Case Studies: Examples of Environmental Benefits through Lean Implementation

The Boeing Company, Boeing Everett

Introduction

Boeing is implementing Lean projects in various ways throughout its Everett Plant. The Company created an overall Lean Group to assist in the development and implementation of Lean initiatives throughout the plant. Programs invite the Group to participate in specific Lean projects if desired. The different airplane programs and organizations have also created their own Lean offices to focus specifically on Lean efforts within the particular program. For example, the 777 program has developed its own office, Critical Process Reengineering (CPR), to look for opportunities within the 777 line.

Throughout the Everett plant, Lean initiatives have yielded measurable results. Larger efforts, like some of those described below, have resulted in substantial resource productivity gains and savings. Smaller efforts have also produced significant benefits. For example, the development and implementation of an alodine pen to be used prior to primer touch up, has reduced hazardous waste generation by approximately 36, 55-gallon drums per year. As part of a small tool recycling and reconditioning program, the 777 Wing Majors shop is recycling plastic spatulas used to apply sealant, reducing hazardous waste generation by approximately 90 percent (only the scraped sealant residue and velcro pad are disposed of, not the spatula itself).

Lean Efforts

To illustrate in greater detail the affect of Lean Manufacturing efforts at the Everett plant, five Lean projects were selected for closer examination. The initiatives selected and detailed below are the 777 Floor Grid Component Delivery Process, the 747 Line Side Supply and Simplified Ordering System, Chemical Point of Use Stations, 767 & 747 Wing Seal Moving Lines, and the 747 Horizontal Stabilizer project. These efforts are at various stages of implementation and the final effort, the 747 Horizontal Stabilizer Project has been put on hold due to technical and regulatory constraints.

777 Floor Grid Component Delivery Improvements

Boeing, as part of its overall Lean efforts, created a Lean Office to support the Twin Aisle Program (747s, 767s, and 777s). The 777 Line also formed its own group, CPR, to analyze current practices and identify potential Lean opportunities within the 777 program. In identifying potential opportunities, 777 operations were examined in total, providing a broader perspective of the overall program. In taking this more global approach, CPR identified as cost reduction opportunities the shipping processes used for seat tracks and floor beams. Boeing produces the parts in Wichita, Kansas and Tulsa, Oklahoma and then ships them to the Everett plant in Washington State.

CPR held a “Link the Flow” workshop to develop a Lean Vision for the shipping of 777 floor grid components. Workshop participants focused on shortening the overall value chain and developed a vision of the ideal shipping process. The participants also developed an interim vision, which serves as a midpoint target in the process of continually improving the shipping system.

Previously, Boeing delivered 777 seat tracks from Wichita and Tulsa to the Boeing Everett plant by truck. The parts were unloaded at Receiving and Inspection and then delivered to the factory for assembly. Boeing shipped 777 floor beams by truck from Tulsa to Kansas City then loaded them onto a train for shipment to Seattle via rail. From Seattle, a truck transported the floor beams to Receiving and Inspection at the Everett plant. Eventually the parts were brought to the factory for production purposes.

The Workshop resulted in a new delivery method for 777 floor grid components. Trucks now transport seat tracks from Wichita to Tulsa, pick up the floor beams then, carrying complete ship sets, travel directly to Everett and deliver the parts directly to the factory for use. Receiving and inspection processes are conducted at the plant. The redesigned shipping process allows a single truck to deliver a shipset of floor grid components directly to their point of use.

As a result of the new shipping process, Boeing has realized the following resource productivity gains:

- Multiple transfers, rail travel, and truck travel to the rail heads have been completely eliminated. Trucks no longer run empty from Kansas City to Tulsa because shipping by rail has been removed from the process.
- Eight days of travel and three days of receiving and inspection have been eliminated.
- Approximately $7,900 has been saved per shipset or $396,000 in annual transportation costs.
- Floor grid inventory has been reduced by 25 percent. Components are now shipped directly to the factory when they are needed, reducing the number of overall ship sets required in the delivery pipeline.
- Each ship set uses 50 percent less transportation (and associated energy and maintenance). Previously, Boeing trucked half of one airplane’s worth of floor grids to Everett and trucked and then shipped by train the other half to Seattle; Boeing now ships one airplane’s worth of floor grids in one truck from suppliers in Tulsa and Wichita directly to the Boeing factory in Everett.
- Overall handling of materials has been reduced, yielding a reduction in forklift use. Decreased forklift operation represents savings associated with fuel, maintenance, and driver time.
- Also, in response to Boeing’s new shipping process, the floor grid component suppliers have adjusted their manufacturing schedules so that they do not produce and accumulate excess inventory at their production sites.

