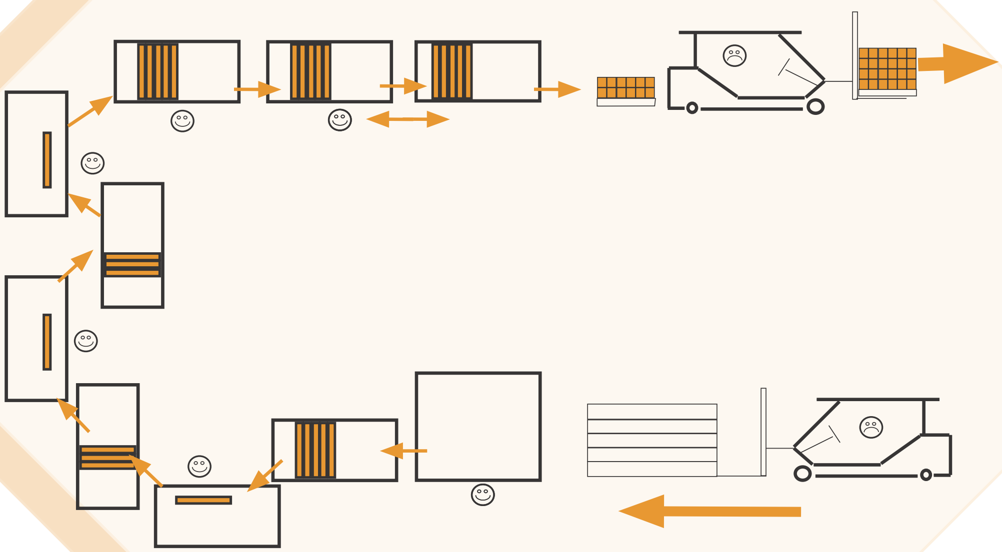
Case studies of lean manufacturing in furniture and supplying industries

Applications for increased international competitiveness

Wood Furniture Components:

Implementation of Flow-Line Technology Based on Lean Manufacturing Concepts



By

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Al Schuler

#3 Case Study

Research Bulletin

Forest and Wildlife Research Center

The Forest and Wildlife Research Center at Mississippi State University was established by the Mississippi Legislature with the passage of the Renewable Natural Resources Research Act of 1994. The mission of the Center is to conduct research and technical assistance programs relevant to the efficient management and utilization of the forest, wildlife, and fisheries of the state and region, and the protection and enhancement of the natural environment associated with these resources. FWRC scientists conduct this research in laboratories and forests administered by the University and cooperating agencies and industries throughout the country. Research results are made available to potential users through the University's educational program and through Center publications such as this, which are directed as appropriate to forest landowners and managers, manufacturers and users of forest products, leaders of government and industry, the scientific community and the general public. Dr. Bob L. Karr is interim director of the Forest and Wildlife Research Center.

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Wood Furniture Components: Implementation of Flow-Line Technology Based on Lean Manufacturing Concepts

Case Study #3

Case Studies of Lean Manufacturing in Furniture and Supplying Industries: Applications for Increased International Competitiveness

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Table of Contents

#3 Case Study

Wood Furniture Components

Implementation of Flow-Line Technology Based on Lean Manufacturing Concepts

Introduction

This case study is #3 in a series of studies that relate specifically to the development and application of lean manufacturing techniques for the furniture and wood component supplying industries. Case study #3 is an example of how productivity can be increased in a furniture manufacturing organization by using flow-line technology.

This case study provides information about lean manufacturing and how a lean manufacturing system can be implemented, followed by a detailed case study of a wood component manufacturing company's adoption of a new flow-line technology based on lean manufacturing concepts.

Other case studies in this series are available as separate reports. (For availability see the publication link at the Institute of Furniture Manufacturing and Management web site: www.ifmm.msstate.edu). Information helpful in understanding lean manufacturing systems can also be found in the resources listed in the next section of this report.

Case Study #3

Overview of Lean Manufacturing

Lean manufacturing systems involve manufacturing and assembly cells, "pull system" methodologies, and other techniques to create the most effective and productive manufacturing system possible for any given product. Lean manufacturing differs greatly from the older "batch" and "job shop" manufacturing system designs offering previously unattainable benefits.

Do the benefits of lean manufacturing outweigh the costs in *your* production facility? Although all facilities and production processes differ, the answer to this question is almost assuredly yes. The benefits of lean manufacturing can be significant, while in most cases the monetary costs are relatively low. However, conversion to a lean manufacturing system is not a simple task and requires a strong, continuing commitment from high-level management within the firm.

