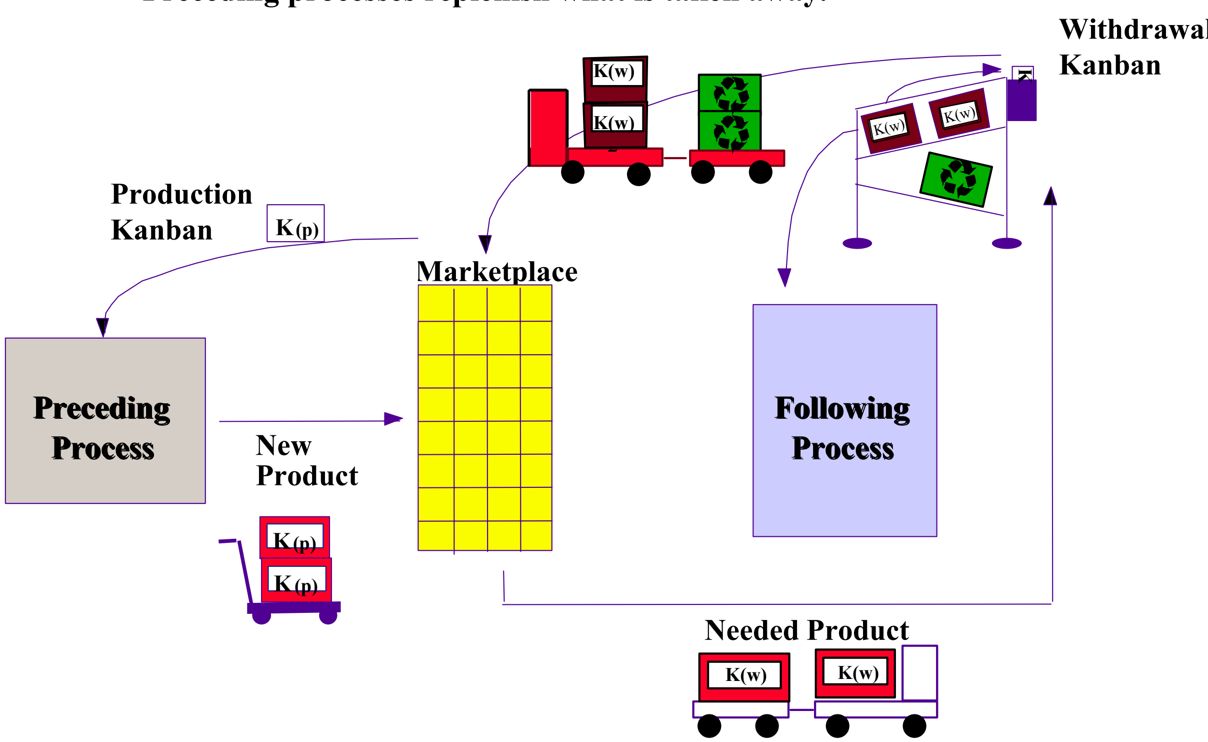
Pull Systems

With a one-piece flow each operation makes just what the next operation needs when it is needed with no inventory between processes. This is the beauty of an assembly line. When some batch sizing is necessary the next best thing is to make the batches as small as possible and use a "pull system" to schedule production and material movement. For example, stamped parts are made in batches and then moved to welding. The mass production approach is to schedule stamping and welding separately. But many things happen that prevent exactly following the schedule. So even if stamping follows the schedule and places what they build in inventory it may not be what welding really needs.

The solution that Ohno, father of TPS, came up with was to imitate the American supermarket system. In this system a maximum amount of food is placed on the shelf (e.g., 50 bottles of ketchup) and clearly organized and marked so the customer can find what they need. At fixed periods, a clerk checks how many bottles have been removed and replenishes them to get back to the 50 bottles. The actual minimum and maximum number of the items that are kept on the shelves is based on sales patterns. This is a simple pull system. The number of bottles brought out to the shelf is "pulled" by actual customer purchases instead of being pushed by a schedule. Ohno asked, why can't we apply this simple visual system in manufacturing?

Figure 19: Example Pull System

- **Following processes withdraw what they need when they need it.**
- **Preceding processes replenish what is taken away.**