747 Line Side Supply and Simplified Ordering System

The Wing Responsibility Center, using a specially-chartered team working with the Parts Control Organization, (the organization responsible for material handling and inventory control across the Boeing Commercial Airplane Group), developed the 747 Line Side Supply and Simplified Ordering System. This 747 Lean project focuses on improving the inventory and supply chain systems for fiberglass panels comprising wing trailing edge areas.

Under the previous inventory and supply system, a supplier in Kent delivered bulk shipments of panels to the Everett plant. Boeing temporarily stored the panels in a factory parts control area before delivering them to the factory floor for installation. The fiberglass panels are fragile, requiring each to have cardboard wrapping, with approximately 60 percent having plastic bubble wrap inside the cardboard. Boeing discarded the cardboard when unwrapping the panels in the factory parts control area and the bubble wrap when a mechanic installed the panel on an airplane.

To provide better inventory control and decrease damage, the Wing Responsibility Center is implementing a "kanban" cart system. This system is built around constructing and introducing custom carts which the vendor in Kent will use to transport the panels directly to the 747 Wing Majors area point of installation. To control the amount of inventory shipped, one set of carts is capable of holding only one ship set of panels. The Wing Responsibility Center's return of an empty cart signals the vendor that Boeing requires another ship set.

The transportation carts are also designed to reduce packaging waste. Carts have restraining straps and are segregated into padded compartments so that individual fiberglass panels require no packaging. Carts are also more ergonomically correct to reduce worker injury.

When fully implemented, Boeing anticipates the following resource productivity gains.

- Fiberglass panel inventory will be reduced from 14 ship sets to 4.
- Rework due to handling damage will be virtually eliminated. (Previously shipping and storing handling damage required fiberglass rework of a significant number of the 140 panels in a ship set.)
- Approximately 350 cubic feet of cardboard and bubble wrap packaging will be eliminated per wing ship set.
- Parts and mechanics travel will be reduced because parts will be shipped directly to the point of use in the wing assembly area.

Chemical Point of Use Stations

Boeing's Safety, Health, and Environmental Affairs organization (SHEA) developed the Point of Use system for chemical materials. Generally, point of use efforts enable the storage of materials where the production process utilizes them. Boeing's key objectives for point of use chemical stations are reductions in mechanic travel and better control of the supply, use, and distribution of hazardous materials. Ultimately, reduced mechanic travel time was the primary financial driver for this change. Currently Everett has over 120 point of use stations.

Prior to implementing the point of use stations, several chemical disbursement centers, known as chemical cribs, distributed the paints, sealants, solvents, and other chemical materials required for airplane assembly. Mechanics were required to pick up new materials from, and return unused and waste materials to, cribs. This entailed frequent travel over substantial distances.

The new stations are self-help areas that allow mechanics to pick up materials and return waste at the point of use. A Hazardous Material worker visits the point of use stations at least twice a shift to check supplies, pick up waste, and resupply material for the specific applications occurring within the station area. Boeing controls the amount of chemical inventory and waste on the floor by using minimum/maximum quantities, right-sizing containers, (holding only the necessary amount of material required for a specific application), and limiting each station's quantity of containers.

Boeing tracks the point of use station materials by bar code to determine what types and quantities each factory location uses. Boeing uses the tracking to prepare a 30 day reduction report. The report analyzes the amount and type of chemicals used and helps to determine how much inventory to carry where in the system. If a particular location does not use a specific product regularly, Boeing lowers the product's maximum amount at the station. Boeing expects to track dry goods for chemical applications in the future to assist in overall waste reduction.

Each point of use station also utilizes small, (less than 55 gallons) segregated cans for waste materials. Shops segregate their own waste, and Boeing color codes chemical products and the waste stream to reduce the possibility of mistakes. Each also has a reuse section. If material is leftover after an application, mechanics can place the excess material back at the station for future use.

Implementation of the Point of Use Stations has yielded the following resource productivity gains:

- chemical use per airplane has been reduced by approximately 11.6 percent;
- the amount of chemicals on the shop floor has been reduced by 23 percent;
- overall material waste has been reduced due to the use of right-sized containers and easier mechanic access to materials; and
- mechanic travel has been reduced by 56 percent, representing an average of 567 fewer trips and 95 hours of less travel per day.

767 & 747 Wing Seal Moving Lines

The Everett Wing Responsibility Center has been engaged in efforts to establish several moving production lines. As part of that effort, the Center examined the 767 and 747 wing sealing processes. Operations within those processes include exterior sealing, in-tank sealing, pressure testing, and painting applications. The Center conducts these large scale chemical processes in a separate, dedicated factory building with full environmental controls, including specialized air cleaning and water collection systems. Cranes lift the large wing assemblies to the building from various areas in the factory where assembly takes place.