Even though this system offers a variety of benefits to manufacturers committed to its use, lean manufacturing has yet to be widely adopted in US furniture production facilities. The results of this case study and the others in this series demonstrate that lean manufacturing processes offer great potential for increasing productivity and product quality in this important industry.

These processes represent a significant means of achieving and sustaining "higher order" competitive advantages in a manufacturing environment facing strong pressures from global competitors. Competitive pressures in the furniture industry today are particularly rigorous from countries with relatively low wages and in some cases relatively low requirements for worker safety, environmental protection, and other regulatory issues that directly impact production costs (Bullard and West, 2002).

Lean techniques help manufacturers produce high quality products, on time, with great flexibility and with a high rate of productivity. Clearly these methods help producers capitalize on "home court" advantages and are "higher order" competitive advantages in that they are difficult to replicate quickly, particularly in countries that are geographically distant from major U.S. markets.

Given the attractiveness of the benefits of lean manufacturing, and their low cost, where might this type of system be used in the furniture industry, and how might its adoption be implemented? Answers to these questions can be found by exploring some changes within the Airline Manufacturing Company.

Compared to previous manufacturing systems, lean manufacturing generally:

- requires less labor and floor space;
- requires fewer design hours for product development;
- requires less stock on hand;
- results in fewer defects;
- increases quality;
- enables faster delivery;
- results in improved ergonomics; and
- results in maximum flexibility in product types and styles produced.

Airline Manufacturing Company

Airline Manufacturing Company president Judy Dunaway (center) and Duane Motsenbocker (r) watch an employee mark defects between interconnected CNC rip and crosscut saws.

Airline Manufacturing Company is a wood component manufacturer supplying upholstered frame and case good parts to the furniture industry. This family-owned business, located in Columbus, Mississippi, was founded in 1956. The company manufactures components from hardwood and softwood lumber and composite engineered panels. Some subassemblies require assembly and finishing. In a typical week of production, the company manufactures hundreds of different wood parts. This case study investigates the manufacture of only one of those parts: part number 146-3843.

Airline Manufacturing began aggressive implementation of manufacturing productivity improvements in 2001. Pressure from both international and domestic competition alerted the company that in some areas, their manufacturing costs were higher than those of their competitors. In response, the company installed more productive manufacturing equipment such as automated lumber cutup lines and high-speed computer numerically controlled (CNC) routers. In addition, the company began implementation of lean manufacturing concepts throughout the facility. This case study reports on the installation of one improvement, a flow-line developed to replace a portion of a functional job shop or batch processing system. (For more information about cell design and continuous flow see *Lean Manufacturing Systems and Cell Design* by Black and Hunter, 2003.)

An analysis of Airline's previous batch processing system was performed in early 2001 by Duane Motsenbocker, Interim Director, Industrial Outreach Service, Mississippi State University. The initial findings confirmed management's concern that movement and storage of work-in-process comprised a high proportion of Airline's total manufacturing cost. Other issues facing the company were defective parts, long lead times, orders misplaced, and missed shipment dates. Implementation of lean principles can solve or reduce all of these problems.

Case Study #3

Flow-Line Production System

Lean manufacturing principles demand the systematic elimination of all steps that do not add value to products. Storage and movement of work in process are non-value-adding activities that should be reduced as much as possible. The company was assisted with the development and implementation of a one-piece continuous flow-line concept to replace some of the batch system operations that were in place. Since completion of this work, the company has replaced many of its batch processes with flow lines.

Typically, manufacturing and assembly cells are designed and implemented first and they are the key to the benefits of lean manufacturing systems. However, in this case study, management determined that a pull system flow-line would be designed and implemented instead of the normally selected lean manufacturing cell. Although not as productive as a manufacturing cell, flow lines are a good choice for some final assembly lines. (For more information about continuous flow see *Creating Continuous Flow* by Rother and Harris, 2001.)

The goals of developing and implementing a new flow-line production system at Airline were to produce high-quality parts while minimizing non-value-added work, reduce work in process, improve on-time shipment, reduce raw materials and finished goods inventories, and reduce lead times. The company sought to achieve these goals without outlay of new capital. This case study documents the company's actions to achieve these goals in the production of the selected part.

One of the more salient issues facing the company in making these improvements was doubt regarding the true benefits of lean-based manufacturing concepts supported by a forty-year history of relative success under previous management. This doubt was shared at all levels, from senior management to machine tenders. However, the company president determined that changes were necessary for the company to survive in a competitive global economy. To overcome management and employee doubts, an intensive lean education program was implemented, posters were placed in the plant to inform employees that changes were coming and discussions were initiated with all employees.