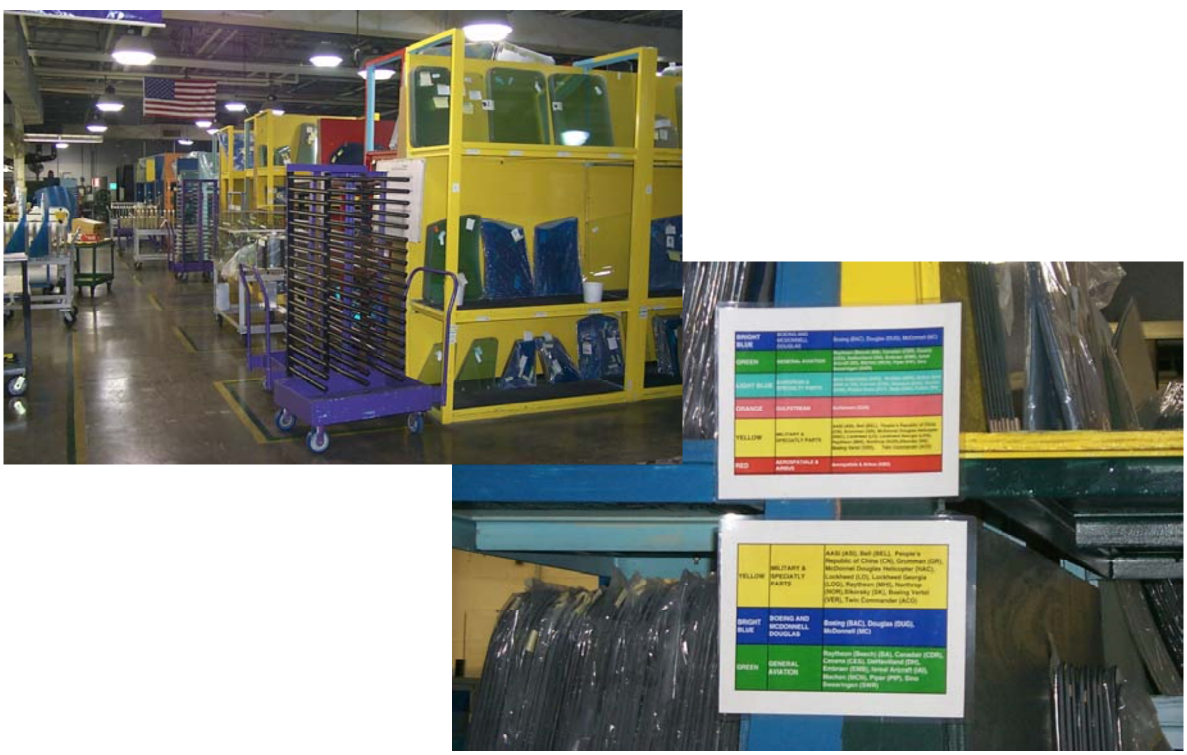


The illustration in Figure 19 shows a typical pull system Ohno created in an automotive assembly plant. When the operator in assembly first takes stock out of a bin he or she takes the "kanban" card and places it in a mailbox. This is a signal that the parts in the bin are being used and will need to be replenished. When the bin is emptied it goes in the bottom of the flow rack. A material handler (call him Fred) makes a regularly scheduled, fixed route and picks up the "withdrawal kanban" from the mailbox and the empties and brings them to the marketplace.

Fred drops off the empties and picks up replacement bins of parts. When Fred "withdraws" a bin of parts from the marketplace he takes the "production kanban" off that bin and puts it in a mailbox and puts in its place the "withdrawal kanban." The production kanban is put in a mailbox so the material handler responsible for the preceding process can pick it up to tell the the preceding process to produce and ship another bin of parts to replenish what was taken away from the supermarket. In this case we have two pull loops—the marketplace to assembly and the marketplace back to the preceding process which is sending new parts in response to withdrawal from the marketplace.

There are many different approaches to pull systems. Figure 19 illustrates a manual card system, the traditional approach developed at Toyota. In some cases companies use electronic pull signals to alert suppliers to send more parts. In a shipyard one could use a pallet of kitted parts as the kanban—sending it back when it has been used to be refilled by the preceding process. A small buffer of kitted parts could be kept between the processes. The fundamental concept remains the same. Pull systems tie operations together with the downstream process pulling from a small buffer and the upstream process replenishing.

Photo 12: Intermediate Goods Marketplace: PPG Huntsville



Photos 12 and 13 show a very simple pull system at PPG Industries glass products plant in Huntsville, Alabama. This plant makes glass window assemblies for most major aircraft producers in the world. There is a very large variety of different shapes, thicknesses, and colors of glass. They shifted to a supermarket and pull system for cut glass and it dramatically reduced inventory and cut lead times. Photo 12 shows the supermarket. As shown in this picture, the supermarket is color coded by customer. So for example if you are picking up glass for a Boeing window you need only look in the bright blue zone. Photo 13 shows a blown up section of the supermarket highlighting the "kanban" system. A card with the number 10 on it in this case is slipped between two pieces of glass at the trigger point. When the piece of glass is pulled which reveals this card the material handler knows it is time to send an order back to glass production for 10 more pieces. It is as simple as that!

Photo 13: Very Simple Pull System

What is Wrong with Inventory?

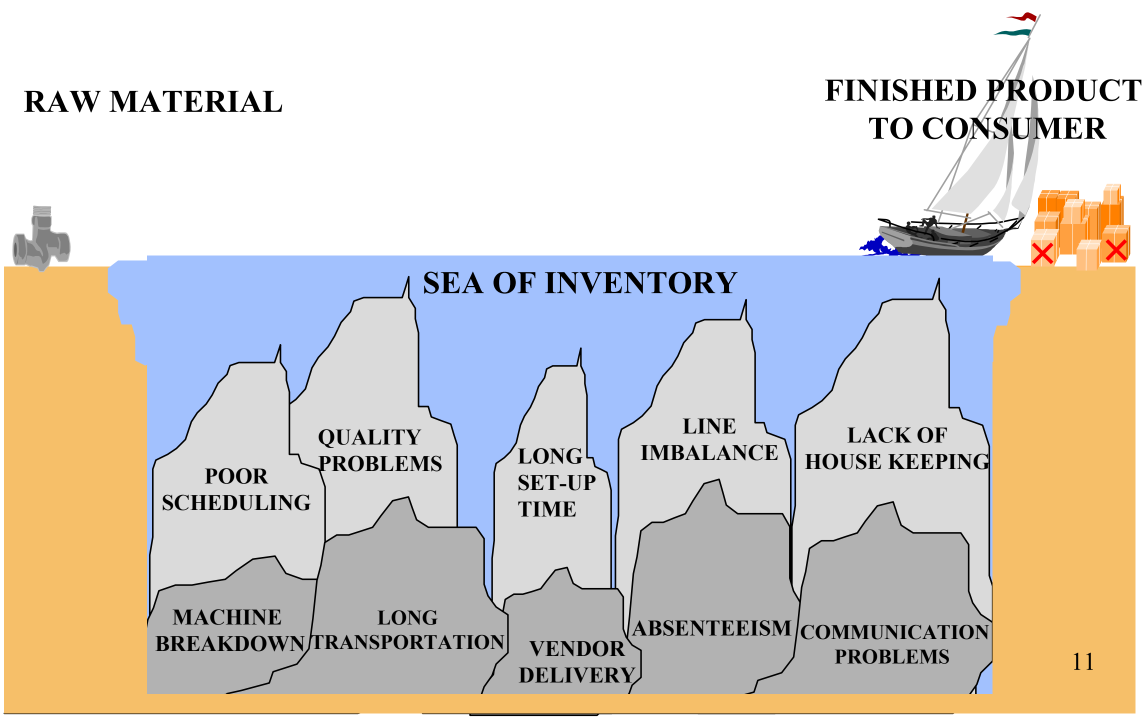
The answer is nothing. Inventory serves a critical function in a lean system. It is a buffer between two operations. When a one piece flow is not possible than the next best thing is to set up a small controlled buffer of inventory that is replenished based on pull signals. But control the buffer so it never gets above a preset maximum limit and never falls below a minimum of safety stock. And make the inventory visible.