Previous operations had each 767 and 747 wing craned into one of 12 different positions in the building for internal and external sealing and pressure testing. Subsequently, cranes moved each wing to three additional positions, each corresponding to separate processes: spar (edge) painting, large surface painting in vertical paint booths, and a final job pickup position. As many as three sets of 767 and 747 wings could be in work at any given time. Chemicals were spread among all 12 positions, and varied depending upon the work being done in each position.

As part its Lean efforts, the Wing Responsibility Center has reconfigured these sealing operations into two moving lines, for 767 and 747 wings. This process results in no more than four wings receiving work at a time: one 767 and 747 wing on the moving lines, and one of each in the vertical paint booth.

The moving lines, established in April 2000, have four or five workstations, depending on airplane model, on each side of the wing. At these fixed workstations, mechanics perform exterior sealing and corrosion sealing as the wings move slowly by on two drive units. Each workstation is height-adjustable to improve ergonomics and has a point of use chemical station containing the materials required for each processing step. Waste is deposited and collected at the point of use stations.

The Wing Responsibility Center has short-term plans to add in-tank sealing, exterior masking, and painting to the line activities. Long-range plans include the possibility of adding leak testing, plumbing installation, and the large-scale painting currently done in the special paint booths.

The moving seal lines, as currently configured, have achieved the following benefits.

- Flow days have been reduced from 13 to 6 for the 747 and from 12 to 6 for the 767.
- Crane moves, required to move the assembled wing throughout the factory, have been reduced from 7 to 5. (Limiting crane moves is a priority for Boeing because the complexities of crane moves for large aircraft parts often cause delays in the overall production process.)
- The point of use stations, affixed to work platforms, allow for better chemical material inventory control, reducing the amount of both chemical inventory and waste. Boeing is also exploring the possibility of developing a process that would allow employees to mix seal at the gun itself, so mixed sealant in freezers would no longer be required. This would reduce the waste generated by sealant inventory that is not used within a specified period of time.
- Fixed position sealing requires less sealant, thereby producing less hazardous waste. In addition, because there is less inventory on the floor, (i.e., 4 wings versus 12), there will be less overall chemical inventory spread throughout the building.
- There have also been significant gains in available floor space, which may be used in the future to accommodate additional sealing and mechanical assembly processes.

WRC's initial design efforts indicated that the ideal configuration for the moving lines would have been two parallel lines (one each for the 767 and 747), thus optimizing building space. Although the building currently has full environmental controls, Boeing determined that this ideal configuration (from a production process perspective) would require new building and environmental permitting activities. Because implementation time was critical to the viability of this project, the anticipated delays of conducting these activities, and uncertainties associated with them, convinced WRC to accept a less than ideal configuration; aligning the moving lines to utilize existing ventilation systems and environmental controls.

Technical constraints have also influenced the development of the moving lines. Specifically, the cure time of sealants and paints dictate the flow time of the moving line. The flow cannot be too rapid because paints and sealants require specific curing times. In an effort to address this issue, the Wing Responsibility Center is currently exploring the existence of new technologies such as faster curing sealant and accelerated paint curing.

747 Horizontal Stabilizer Project

The Everett Wing Responsibility Center also has examined the possibility of establishing a moving line for the 747 Horizontal Stabilizer. Like the Wing Seal process, the Horizontal Stabilizer production consists of both chemical and assembly processes. Unlike the Wing Seal line, however, the WRC had interest in locating the entire horizontal stabilizer process line on the main factory floor. The WRC currently joins the 747 horizontal stabilizer in the main factory, then transfers it to an environmentally controlled building, roughly ½ mile away, for sealing, painting, and seal testing. As a fuel cell, the 747 horizontal stabilizer must receive a seal test. The current test entails filling the cell with ammonia to detect any leaks. Additional seal work and paint applications are also conducted in this facility. The WRC then moves the horizontal stabilizer back to the main factory for anti-corrosion applications and final assembly. (The anti-corrosive application is conducted within temporary confinement walls with a ventilator.)

The Wing Responsibility Center has envisioned using small booths or other technologies to replace large scale chemical and painting processes and integrating these processes into a continuous manufacturing cell-based production flow, thus eliminating multiple crane-dependent stabilizer moves in and out of specialized facilities. This would create a one-piece, pull-production system capable of all stabilizer process steps: assembly, sealing, painting, leak testing, and paint and corrosive inhibitor compound (CIC) applications. WRC would depend on smaller, right-sized, moveable equipment to support this redesigned process.

The Wing Responsibility Center anticipates the following resource productivity gains from implementation of the 747 horizontal stabilizer moving line.