Some further resources outside of this series regarding lean manufacturing processes:

Black, JT., and S.L. Hunter. 2003. Lean Manufacturing Systems and Cell Design. Society of Manufacturing Engineers, Dearborn, MI, 336p.

MacInnes, R.L. 2002. The Lean Enterprise Memory Jogger. GOAL/QPC, Salem, NH, 166p.

Ohno, T. 1978. Toyota Production System. Productivity Press. Cambridge, MA, 143p.

Schonberger, R.J. 1982. Japanese Manufacturing Techniques. The Free Press, New York, NY, 260p.

Sekine, K. 1992. One-piece Flow. Productivity Press. Cambridge, MA, 286p.

Womack, J.P., D.T. Jones, and D. Roos. 1991. The Machine That Changed the World. First Harper Perennial Publishers, New York, NY, 336p.

Before Lean

A schematic representing a portion of Airline's original batch production layout is shown in Figure 1. Work in process parts were moved in the plant via buggies with an approximate three- by five-foot load carrying area. Parts are normally stacked on these buggies to a height of about four feet, thereby providing a total volume of about 60 cubic feet (about 1800 pounds) per buggy. Table 1 details the large number of buggy movements and the distances traveled by workers to produce 2900 of the subject part. Based on actual measured distances and the number of workers moving these parts, the total distance traveled by workers to move the selected parts between machine centers to produce the required 2900 parts was 34,158 feet, or about 6.5 miles. Only eight of 25 workers or less than 1/3, were adding value to the part as it moved through the original system.

It should be noted that the 25 workers involved in the production of the part did not spend 100 percent of

Table 1. The part movement and labor requirements in Airline's original batch processing system.

Travel Distance Using Flow Line Make 2900 each of part 146-3843							
Description	Movement Method	Pieces per Load	Number of Loads	Number of People	One Way Distance	One vs Two Way	Total People Distance
Plywood warehouse to CNC	Forklift	1104	3	1	272	1	1,632
CNC to Vertical Bore	Buggy	380	8	2	288	2	9,216
Vertical Bore to Horizontal Bore	Buggy	380	8	2	153	2	4,896
Horizontal Bore to T-nut	Buggy	380	8	2	215	2	6,880
T-nut to Clip	Buggy	380	8	2	6	2	192
Clip to Dowel	Buggy	380	8	2	139	2	4,448
Dowel to Band	Buggy	380	8	2	20	2	640
Band to Finish Warehouse	Forklift	380	8	1	173	1	3,664
Band to CNC	Buggy	0	8	1	153	1	2,448
			Total People Distance Traveled				34,158 Feet
							6.5 miles
							11.8 FT/Pc