Figure 20 presents a metaphor for the problems with inventory. Inventory is like water sheltering the ship from the rocks. The rocks in this case represent problems with a manufacturing process. The problems are still there, but they are not visible. So for example if a cutting operation is running behind schedule it will not effect subassembly for a long time until the inventory is worked off. The problem with cutting does not go away because the inventory is there. The long feedback loops of learning about the problem can mean defects are passed through the system undetected until they are on board the ship.

Some of the problems that can be caused by inventory include:

- Need resources (people and computer) to track, move and monitor inventory
- Parts get lost
- A stack of containers fall over and parts get damaged
- Must use facility floor space to keep inventory
- Engineering or product change happens so inventory must be scrapped, reworked or sold at a discount
- Sales drop so inventory must be sold at a discount to clear it out of the system

Figure 20: INVENTORY HIDES WASTE



Fast Changeovers and Leveled, Mixed-Model Production

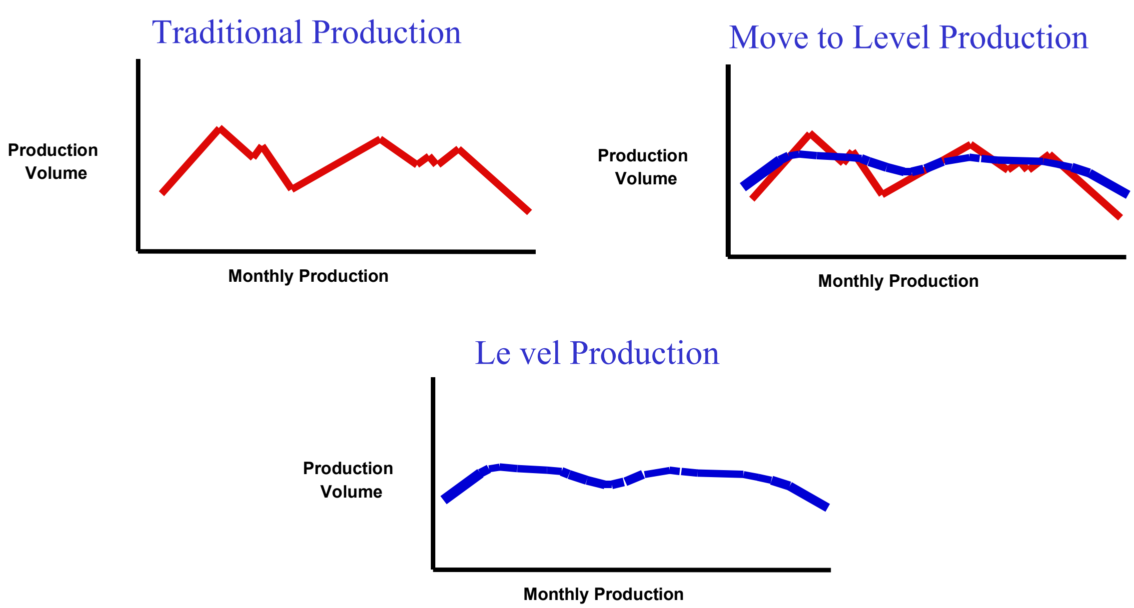
When we are thinking in a batch processing mode we would like to achieve economies of scale for each individual piece of equipment. Changing tools seems wasteful—we are not producing parts when we change over. So the logical solution is to build large batches of product A before changing over to product B. The result is large batches, and as we have discussed the system inefficiencies associated with large batch production.

In lean manufacturing, we want to keep batch sizes down and build what the customer (external or internal customer) wants. In a true one piece flow, we could build in the actual production sequence of customer orders (e.g., A,A , A, B, A, B,B,A.,A). The problem with building to an actual production sequence is that it is irregular and causes you to build parts irregularly. In the example earlier, if each letter represented a batch of product A or B you would need the parts for three batches of A in a row. Thus, you would have to have enough parts on hand for three batches of A. And it is even possible you will get orders for nine As in a row and need enough parts for this large number. To smooth out parts usage and send a more level set of orders to upstream operations it is often better to level the schedule. So instead of building to the actual customer demand you would notice you are making six As for every three Bs. You could then create a level production sequence of: AABAABAAB. This is called leveled, mixed-model production because you are mixing up production but also leveling the customer demand to a predictable sequence which spreads out the different product types.