- A reduction from 16 to 4 flow days.
- Elimination of 23 overhead crane moves, reducing the total number from 31 to 8.
- Space requirements reduced from 29,600 to 14,800 square feet.
- Significant energy savings due to the reduction in crane moves and space required for production.
- An approximate 10-20 percent reduction in paint overspray and solvents required for component applications due to the use of small, in-line chemical operations.

Regulatory and technological constraints (and the time required to develop possible solutions) has caused WRC to place the entire 747 Horizontal Stabilizer project on hold. WRC directed manufacturing, engineering, and technical resources toward overcoming some of these obstacles, however the work was expensive and time consuming. Approaches explored to overcome some of these constraints included changing the technology associated with certain processes, eliminating the processes, or substituting another, less hazardous process.

In particular, the seal test and painting applications have presented significant obstacles. WRC currently conducts the seal test (which uses ammonia, a compound strictly regulated by OSHA, fire code, and environmental regulatory requirements) under only highly constrained conditions. These strict requirements dictate the limited conditions under which the seal test can occur. In response, Boeing is exploring alternative substances (such as helium) and methods for conducting the seal test. If helium proves viable, WRC would completely eliminate ammonia from the process.

Spray painting/coating operations also presented various obstacles. To move painting processes onto the main factory floor, the Wing Responsibility Center began developing self-contained, moveable, right-sized painting units. The Center examined smaller units because it viewed the costs of moving "as is" painting operations onto the floor as too great.

As WRC explored various technological approaches to small scale, in-line mobile equipment, the number and variety of requirements associated with moving the spray painting/coating operations onto the factory floor became apparent. Requirements included those associated with the Building and Fire Code, OSHA, and the Clean Air Act. Although no single requirement or regulation proved to be an impediment that could not be overcome, the combination of requirements was overwhelming in light of the time and resources WRC could make available to the project. WRC also perceived significant uncertainty as to whether any self-contained, moveable, right-sized painting unit could receive a permit under the Clean Air Act. Because of the cost, time, and uncertainty associated with the identified regulatory requirements, WRC discontinued further technological development efforts and placed Horizontal Stabilizer moving line development entirely on hold.

Boeing Auburn Machine Fabrication

Introduction

The Boeing Machine Fabrication Manufacturing Business Unit (MBU) in Auburn, Washington produces various components for Boeing aircraft, including wing, landing gear, and fuselage parts. It produces over 1,000 different products and an average of 22,000 parts per month. The MBU employs approximately 700 people, and the factory itself is 550,000 square feet.

The Machine Fabrication factory was previously organized in a job shop layout, supporting "batch and queue" production techniques associated with producing large quantities of goods in a function-driven structure. This meant that all processes were co-located throughout the factory based upon functional commonality (e.g., boring mills were all located in a boring mill area, assembly in the assembly area, etc.) Work traveled throughout the factory from job shop to job shop in order to produce a final product.

This manufacturing structure required substantial space. As work traveled from one area to another, it sat in area "queues" until ready for work. Vast amounts of factory floor space was dedicated to storing Work in Process (WIP). In addition, space was required to store inventory, as bulk purchasing of raw materials and production of new parts continued even as WIP sat in area queues. Space was also needed for storage of finished products because the production schedule was not necessarily based on completing production of a part at the time a customer required it. Overall, the Machine Fabrication shop utilized approximately 650,000 square feet, including rented off site storage space.

Because of the factory's configuration and size, WIP traveled literally miles throughout the production process. A typical job had as many as 30 station moves from raw material to finished product. Cranes, trucks, and forklifts were the primary methods for moving WIP and materials from job shop to job shop.

As the MBU brought new and varied products in, it needed to acquire large complex equipment to support the changing volume of goods. These machines were capable of machining many different types of features, but were costly and required construction of their own foundations to operate. The variety of new products also required a variety of support tools, including measuring and burring equipment, shop supplies, and perishable tools.

The complex flow of these new products additionally required a large staff to support programming, tooling, planning, and engineering. Within Machine Fabrication, employees generally operated only within their particular job shops, developing and applying a single set of skills to specific facets of the production process.

The MBU measured success in terms of machine efficiency and utilization, production backlog, and machine tool setup savings associated with "batching." The MBU consider these factors to be representative of productivity. Although the batch and queue process minimized marginal unit cost at each job shop, it was susceptible to problems such as inflexibility, excessive travel and inventory, a higher number of flow days[1], greater overall costs, and quality issues. For example, operating within this manufacturing environment, generally required 6-10 months of raw material to finished good processing time.