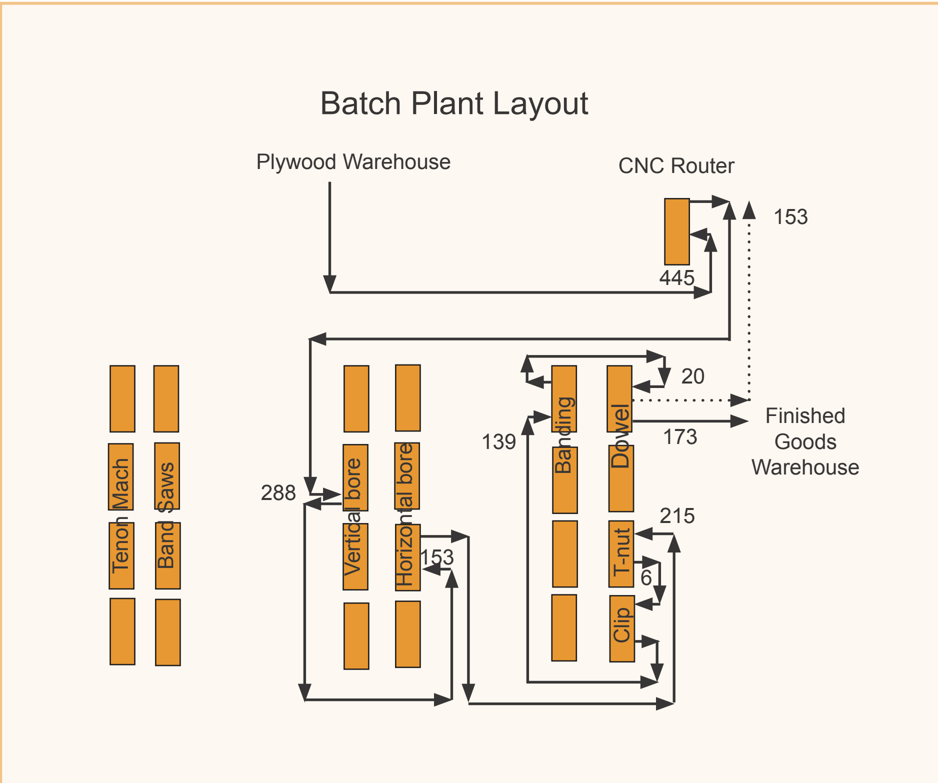

Figure 1. Airline's original batch processing flow for part number 146-3843. Only a small portion of the plant is shown. Numbers represent actual distance traveled in feet and are not to scale.

their time producing only the one part. Two workers might push a loaded buggy from the vertical boring machine to the horizontal boring machine and then help with the boring or assist at another machine or move another buggy. Likewise, a machine operator might only spend an hour or two completing a process on a batch and then move to another machine, or process another part at the same machine. Frequently, the two workers involved in moving a loaded buggy from point A to point B walked back to point A or to a different work area. The result was a large number of workers walking around the plant after delivering buggies and/or machine operators moving to another machine. After about three years of implementing lean production systems, the company reports that about 2,000 buggies have been permanently removed from the plant and head count has been reduced by about 50 percent.

Implementation of Lean

The first step taken by the company to implement flow-line production was to prepare a *product-grouping matrix*. This initial step involves analysis of the "high-run" parts, the company term for parts produced in large quantities. High-run parts represent about 20 percent of the total part numbers produced, and represent nearly 80 percent of the company's total parts volume. The matrix was created by listing part numbers in the left column with the production processes heading columns across the top. Across from each part an "X" was marked under the processes required to manufacture the part. Parts that required the same manufacturing processes were combined to form product groups. In most cases it was judged that these product groups could be produced on a flow line created by arranging the machine centers that followed the current batch manufacturing sequence. Parts within a product group could then flow between machines without the necessity of between-machine buggy parts movement, and the resultant work-in-process. An example of the product-grouping matrix is given in Table 2.

It is not necessary for all parts within a product group to require processing at every machine within the flow line. For example, a part might not require horizontal boring. To avoid the use of a buggy to by-pass the horizontal boring machine, the company simply used a 10-foot-long, wheeled gravity conveyor. The conveyor was placed in front of the horizontal boring machine and parts are placed on the conveyor after the vertical boring is completed. Gravity then carries the part past the horizontal boring machine to the T-nut machine.

Table 2. Part manufacturing operation matrix as the first step in production analysis

		Manufacturing Operations								
	Average Volume per week	Router	Tenon	Vertical Bore	Shaper	Horizontal Bore	T-nut	Clip	Band	Dowel
Part Number										
146-3843	15,000	X		X		X	X	X	X	X
146-2000	15,000	X				X			X	
146-4000	20,000		X			X	X		X	
150-1000	45,000	X		X		X	X		X	X
167-1200	39,000		X			X	X	X	X	
189-3000	21,000				X	X			X	
250-3800	16,000				X	X			X	
260-2100	12,000	X		X			X		X	X

Benefits of Lean

In addition to a significant reduction in non-value-added work, there are other benefits associated with using a flow line. In batch manufacturing, a relatively large number of parts are moved in batches between machine centers. For part number 146-3843, a batch normally consisted of one buggy containing 380 partially manufactured parts. With this batch system, when a manufacturing error occurred at one or more of the machines, frequently the entire batch of 380 defective parts passed through the remaining machines before the error became evident at one of the downstream machine centers. In the new flow line, parts are passed from machine to machine, typically a few at a time. This allows identification of manufacturing error at the downstream machine centers almost immediately after the production of only a few parts. One goal of the flow-line methodology is to continually reduce these small batches to a batch of one part—one-piece-flow—thereby reducing the likelihood of having a large batch of defective parts produced prior to discovery of a manufacturing problem. This illustrates the superiority of one-piece flow-lines. With one-piece flow lines, defects are typically detected immediately at the work station which created them or at the next downstream process.

Lean Benefits

- promotes teamwork
- improves quality
- reduces space requirements
- increases productivity
- reduces work in process
- improves order turn around time
- reduces waste and reject parts

Another interesting facet of flow-line manufacturing is that quality improves not only by reducing manufacturing errors, but also as a result of the flow-line workers functioning as a team in which each member develops responsibility for product quality. In a batch plant operating as a functional job-shop manufacturing system, machine centers are normally grouped in departments, where each department operates similar processes in isolation from other departments. As a result, workers in these departments have less concern for quality as they have little or no contact with, or control over, work produced in other departments. The mentality of "it's not my job" frequently causes one department to have no interest in the quality of product produced elsewhere in the manufacturing system. Workers tend to push product volume through the system to achieve the required production volume. Quality is often viewed as the next department's or the quality manager's problem.