Figure 21 illustrates the leveling of production over time so that resources are used on a more constant basis. Why do you want to use leveled, mixed-model production? (Japanese term is *heijunka*):

- Risk of Unsold Goods is reduced
- Quality is improved
- Less floor space is needed
- Demand on upstream processes is smoothed
- You can better control/monitor the production environment

Figure 21: Leveling Production



There are a variety of ways of leveling the flow of work in shipyards, some are feasible in some circumstances, while others are better in other circumstances. They include:

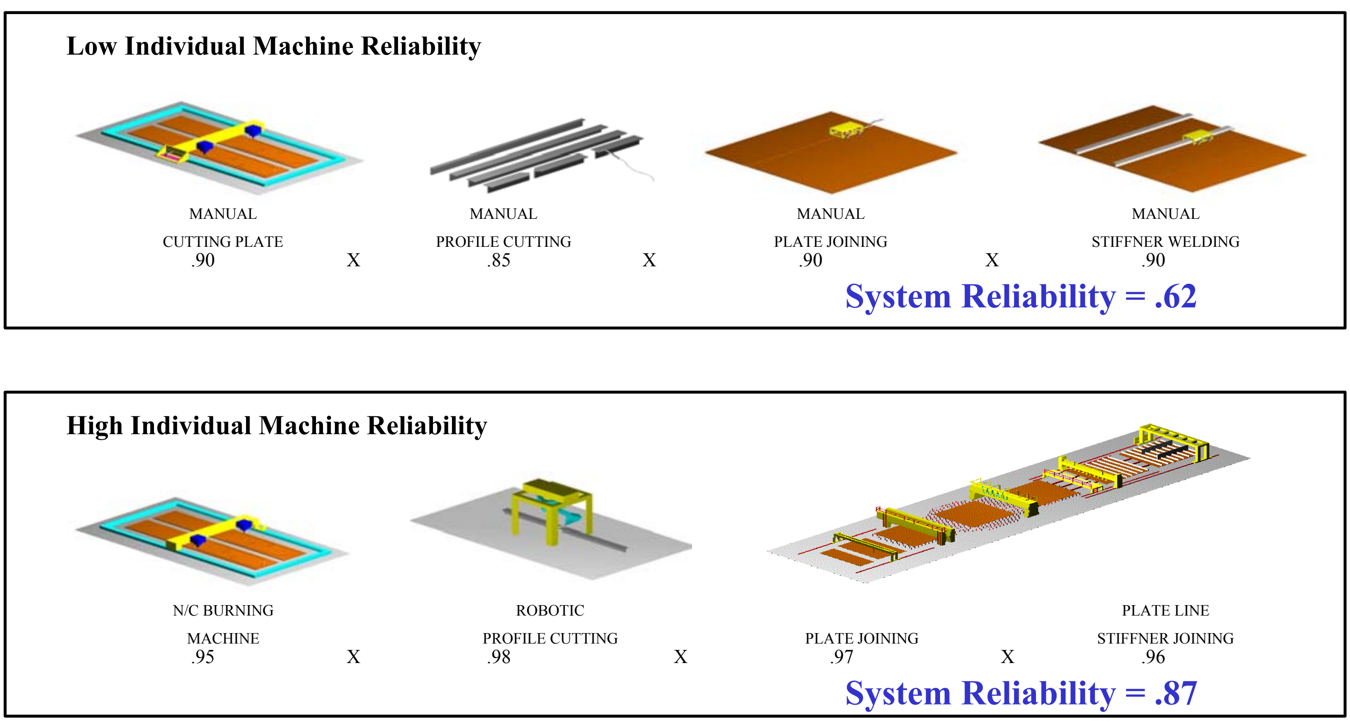
- Using Temporary Employees
- Cross Training Employees
- Careful planning
  - *Standardized Times for Processes*
  - *Standardized Designs*
  - *Balancing Processes across the Shipyard*
- Takt Time Planning

Built-In Quality

The shipbuilding industry has recognized for sometime the importance of quality. Built-in quality is much more effective and less costly than inspecting and repairing in quality. Accuracy control is a term used in shipbuilding and refers to a body of statistical and problem solving tools that can help do the job right the first time. In so doing we make a great leap forward toward lean manufacturing. Lean manufacturing ratchets up a notch the requirements for building it right the first time. With very low levels of inventory there is no buffer to cover ourselves in case there is a quality problem. Problems in operation A will quickly shut down operation B.

This problem is multiplied when there are a whole series of operations. The problem of serial unreliability is illustrated in figure 22. As this figure shows, even four fairly reliable operations individually (85% to 90% reliable) can lead to low overall system reliability (62%).

Figure 22: Serial Unreliability leads to No Control



The key to building in quality is to only pass on good parts to the next process. Occasionally there will be a problem and if it is not solved quickly we may shut down downstream operations. So we need a way to quickly signal a need for help. If the problem cannot be solved quickly, we should shut down the machine to prevent making more parts that might be passed on to the next operation. "Error-proofing" devices prevent errors from occurring (e.g., automatically shutting down the machine if the wrong part is inserted in the machine).

Toyota made famous the andon system which is illustrated in Figure 23 for the case of an automated process. The "*andon* system" is simply a way to signal when there is a problem. Andon means signal. In this case the machine has been equipped with a sensor that will sense a problem and cause a signal to go off (e.g., light, sound). Typically a yellow signal indicates a problem and a red signal indicates the problem is so severe the machine has shut itself off. For manual operations a person sends by pushing a button or pulling a cord. The signal should be very visible so people will come and help immediately. The signal without the tools to build in quality is useless. So there must be a full range of tools in place that support building in quality (e.g., quality checks, error proofing, etc.). The point of stopping production and signaling problems is to make the problems visible so they can be solved. This is not useful without a culture that supports problem solving and continuous improvement.