Lean Manufacturing

In January of 1996, the Boeing Company introduced Lean Manufacturing to the Machine Fabrication Shop leadership as an initiative to promote cost reduction. The Machine Shop created a "Lean Team", which analyzed and documented factory data associated with quality, cost, delivery, safety, and morale. Members of the Team represented various entities throughout the production process including management, tooling, quality assurance, Safety, Health, and Environmental Affairs (SHEA), production staff, programming, and more. The Team was empowered to identify waste in the Machine Fabrication Shop's processes, develop actions to minimize that waste, measure the results, develop any additional actions to improve minimization, and to repeat the cycle continually. The Lean Team began by conducting a Lean Manufacturing Assessment, which analyzed where the MBU spent resources, identified what products the MBU produced, and how much it cost to produce those products. The Team also developed a "Lean Vision" to describe and communicate to the Machine Fabrication Shop as a whole the initial production system changes envisioned for the MBU.

The Lean Team's four key "Vision" elements were: product/process focused cells; simplified scheduling; shop floor control; and focused support.

- *Product/process focused cells:* As described in the Vision, product/process focused cells "combine processes and equipment re-located from functional areas, employ multi-skilled personnel, and will be utilized to manufacture and assemble single ship-set quantities." The cell structure addresses problems associated with a batch and queue structure, such as excessive travel and inventory, higher flow time, higher costs, quality problems, and a lack of product ownership.

- *Simplified scheduling systems:* The Lean Vision states that the MBU will utilize simplified scheduling systems where possible to reduce the impact of schedule changes. "Simplification will be achieved by utilizing a repetitive production cycle based on the

[1] Flow days comprise the period of time required to produce a finished good from raw materials. The costs associated with a flow day include floor space, managing inventory, heating and lighting, handling time, taxes, engineering changes, and capital tied up in the production process.

firing order[2], pull aheads[3] for the level loading of bottlenecks and first in/first out[4] (FIFO) for cellular order completion."

- *Improved shop floor control*: The third component of the Vision calls for visual controls to replace information systems to simplify and improve overall shop floor control. Because cellular production greatly decreases product movement, "additional simplicity will be achieved by utilizing visual controls, traveler reduction, and managing post-cell processing via first in/first out."

- *Organizational support structure:* The last element of the vision calls for Manufacturing Engineering to change to "provide focused and dedicated support at the product center and cell levels." This product and cell specific support is designed to improve customer focus, optimize production efficiency, and promote ownership of the products and processes.

To implement the Lean Vision, the Machine Fabrication Shop made fundamental changes, (based upon the four key elements listed above), to its manufacturing structure. Factory operations are no longer co-located throughout the Shop based upon functional commonality; instead, the MBU has designed and implemented product-focused cells. The MBU has moved all the necessary equipment, people, and resources required to produce a product into a specific cell and all operations are performed in that cell, using a first-in/first-out approach to scheduling. The MBU has structured cells so that single ship sets[5] flow through the production process from one operational step to the next. This has required incorporation of component and tool storage, milling, drilling, honing, grinding, turning, deburring, and assembly, as well as shipping, receiving, and quality assurance into each cell.

The MBU also designed a variety of processes to compliment and enhance the performance of the cell manufacturing structure. Tooling and equipment capability are matched with the fit, form, and function of the part being fabricated in the cell. The MBU has scaled manufacturing equipment, where possible, to need and placed it on wheels to increase flexibility. Product teams exist instead of process teams, and employees receive cross-training to perform effectively the different operational functions within the cell. Ergonomic work tables and stations have been installed to help reduce worker injury.

A key component of implementing the Machine Fabrication Shop Lean Vision was, and continues to be, employee inclusion and training. The MBU encourages all shop employees to

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[2] The firing order is the sequence in which airplanes are built.

[3] "Pull ahead" is done so that production requirements are met while a manufacturing area is shut down for any of a variety of reasons, including planned maintenance.

[4] Products are completed in the same sequence as started.

[5] A ship set is one airplane's worth of parts. If two of one item go on any given plane, the ship set value is two.

participate in the effort, including identifying areas of waste and developing process changes to remove waste from production. The MBU utilizes Accelerated Improvement Workshops (AIWs) to maximize employee education, involvement, and support a continual improvement culture. Approximately 5-10 AIWs are scheduled each month. The MBU held the first AIW in May of 1996 and since that time hundreds of Machine Shop employees have participated in AIWs.

To measure the success of Lean initiatives, the Lean Team established performance standards for the MBU. These standards include quality (defects and cost of quality), product cost, delivery performance, flow, inventory turns, safety, WIP, and productivity.

