The Application of Lean Manufacturing and Theory of Constraints Principles in Jewelry Manufacturing Operations

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Introduction

Andrea Hill summarized the principles of Lean Manufacturing and Theory of Constraints for a jewelry manufacturing environment in a presentation at a recent Santa Fe Symposium (1). Briefly, *Lean Manufacturing* focuses on the elimination of waste in all its forms in all the value streams that flow through a manufacturing organization to generate sales revenue and profit. Value streams are all the actions that must be taken to bring a specific product to the hands of a customer. Elimination of waste will maximize available capacity, reduce costs, maximize profits, and create an atmosphere of continuous improvement within an organization.

In contrast to Lean Manufacturing, Theory of Constraints seeks to achieve organizational growth and profit by maximizing the throughput in value streams. This concept is based on the assumption that organizational achievement is limited by identifiable constraints. Theory of constraints postulates that identifying and eliminating constraints will increase throughput, decrease inventory and reduce operating expenses in a natural, unavoidable manner.

Experience with Lean Manufacturing and Theory of Constraints within Stuller's manufacturing operations in Lafayette, LA has been reviewed and analyzed. Both concepts have been found to have their merits in a complex manufacturing environment.

Stuller, Inc.

Stuller, Inc. employs approximately 1,500 individuals around the world and is a major manufacturer and supplier of precious metal jewelry products, diamonds and gemstones, and tools and supplies to the jewelry industry. Stuller employees provide their customers in the jewelry industry with the products they want, when they want them. Stuller is required to be the service, quality, price and styling leader in products it sells. Figures 1 and 2 are photographs of Stuller's Global Headquarters. Manufacturing operations are located in Lafayette, Louisiana, and Chattanooga, Tennessee in the USA and Merida in the Yucatan state of Mexico. Products are typically distributed by overnight delivery services or they are directly purchased at 11 service center locations in major US cities and Canada.

Organization

Stuller's Vice-President of Manufacturing is responsible for five operating units within the company with manufacturing operations focused on the production of gold and platinum mountings, findings, wedding bands, and fabricated metals. Figure 3 is a "traditional" organizational chart that has been constructed according to reporting relationships within the Manufacturing and Logistics Groups at Stuller, Inc. in Lafayette, LA. The manufacturing units represent various combinations of capital intensive versus craft intensive versus labor intensive processes. The manufacturing operating groups in Lafayette are described as follows.

Figure 1 - Stuller, Inc. Global Headquarters, Lafayette, Louisiana, USA

Figure 2 - Aerial photograph of the global headquarters of Stuller, Inc. during expansion to 600,000 square feet

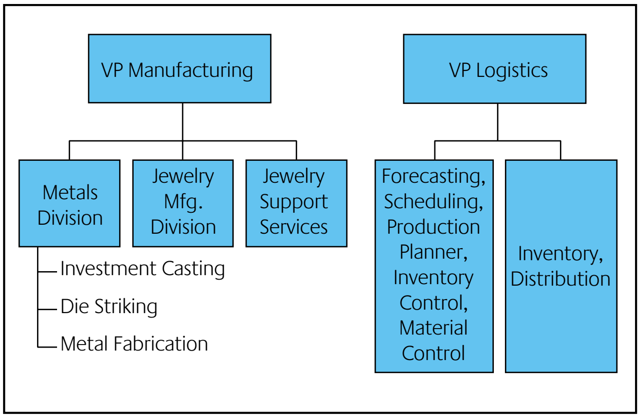

Figure 3 - A traditional organizational chart describing the reporting relationships within the Manufacturing and Logistics Groups at Stuller, Inc. in Lafayette, LA

Stuller's Metals Division includes all departments that produce high volumes of precious metal components in raw, unfinished form. Operating departments include Investment Casting, Die Striking, and Metal Fabrication. The Metal Fabrication department produces casting grain, sheet, wire, sizing stock and solder for both internal consumption and sale to outside customers. Average production of raw, precious metal components by all Metals departments exceeds 20,000 pieces per day. Stuller's Metals Division has the largest concentration of capital intensive process capabilities within the manufacturing organization.