In traditional systems the operator is tied to the machine and must wait for it to cycle, leading to waste of the operator's valuable time. Giving machines the ability to stop themselves when there is a problem and alert the *operator* can free up the operator to do more value-added work.

The separation of person and machine is illustrated in Figure 24. An example of person-machine separation could be an automatic tak welding machine. This separation is enabled by an andon system. That is, the operator can be freed from watching the machine if it has the ability to detect a problem and alert the operator.

Figure 23

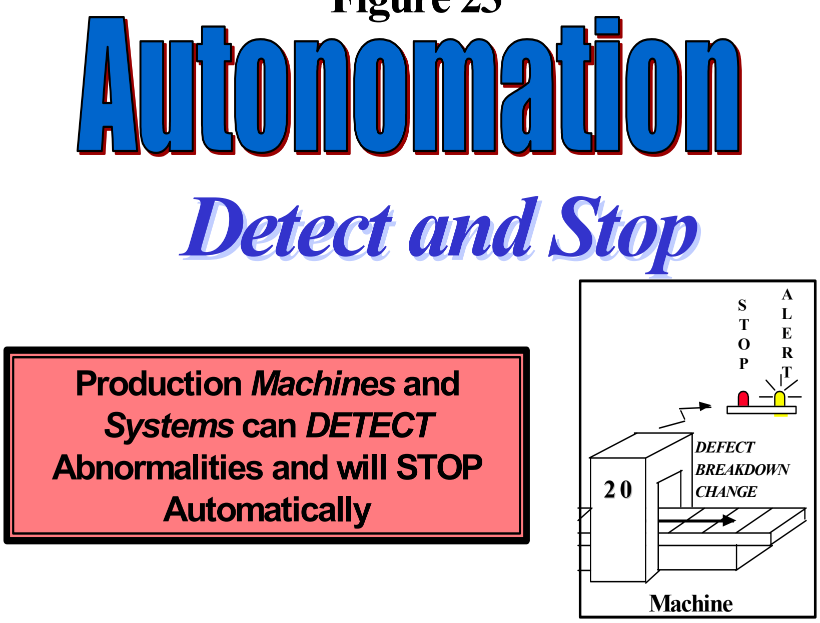
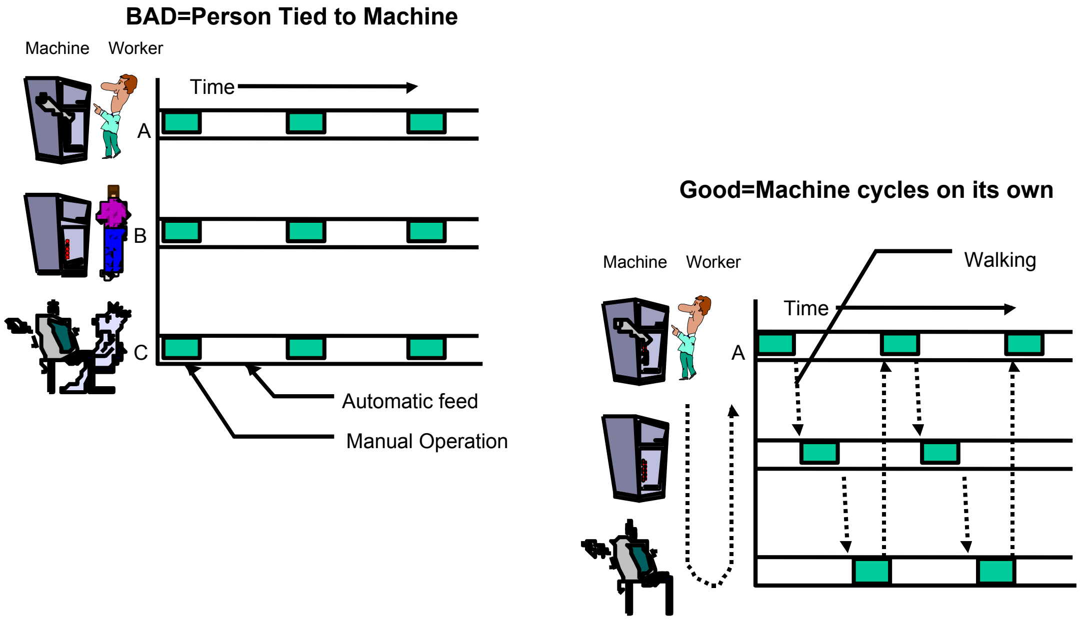


Figure 24: Person-Machine Separation: A Benefit of Autonomation



Photos 14 through 17 are photos of various uses of visual means to control processes in Japanese shipyards. Photo 14 is a type of andon system, in this case designed to show the operator when steel parts will be completely welded to form a panel so the operators can prepare for the next parts to go through the system. Figure 15 shows how different pallets of parts are color coded according to the ship they will be installed on. Figure 16 shows various charts and graphs showing the state of the process—posted right next to the process. Figure 17 is a simple status board showing how much has been produced relative to the target These are all forms of visual control.

Photo 14: Typical Andon (lights) and Status Board

Photo 15: Key Shop Data
+ Color Code by Ship

99.74% kits on time of 99.60% Target
45 Weeks reached Target

Photo 16: Visual Control Boards

Photo 17: Target and Status Board

Stable Shipyard Processes

Working without the safety net of large inventory buffers requires very stable and reliable operations. Standards are one of the keys to this stability. As Henry Ford observed, standards represent the current best method of doing things, but should continually be updated as we learn. So standards go hand in hand with continuous improvement.