High Level Results

According to Boeing, since initiating Lean Manufacturing efforts, the MBU has experienced substantial overall improvements:

- the MBU has reduced total cost by 30 percent;
- productivity has improved by 39 percent;
- the factory has reduced approximately 70 percent of flows by 70 percent;
- production flexibility has increased approximately 40-50 percent;
- defects have been reduced from 1,200/10,000 in 1996 to fewer than 300/10,000 presently; and
- the MBU has reduced by over 51 percent its quality cost performance measure (measured as total cost of dollars lost due to defects).

In addition, Lean strategies have yielded significant gains with respect to specific elements of the manufacturing process, contributing to the MBU's overall improvements. Three specific manufacturing elements (travel, space, and inventory), illustrated below, highlight some of the higher level changes and results produced in the MBU.

<u>Travel</u>

Numerous Lean strategies/tools have had an affect on the amount and mode of people and product travel. Key strategies include the following.

- Production processes have been reconfigured into product cells, which include most manufacturing operations necessary to produce specific products.
- Wheels are attached to much of the equipment within the product cells, reducing the need for trucks and forklifts throughout the production process.
- Point of use stores are incorporated into each product cell and are stocked using a minimum/maximum system.

These strategies have produced significant travel-related resource productivity gains. For example:

- internal factory product travel has decreased anywhere from one to three miles, depending upon the product;
- overall people travel has been reduced by approximately 34,000 feet; and
- energy use and maintenance costs have been reduced due to the decrease in truck and forklift use.

Space

Lean techniques implemented have also significantly affected the amount of space utilized, and the way space is utilized, by the MBU.

- Reductions in bulk purchasing have decreased the amount of inventory on site.
- Manufacturing occurs in ship sets of one resulting in little WIP within the product cells and on the factory floor.
- Products are completed and delivered when needed by the customer, so there is less finished product on site.
- Coordinate Measuring Machines (CMM), used to inspect the quality of products, are programmed to adjust themselves for temperature differentiations (all CMM testing was previously conducted in an 8,000 square foot temperature controlled space).

These techniques are directly associated with a substantial decrease in the per unit of product manufacturing space requirements and associated energy and building maintenance needs. Specifically:

- Space utilized by the MBU has decreased from 650,000 to 450,000 square feet. Of the 200,000 square feet reduced, 100,000 square feet is storage space that is no longer required and the other 100,000 is now open factory floor.
- Newly open floor space allows for new products to be absorbed into existing space without adding to the MBU's cost structure.
- The need for a temperature controlled atmosphere for CMM inspection has been eliminated, freeing up 8,000 square feet and yielding energy savings associated with eliminating the lighting and cooling of the temperature controlled, enclosed space.
- Use and occupancy fees from off-site storage space have been eliminated.

Inventory

Improved inventory control is an important focus of the Machine Fabrication Shop's Lean efforts. Significant changes made to its inventory practices include the following.

- Existing inventory "burn down" efforts have eliminated the need (in the short-term) to purchase new raw materials.
- Regular bulk ordering of materials has been eliminated.
- Modifications to the supply chain have tied raw material purchasing/delivery to production scheduling. For example, one supplier now produces only 60 days worth of materials at a time. The Machine Fabrication shop stores one 30 day supply on site and the supplier holds the second 30 day supply at its site. When the Shop has used its on hand supply, it requests the remaining stock from the supplier. This request notifies the supplier that it should begin producing the next 60 days worth of materials.

Resource productivity gains associated with these improvements include:

- Short-term raw material spending has been reduced by $22 million.
- The amount of storage space required for inventory has been reduced.
- The total inventory turn rate has increased from three to seven per year.
- Increased inventory turn rates have reduced the chance for engineering design changes to render WIP or finished goods "off specification," and therefore in need of scrapping or rework. (Because there is less material moving faster through the production process,

engineering changes affect fewer parts.)

- Holding less inventory reduces the opportunity for damage or spoilage, resulting in better overall utilization of raw materials.

Specific Product Cells

To illustrate additional and more detailed Lean strategies and tools incorporated into the manufacturing process, two specific cells were selected for closer observation; the 777 Stow Bin Arch Cell and the 777 Side of Body Fittings (pickle fork) cell.

High Speed Machining Cell: Stow Bin Arch (777 Overhead Storage Bin Arches)

The Stow Bin Arch was a new product line when the Machine Fabrication Shop brought it into the factory in 1997. This enabled Lean strategies and processes to be implemented at the onset in a cell structure specifically designed to produce the Stow Bin Arch.[6]

The Stow Bin Arch cell capabilities include sheet metal details, three axis high velocity milling, and assembly. The cell incorporates several key Lean tools, most notably small, right-sized equipment for specific production operations, including a table top boring mill and tapping machine. In addition, there is a right-sized hand drill tool, which requires no flooding lubricants and can be turned off when not in use. The right-sized machines are often built on wheels, increasing production flexibility.