An additional benefit of flow-line manufacturing is a more accurate count of finished parts. This benefit has particular significance when parts are made of wood or other materials that are not homogeneous and the material itself may contain hidden defects. Occasionally, those defects may not become evident until a late stage in the processing system. At Airline, defective parts were most often discarded without remanufacture. Production runs were normally increased by some predetermined percentage to account for those expected defective parts. If defective parts were less than the estimated amount, "extras" were made and subsequently discarded, sent to the customer at no charge, or placed in the finished goods warehouse and carried on inventory with the hope of a future order. Airline found that their new flow line was sufficiently closecoupled that a final count of completed parts could exactly match the order quantity.

As in many batch-manufacturing plants, batches were often misplaced at Airline. Such misplacements appear to have occurred when batches were moved into a department and not immediately processed. If a machine or worker was not available or work backed up for a variety of reasons, the batch was moved out of the way of other activity. As more batches of the same or other parts arrived in the department, the batch may have been moved out of the way several times and eventually arrive in a corner or some less frequently traveled area to be neglected until its shipment date arrived. When the batch was discovered to be missing (usually on the ship date), it was either found after hours of time expended in searching, or another batch was rushed through production—often requiring overtime. In either case, as the now-late part was rushed through the plant other batches were pushed out of the way and the cycle continued. With Airline's new flow-line system the above situation does not occur because upstream cells and flow lines do not produce parts until they receive a signal to produce from downstream work stations.

To clearly understand the benefits of a flow line, the following describes the change from the original batch processing at the vertical and horizontal boring machines (Figure 2) to a two-machine flow line. In the example, a

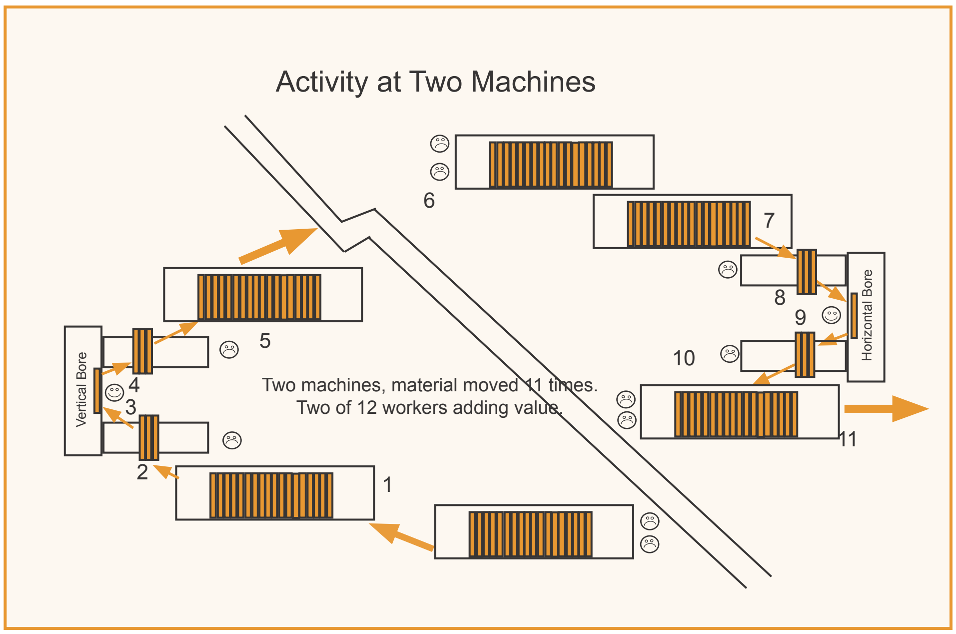

Figure 2. The original batch-processing layout at the vertical and horizontal boring machines. Smiling faces indicate workers who add value while frowning faces indicate workers who are not engaging in a value-added activity.

part must receive both a vertical and a horizontal boring operation. In the original plant layout, these two machines were located 153 feet apart. Because of the loaded buggy weight, two workers were required to move the buggy. Smiling faces in Figure 2, and in the figures that follow, indicate workers who add value as a result of their activities; frowning faces indicate workers adding no value to the product.