Stability starts at the worksite. There are a number of key processes at the worksite that lead to stability:

- Standardized Work
- Efficient workplace design and layout
- 5S
- Ergonomics (see accompanying ergonomics guide)

One type of standard is standardized work processes for manual operations. Standardized Work sheets show the standard sequence of tasks, quality checks, safety issues, and other information. Standards for all disciplines e.g., preventative maintenance, equipment design, product design, should be established.

Photo 18: Standard Method for Assembling Webs & Profiles

Photo 19: Standard Assembly Method for Double Bottoms

Photos 18 and 19 show Japanese shipyards where standard methods have been established for assemblying webs, profiles and double bottoms. The standard methods lead to a predictable process. This is critical for knowing how long the operation will take and balancing it to takt time, discussed earlier in the guide.

Figure 25: Operator as Doctor

Photo 20: Welding Units Suspended from Overhead

Standardization of a poorly set up operation means standardizing waste. The goal of lean manufacturing is to eliminate waste and support only value-added work. The yard workers are the ones doing value added work. Thus, they should be supported by management. A useful analogy is to think of yard workers (operators) as doctors. The last thing we would want from a surgeon operating on us is for he or she to have to walk around searching for surgical instruments to perform the operation. We want the surgeon focused on us, the patient. Similarly, the yard worker should be focusing on value-added work and materials and tools should come to the worker well presented for performing the work. Figure 25 illustrates the operator as doctor concept. Photo 20 gives an example of treating the yard worker as a doctor—hanging welding units so they can easily be found and are right where the operator needs them to do welding work.

A well organized workplace is necessary for stability. Having clear standards for where things belong enables visual control—it becomes clear when there is a deviation from the standard. Making the workplace clean and organized is called the 5Ss in lean manufacturing:

Sort—Sort through items and keep only what is needed while disposing of what is not.

Stabilize (orderliness)—"A place for everything and everything in its place."

Shine (cleanliness)— a form of inspection which exposes abnormal and pre-failure conditions.

Standardize (create rules)—Maintain and monitor the first three Ss.

Sustain (self-discipline)—Maintaining a stabilized the workplace is an ongoing process of continuous improvement.

Figure 26: The 5 S's

The 5s together create a process for improvement (see Figure 26). First we must sort through what we have in the yard or shop to separate what is needed every day to perform value added work and what is seldom or never used (see Figure . The red tag excerise is a useful tool—placing a red tag on anything that is not used often or never used. Red tagged items can later be relocated to long-term storage or disposed of.

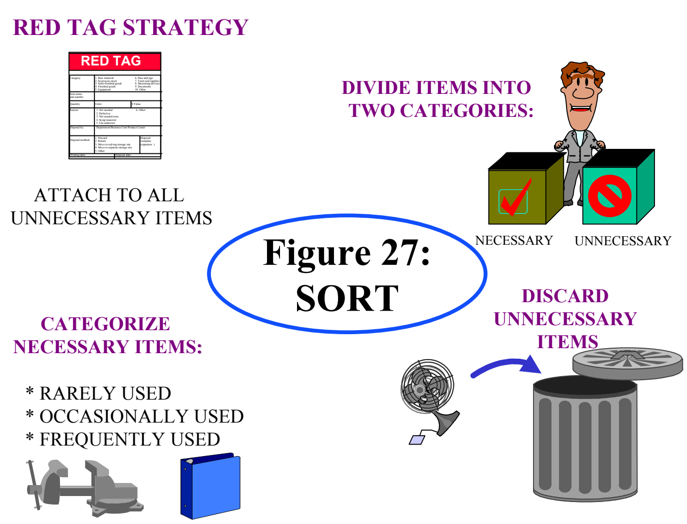


Figure 27: SORT

Once you have narrowed down items to those used regularly you can put them in order (straighten) near where they are used and label them so the right material or tool is easy to identify (see Figure 28). Ideally it will be obvious when something is not in its place. In Figure 30 can you tell if all the required tools have been put back in the container? Now can you tell when you look at Figures 31 and 32? Next, clean up the work area. Then create a written standard for the current best organization. And finally sustain the new standard through maintenance. This cycle continues in a process of continuous improvement.

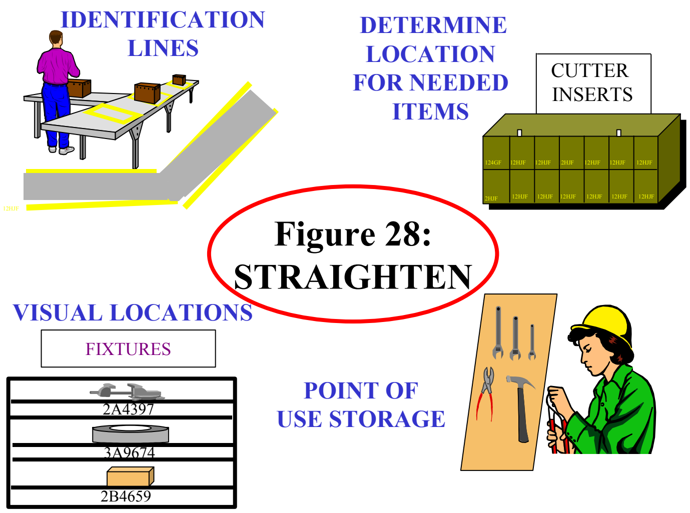


Figure 28: STRAIGHTEN

Figure 29: Are all the required tools present?