The Stow Bin Arch cell also contains a chaku chaku line for production of sheet metal clips, brackets, and angles. The line consists of right-sized table top blanking, holing, and tapping machines. This allows an operator to produce only the parts that are needed at a specific time.

In addition to smaller, right-sized equipment, the Stow Bin Arch cell utilizes more efficient equipment for those operations that cannot (to-date) be completed with the use of right-sized machines. Smaller, moveable high precision milling machines are now being incorporated into the Stow Bin production process instead of the traditional, larger, immoveable milling machines. The larger machines require their own foundations and cannot be easily and inexpensively moved. The newer, smaller machines are moveable and can be installed with less effort. These machines are also less expensive than the larger machines to run and maintain.

The cell also contains its own “store” where required parts and tools are kept. Inventory is maintained through a visual que system. Part containers are designed with cutouts, which hold a specific, maximum number of parts. This provides a visual inventory control system to minimize the amount of inventory in the cell. A similar inventory control system is used as part of a moving line within the cell. Inventory kits are created and stored beneath the line itself, where the parts are needed. The kits consist of the number of parts required for one shift’s worth of work.

Visual controls are also used to simplify and improve inspection processes within the cell.

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[6]The previous manufacturer produced the stow bin arch in a batch and queue environment.

"Go/no go" inspection boards are used to determine if a part has been properly holed. Employees simply place the specified part on an inspection board, which is appropriately configured with rivets. If the part fits over the rivets properly, the part has been produced correctly.

These Lean initiatives have produced important resource productivity and cost per unit gains for the MBU. For example:

- The number of components in the arch has gone from 40 to 26 as a result of a design for manufacturability effort. The arch is now produced from a monolithic plate instead of numerous sheet metal parts.
- Production cycle time has gone from 31 to 11 days.
- Overall cost per ship set has decreased from $350,000 to $155,000.
- Right-sized machines have resulted in less energy used, fewer chemicals/flooding lubricants required, scrapped material reductions, and less space required for equipment.
- Conversion to smaller milling machines has resulted in less energy used, easier maintenance, and cost savings of $1.5 million a month.
- Point of use stores have reduced employee travel and improved inventory control.

Large Aluminum Parts Cell: 777 Side of Body Fittings (pickle fork)

The pickle fork cell produces the body fittings that attach the wing to the body of the plane. The MBU previously produced the pickle fork using batch and queue techniques. When implementing Lean, the primary initiatives for pickle fork production were to create a product-focused cell, increase material efficiencies, and more effectively manage quality within the cell.

The pickle fork cell's capabilities include large part machining, close tolerance boring, hand drilling and finishing, assembly, and coordinate measuring machine inspection. In addition, like the Stow Bin Arch cell, the pickle fork cell maintains its own "store." The store contains the maximum number of parts required on the floor and uses cutouts as a visual control to maintain the proper inventory levels within the cell. Visual controls are also used to standardize and improve work quality. Color coded systems are used to ensure that the proper drills are being used to perform the right task at the right time in production.

To increase materials efficiency, the main component of the pickle fork is now produced out of forged, restrike aluminum. Previously the part was produced from block aluminum, which generated a significant amount of scrap because the pickle fork component was cut and shaped from the block. The pickle fork forgings now arrive in the approximate shape of the component so less aluminum is scrapped. In addition, the type of aluminum previously used for the pickle fork required shipping to California for stress relieving and return back to Auburn for continued production. The current aluminum forgings do not require stress treatment.

Resource productivity gains:

- Part assemblies are now produced in less than 25 days vs. 180 days previously.
- Rejection rate for pickle forks has been reduced from 100 percent to zero, with zero scrap.
- Visual controls have supported less defects and scrap and more standardized work quality.

- Use of forged aluminum has produced less scrap.
- Use of restrike aluminum has reduced transportation requirements (and associated energy and costs) and flow days required for production.

Obstacles

Despite significant gains in production, the MBU's conversion to cell manufacturing is not ideally configured. Several key operations remain batch and queue processes; specifically, painting, chemical treatment, shotpeening, and oven processes. For example, the pickle fork cell process flow is interrupted for chemical processing and painting operations. These processes cannot be contained within the cell because of technological and regulatory issues. The Machine Fabrication Shop has explored moving these processes into product cells, but has encountered obstacles that make it difficult and/or cost prohibitive to do so. Among the key obstacles encountered are environmental regulations, safety regulations, and lack of necessary technology.