In our example, the process occurs as follows: two workers push a loaded buggy to the vertical boring machine. A machine operator assistant unloads the buggy and places parts on a supply table adjacent to the machine. The machine operator bores the pieces two at a time and places the finished parts on a table to be reloaded onto a buggy by another assistant. Then two workers push the buggy 153 feet to the horizontal boring machine where the same process is repeated. As shown, the batch system organization required a portion of the time of 12 workers. Only two added value to the product. The material is moved 11 times to complete these two processes.

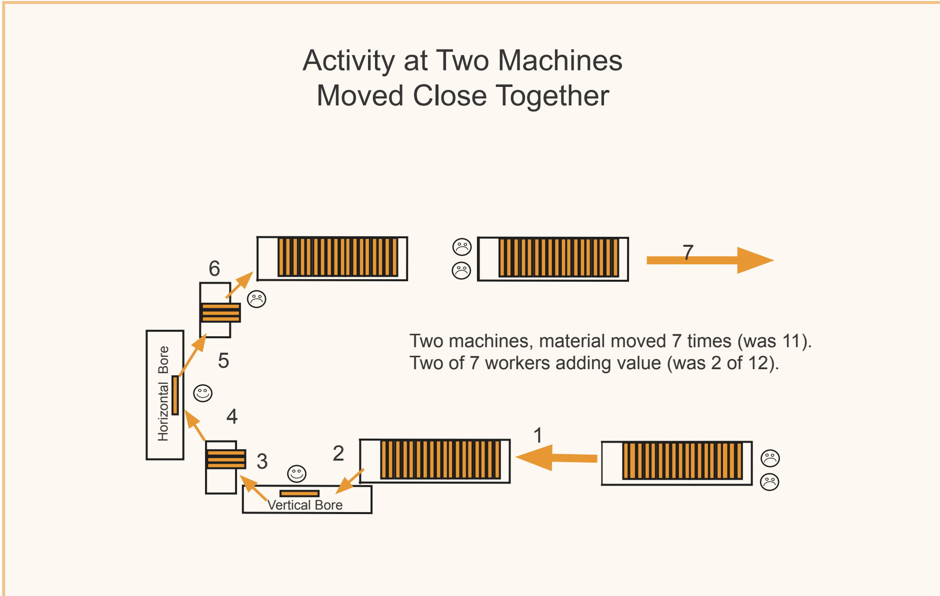

Figure 3. The layout resulting from moving the vertical and horizontal boring machines adjacent to each other.

Airline management was shown conceptually that significant improvement was possible simply by moving the vertical and horizontal boring machines adjacent to each other as illustrated in Figure 3. This proposed relocation was estimated to reduce the number of times the parts were moved from eleven to seven. Non-value-adding workers would be reduced from ten of twelve to five of seven. While this was a considerable improvement in productivity, it was obvious that significantly greater reduction in non-value-adding activity was possible by moving all the machines needed to produce the product group into one flow line.

In retrospect, this simple move may now be obvious. However, experience has shown that in typical batch plants these moves have not been easy. Company personnel often have reservations on whether lean-based flow lines will work in their particular situation. Most of these doubts probably arise based on a century of experience in processing large batches where efficiency at each single machine is the measure of success. One person operating a vertical boring machine might bore 30 holes per minute. Thirty holes by one machine in one minute is probably an efficient use of time and machinery. This measure of production, however, does not take into account the fact that at the end of the day our customer doesn't want 14,000 holes, but desires 3,000 completed parts. When we examine the productivity of the entire batch system, and not just the efficiency of a single machine, we may see many opportunities to improve the total effectiveness of the system so that we produce exactly what the customer wants—exact count, perfect quality, and on-time delivery.

Experts consider it important to include a variety of employees in the flow-line layout and location discussion when such changes are implemented (See *Leading Change* by J. K. Kotter, 1996). Weekly flow-line development meetings were held at the plant to discuss manufacturing of the product group, processes required and their location, operator workstations, tools required, etc. Many hours were spent determining the location of the flow line within the plant, its relation to future plant changes, and ancillary needs, and in balancing the work distribution among the machine operators. Work balancing is important to maintaining smooth flow through the flow line. In this respect, flow lines differ from fully implemented lean manufacturing systems, which by their nature do not require line balancing.

To assist in developing the final flow line, the team first prepared a layout drawing of the plant and equipment. Flow-line development meetings included the manufacturing director, operations director, plant engineer, plant foreman, and maintenance director. The mechanism for coordinating input from participants was to project the plant drawings onto a screen and move equipment on the drawing until a consensus was reached about the best location and arrangement. The difficulty of making the basic changes being considered was evident in the intensity of discussion within the group as all involved moved beyond their past batch processing experience.