Figure 30: Is anything out of place?

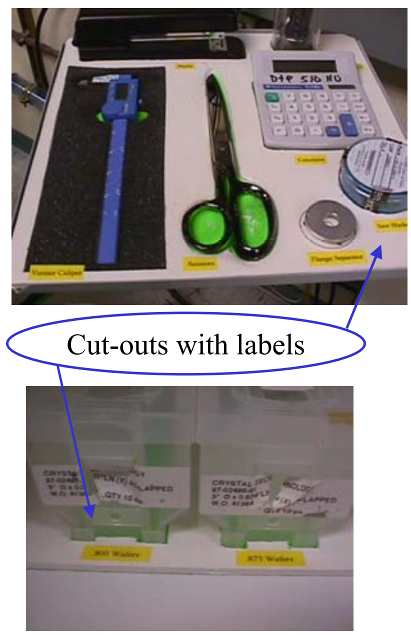


Figure 31: Good 5S

Dicing Saw Prep Area

Photos 21 to 23 show various ways of palletizing materials so they are well organized and presented to the operator. In Photo 21 a set of different profile sizes and shapes are presented in sequence so the operator does not have to sort through them to find what to use next. Photo 22 shows standard pallets to build a subassembly, while photo 23 shows specialized pallets designed specifically for frequently used small standard parts. Photos 24 to 26 show well organized materials ready for installation. But even with the neat arrangement of materials there is always room for improvement. For example, in Photo 25, can you tell what wiring should be used where? Is it within easy reach of operators? In Photo 26, can you tell whether there are the right amounts of pipes here or too many? Where should they go?

Photo 21: Sequenced Material for Profile Construction

Photo 22: Standard Pallets for Sub-assemblies

Photo 23: Special Pallets for Small Standard Parts

Photo 24: Well Organized Staged Materials

Photo 25: Wiring Cut to Length & Staged

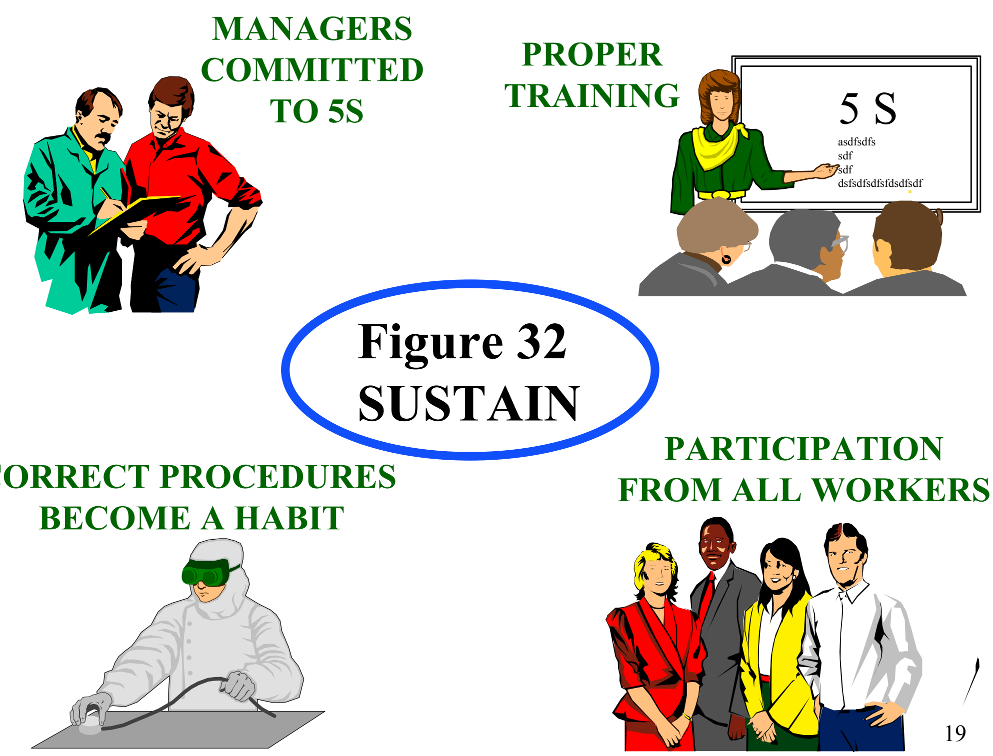
Photo 26: IHI Organized Pipe Kits: Too Much?

Flexible, Capable, Motivated and Empowered People

Lean manufacturing means, more, not less dependence on people. When inventory is high, there are no standards for how work is to be done, the workplace is a mess, and quality is inspected in. Problems are hidden. Reducing inventory brings problems to the surface and either they get fixed or we run out of inventory. When there are standards and visual controls it is obvious when the standard is not being followed—problems are visible. When production is stopped for quality problems again the problems become visible to everyone and demand to be solved.

Who will solve all of these problems on a day to day basis? The answer is everyone! Engineering, skilled trades, quality, vendors, team leaders, and most importantly—operators—must all be involved in continuous problem solving and improvement.

In addition to improvement there is the fifth "S", arguably the hardest one, of sustaining the improvements made. As shown in figure 32, this requires a combination of committed management, proper training, a culture that makes sustaining improvement habitual behavior, and involvement of all workers.



When we first looked at excellent companies practicing lean manufacturing it was clear that people were well treated. They were not laid off at the drop of a hat. They were involved and energized by their work. They were treated like citizens, not disposable labor. It was also clear at the top of the pyramid that they were active in making improvement suggestions.