Painting

Cell process flows are currently interrupted for painting operations. Ideally, the Machine Fabrication shop would like to use small, flexible, right-sized equipment for painting applications. Painting booths would be designed for specific applications, and to increase production flexibility, would be moveable.

The Machine Fabrication Shop considered various paths in its effort to incorporate painting applications into the product cells. In exploring options to the current painting process, the MBU examined the feasibility of developing smaller, right-sized booths, located appropriately throughout the production process. As this examination progressed, however, several obstacles became apparent.

Ventilation systems for the booths presented a series of impediments. Under OSHA, the smaller painting booths require proper venting. The MBU considered a variety of outside venting options, including venting through the roof of the building and through its walls. Overhead obstructions eliminated roof venting as a possibility so the MBU focused on venting the smaller booths through the walls of the building, noting that outside venting would tend to lock equipment into a given configuration, thereby reducing some of the desired flexibility.

The need for outside ventilation through the walls of the building reduced the number of possible painting locations. Further analysis indicated that both the lack of appropriate and available locations for the booths as well as the cost of materials required to properly construct multiple booth sites presented significant costs.

In addition, because the booths required outside venting, federal and local air permitting would apply. Although the MBU did not pursue development of the smaller, flexible booths to the permitting stage, air permitting issues were considered in its decision to discontinue the effort. The MBU weighed the uncertainty associated with permitting an unconventional painting application process. Uncertainties such as whether the smaller, more flexible booths could get permitted, in what time frame, at what cost, and with what limitations were taken into account.

The combination of total construction cost, lack of appropriate booth locations, and the uncertainties associated with permitting, resulted in the MBU abandoning the effort. In light of the obstacles encountered, the MBU opted instead to purchase new painting equipment to upgrade the current process.

The Machine Fabrication Shop anticipated that using smaller, right-sized booths would produce significant results if the current obstacles could be surmounted. The anticipated resource productivity gains are listed below.

- Reduction in energy use as smaller, right-sized painting booths could be turned off when not in use. The current, larger booths remain on all day, whether in use or not.
- The existing paint shop would be eliminated, opening up approximately 10,000 square feet of floor space and reducing maintenance activity.
- Reduction in overall waste associated with painting operations. Currently, if paint mixtures are not used within a specified period of time, the paint must be thrown out. In a cell structure, with a right-sized machine, only the amount of paint currently required for a part would be mixed. Paint supplies and inventory would also be more easily and effectively managed within the cell.
- Production flow days would be decreased by two to four days.

As a result of the MBU's effort to move painting processes into the product cells, and the regulatory obstacles associated with doing so, the MBU has been supporting the company's reserach into development of non-chromate paints. The MBU has explored using alternative paint products that are less hazardous and has conducted experiments using various alternative materials. The MBU has tested water based paints and is currently exploring the use of powder coating. The MBU continues to explore alternatives to chromate paints to gain the ability to have greater flexibility for applying Lean concepts to paint processes.

Chemical Processing (Dye penetrant inspection and tank lines)

Like the painting processes, the Machine Fabrication Shop would like to incorporate chemical processing into the cell structure. The ideal equipment would be small, flexible, scaleable resources that could be right-sized and placed in multiple areas. However, regulatory requirements and technical complexities have constrained Boeing's ability to convert from a batch to a cell-based process.

The MBU encountered a variety of obstacles to implementing a non-batch chemical processing system. In particular, it was unable to resolve, in a cost-effective manner, issues raised by the building and fire code. Under the Code, the design and size of the Machine Fabrication Shop's building did not allow for targeted distribution of smaller scaled chemical processes throughout the product cells. However, the MBU did resolve technological issues associated with small, chemical processing. A right-sized chemical processing line prototype was developed and tested with water. Initial testing proved successful, however it was cost prohibitive to move the smaller processing lines onto the factory floor and comply with the building and fire code.

Additional obstacles were also identified, however the MBU did not attempt to address them in light of the obstacles presented by the building and fire code. These issues included difficulties in locating the chemical processing lines where they could be easily hard plumbed and employee safety issues related to exposure.

The Machine Fabrication Shop anticipated that smaller, right-sized chemical processing would produce important results. The anticipated resource productivity gains are listed below.

- Reduction in overall chemical usage.
- Reduction in the amount of rinse water required. Currently large tanks are filled for each run, regardless of the number of parts being processed. This represents a major incompatibility between the batch and queue environment and Lean Manufacturing. Because of Lean practices, fewer parts are processed at a time. The same environmental load exists however, because the tanks are filled whether three or 50 parts are being processed.
- Production flow days would be reduced by two to four days.

As with paints, the MBU continues to explore the use of less hazardous materials in its chemical processes. This exploration is driven by the regulatory obstacles encountered by the MBU in the course of its Lean efforts.