The final-flow line concept that emerged from the group meetings is shown in Figure 4. Raw material, in this case plywood, is moved to the CNC router by a forklift directly from the raw material warehouse. Completed parts are banded in packages of 10 on the flow line and placed on a pallet to be carried by forklift either to the finished goods warehouse or, more ideally, directly to a truck for shipment. All of the workers on the flow-line are performing value-added work. Only the forklift operators are performing non-value-added work.

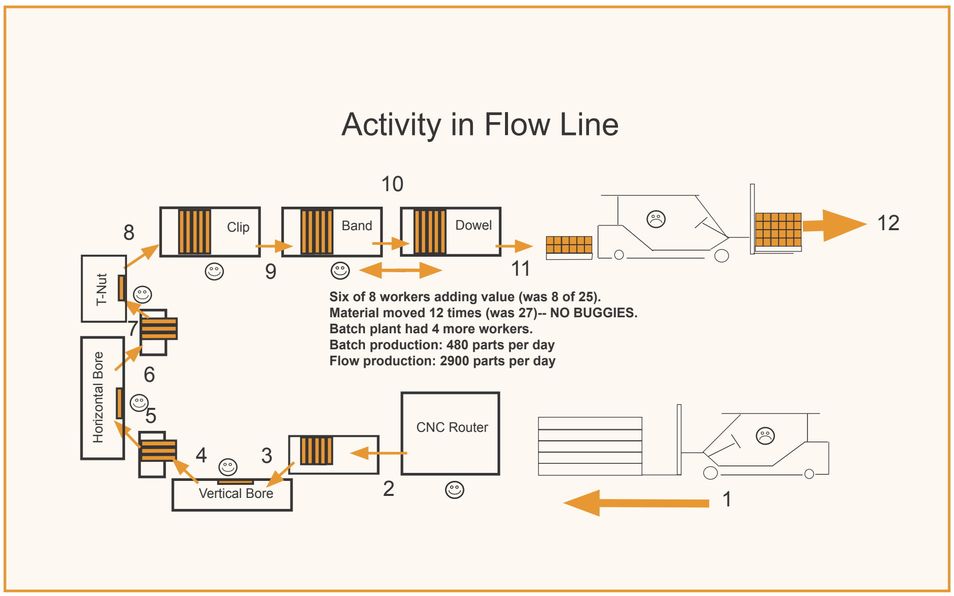

Figure 4. Airline's new flow-line includes all the operations required to complete the product-group parts.

Case Study #3

Summary

The flow line summarized in this report is comprised of a CNC router, vertical and horizontal boring machines, and a T-nut machine, followed by clipping, banding, and automated doweling machines. Raw material is delivered to a CNC router that provides shaped parts directly to the vertical boring machine. A queue area is required following the CNC router due to the batches of about 40 parts produced from each 4-by-8-foot sheet of plywood. Each of the subsequent machine operators receives parts as they are completed by the upstream operator and placed on a small table within reach of the downstream operator.

In the flow line, small accumulations of parts occur between operators as variations in individual work and the skill and speed of workers prevents the line from ever being perfectly balanced. Part accumulations between operations are not allowed above five to ten parts. And, parts are never allowed to be stacked on the floor. If accumulations begin to occur, the upstream operator steps over to the CNC router for a few minutes and assists with picking parts off the table, vacuuming sawdust or some other needed work.

Another less obvious benefit of a flow line is constant demand for work at each machine as parts are pulled away from the upstream operator. The production pace of the slowest machine becomes the production constraint. In this flow line, the CNC router is the constraint. There are always little things the other operators can do to help the CNC operator when they have a few minutes available. The result has greatly increased production from the router. Prior to the router being moved into the flow-line, two operators were required for its operation. After moving the router, the number of sheets processed by the machine per day increased approximately three times with only a single operator being assisted occasionally for a few minutes by other workers.

With the exception of the CNC router operator position, all machine operators are cross-trained to perform other jobs within the flow-line. The benefit of this cross-training is twofold:

Table 3. The transportation and manpower requirements in Airline's new flow line

Travel Distance in Lean Plant Make 2900 each of part 146-3843		
Description	Movement Method	Total People Distance Traveled
Plywood warehouse to CNC	Forklift	1632
CNC to V Bore		
Vertical Bore to Horizontal Bore		
Horizontal Bore to T-nut		
T-nut to Clip		
Clip to Dowel		
Dowel to Band		
Band to Finish Warehouse	Forklift	3664
Band to CNC		
Total People Distance Traveled:		5,296 Feet
		1.0 Miles

(1) when a worker misses a day or steps away to the rest room, others in the flow line can take over the missing person's job; and (2) the volume of product output can be adjusted by changing the number of workers on the flow line.