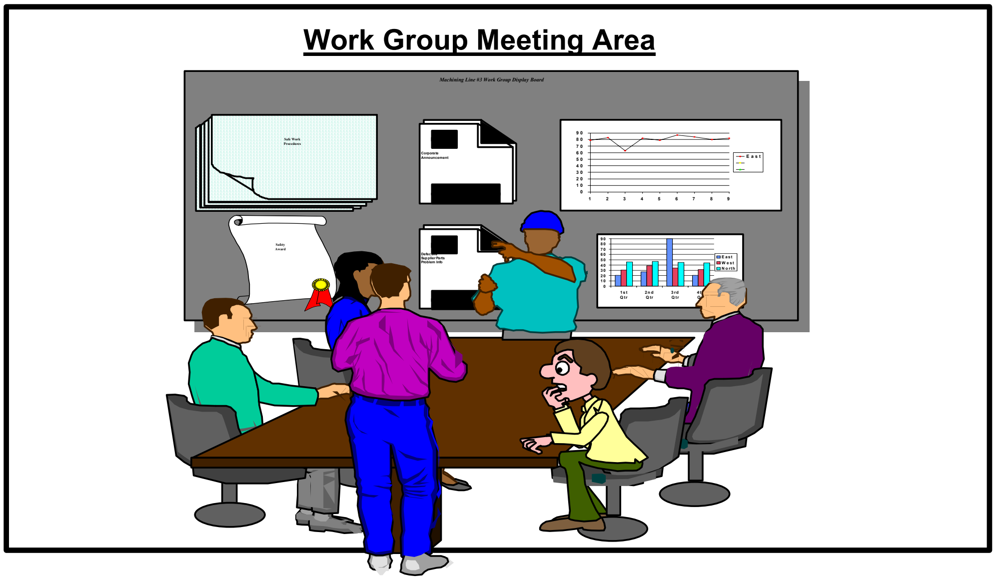
But what we did not see at first were the lean manufacturing systems which encouraged, and in fact demanded involvement. Standardized work must be continually improved by operators. Stopping production for quality problems is a big responsibility. Pull systems mean operators are ordering their own materials. In short, responsibility is pushed down to the level of the operator who becomes a decision-maker.

At the working level, employee involvement requires an organizational structure based on work teams. Work teams can not be cosmetic. In lean manufacturing, as waste is eliminated people become more interdependent—they depend on each other. With little inventory if I do not do my job on time I will immediately effect downstream operations. Getting work done within takt time often requires mutual help, above the narrow boundaries of job titles. Leveling the work load means people with the skills and flexibility to move between operations which requires cross-trained operators and job rotation.

Photo 27: Work Team Performance Measurement

Photo 27 illustrates a bulletin board that displays critical operations for a work team. It shows performance of the team over time relative to targets, 5S inspection sheets, and other pertinent team information. Figure 33 shows an example team meeting area, located right next to the work area. Teams need to meet and the best place to meet is next to the work site so meetings can be held spontaneously and it is easy to walk to the work area to try out ideas developed in the meetings.

Figure 33: Work Groups and Support Teams



- **The elimination of waste begins with employee input. We must design our work areas to ensure employees can meet regularly and work on continuous improvement activities.**
- **For teams to function effectively, we have to make it easy for them to get together.**

Lean Value Chain

Lean manufacturing depends not only on processes inside the yard, but integration with suppliers as well. Ultimately it is a value chain proposition. For example, getting steel to the yard so large inventories do not have to be held requires a new way of working with steel suppliers. Similarly with pipe and other raw materials as illustrated in Photos 28 and 29.

Photo 28: Frequent Delivery of Steel Minimizes Inventory

Photo 29: Frequent Delivery of Pipe Minimizes Inventory

Some of the best Japanese ship builders take delivery of steel every day or even multiple times a day. On a larger scale, in some cases it may be necessary or cost-effective to purchase whole modules from outside in which case the suppliers of those modules must fit into the pr. ecise timetable of the ship builder—Just-In Time. Photo 30 shows an entire stern that was outfitted turnkey offsite by a supplier than shipped to the yard for final assembly in dry dock. Photo 31 shows an entire deck housedone in this way.

Photo 30: Turn-key Outfitting of Stern

Photo 31: Turn-key Sub-contractor Deck House

How many American shipyards would trust their suppliers to bring in steel every day and risk being shut down if the delivery was delayed. How many American shipyards would trust a supplier to deliver a deck house just in time? Clearly this level of dependence on outside contractors is not possible with an arms length relationship with suppliers. It requires a very high degree of trust and a high degree of mutual learning between customers and suppliers to understand program timing and how to adjust to the inevitable changes and setbacks that occur in a major construction project.

Conclusion

This guide presented a model of lean manufacturing and a set of principles that have made many different industries far more competitive than what is possible through traditional mass production methods. Lean manufacturing is a philosophy, a way of thinking, not a set of individual tools which can be cherry picked. Moreover, lean manufacturing requires an enterprise-level view of the value stream—from raw materials to the finished ship delivered to the customer.

The main goal of this guide was to present lean manufacturing as a system of production. Many of the examples are from world class Japanese shipyards. These shipyards did not start out with a course on lean manufacturing. In fact, by and large, the ship industry was insulated from the development of the Toyota Production System in Japanese automotive. But a similar underlying philosophy can be seen in the best practices in Japanese ship building. There is a focus on flow, use of standardized methods, built-in-quality, continuous improvement, and a high degree of involvement by flexible, motivated employees. Can lean manufacturing work in American shipyards? The answer is that it has proven successful time in case after case of American companies in many different industries. We can ask a different question: Can American shipyards become competitive by simply following the current traditional paradigm and doing it better? We think not!