Lean Implementation
Plant Wide Realized Benefits to Date

- Over 40,000 square feet of floor space cleared for new uses
- Shortened order lead time from average of 5 weeks to one week (many items only 2-3 days)
- 83 percent reduction in finished goods inventory
- 78 percent reduction in raw material goods inventory
- $800,000 reduction in work-in-process
- $3 million in annual labor savings
- 42 percent productivity improvement

The reduction in travel distance resulting from this flow-line installation is summarized in Table 3. Forklift delivery of panels to the CNC router and subsequent removal of components by forklift are the only materials movement required above that provided between work stations by operators moving individual work pieces. Table 3 summarizes the comparable flow line productivity and travel distance values in the same terms as Table 1 for the previous batch system. Table 3 shows that the new flow line reduced total distance traveled to 5,296 feet from the previous 34,158 feet, a reduction of more than 84 percent. Total non-value-adding workers have been reduced to 2 from the 25 required for the batch system, a 92 percent reduction. Product is moved 12 times compared to the previous 27 times. In addition to reduction in handling and travel time, the production of component parts increased from 480 to 2900 parts per day, a 600-percent increase.

The result of the installation and implementation of the new flow line was a dramatic quality improvement, increased on-time delivery, sharply reduced work in process and finished inventory, and a large area of floor space made available for other uses. The success of this flow line has encouraged Airline to proceed with the installation of additional flow lines, cells, and other improvements based on lean manufacturing principles. These improvements have allowed Airline to permanently remove 2,000 buggies from the plant freeing over 30,000 square feet of floor space and eliminating as much as 12,000 cubic feet of work in process (about $800,000).

According to Judy Dunaway, President of Airline, when speaking of the company's lean manufacturing conversion, "We would have closed our doors by now without implementation of lean manufacturing concepts in our manufacturing processes. We are now totally committed to adhering to the key lean principle that our lean manufacturing journey has begun but will never end."

Glossary

Batch and queue operations - a manufacturing process used by the functional job shop manufacturing systems that manufactures and moves large numbers of identical units at once. Each lot of units, called a batch, moves through a queue of operations during the process of production.

Cellular manufacturing system - a manufacturing system using a one-piece flow through a variety of work-stations in a cellular way to achieve a final product. Each cell specializes in manufacturing a family of parts completely in one aspect of the production process. Machines used in cells are not "super machines" instead, they accomplish only one task in parallel. Workers check product quality, machine function, and performance with each step of production.

Cycle time - the time it takes to complete the tasks required for a work process to be completed successfully.

Economy of scope - a characteristic of lean production where a factory is capable of productivity and making a profit on a wide variety of products.

Kanban - a physical production-control system that uses cards or other visual signals to trigger the flow of materials from one part of the production process to the next.

Lean manufacturing - a manufacturing process that productively adds value to materials by capturing production processes in manufacturing cells supplied by sole-source vendors. Lean manufacturing addresses material, administration, and labor costs - including the costs of storing and handling materials within the factory.

Lean production - a manufacturing system consisting of manufacturing and assembly cells and other vital subsystems dedicated to elimination of waste. Products created using a lean production system are produced on an as-needed basis using one-piece-flow methodology.

Manufacturing cell - an area, usually "U" shaped, on the production floor responsible for manufacturing parts, subassemblies, and the end product. These cells are flexibly designed to decrease cycle time and normally consist of different machining processes arranged to produce a family of parts.

Manufacturing system - a system focused on converting raw materials into usable goods.

Multifunctional worker - a worker responsible for more than one aspect of the manufacturing process. Workers often carry out all of the processes required in a production cell in a lean manufacturing system.

One-piece flow - the movement of products through the cell one unit at a time rather than in batches of multiple units.

Pull system - a production system in which nothing is produced until it is needed by either the internal or external customer. Goods are manufactured only when they are requested by a downstream process or a customer order.

Push system - a production system in which goods are produced then stored as inventory until needed.

Stock-on-hand inventory - when labor, new materials, and process capacity is available regardless of system needs. Material within a cell is called stock-on-hand. Material between cells is referred to as work-in-process.

Takt time - the total available work time per day or shift divided by customer-demand requirements per day or shift. Takt time sets the pace of a production system to match the rate of customer demand.

Work-in-process inventory - material, usually in small batches, between cells is called work-in-process. Material within cells is referred to as stock-on-hand.

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