Stuller's Jewelry Manufacturing Division receives raw, precious metal components from the Metals Division and performs all the assembly and finishing operations that are required to produce jewelry products. The Wax Department which produces patterns for investment casting is included in jewelry manufacturing operations. This division has the most labor intensive processes in Stuller's manufacturing operations.

Jewelry operations are supported by Jewelry Manufacturing Services, which produces models, injection molds and provides stone setting and new product development services. The activities performed by this group are both craft and labor intensive.

The Logistics Group is divided into two major sections as depicted in Figure 3. The Inventory and Distribution sections handle all the physical product required for shipment to customers. The Operations Management section is responsible for all the analytical functions that are required to manage the operations of both the Manufacturing and Logistics Groups.

Organizational Relationships

The interface between Manufacturing and Logistics at Stuller is critical and particularly so between the Metals Division and the Material Control Department within the Logistics Group. Material Control is the driving force for all aspects of production forecasting and planning, scheduling and monitoring, and inventory control as well as precious metal procurement and accountability for the metalworking operations within the Metals Division. Production plans and schedules to meet sales and inventory requirements are modulated on a daily and weekly basis to assure that proper resources are available to all manufacturing departments and conflicts for scarce materials, labor, and craft resources are resolved.

Figure 4 is a "functional" organizational chart that describes the operating relationships between departments in the Metals Division and the principal analytical sections within the Logistics Group. In Figure 4, the Metals departments are depicted as circles while the associated Logistics departments are drawn as ovals. The degree of overlap between the circles and ovals indicates how closely these disparate organizational elements must work together to be successful. At the start of any production cycle, Metal Fabrication and Material Control are intimately involved in scheduling, procuring, and manufacturing raw materials that are required to fabricate the components that are passed on to the Jewelry Manufacturing Division for final finishing. After this transfer of pieces, the Production Forecasting, Planning and Monitoring section of the Logistics Division provides the analytical services that are necessary to manage all final operations.

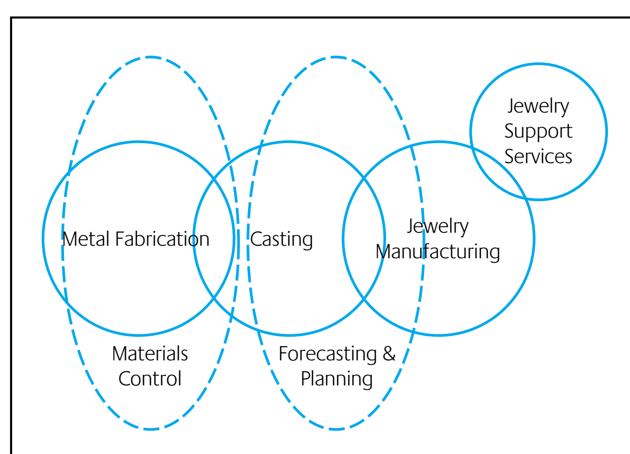

Figure 4 - A functional organizational chart between Metals Departments and analytical sections of the Logistics Group

Figure 5 - Production of 14K Yellow Gold Casting Grain at Stuller

Metalworking vs. Jewelry Manufacturing at Stuller

Within the Metals Division, production of individual parts is done on a bulk basis with no regard for specific SKU (stock keeping unit) items. For example, a production lot of karat gold casting alloy is used for casting thousands of mountings and findings and other types of components. Figure 5 is a photograph of a large lot of 14K yellow gold as it is poured and converted into casting grain. An investment cast basket setting may be used as a pendant or as any one of several different styles of assembled earrings. Sheet and strip material could be stamped into hundreds of different component SKUs. In short, Stuller's Metals Division looks like a captive supplier of material and jewelry components to the material control and jewelry manufacturing elements within Stuller. The major issues then become production at minimum costs with maximum utilization of precious metal raw materials on a schedule that is established by the requirements of jewelry manufacturing and finishing and material control.

Within the principles of Theory of Constraints (TOC) which will be discussed in detail in a later portion of this review, it will become obvious that the Metals Division could be a constraint on operations within the craft and labor intensive operations in jewelry production and finishing. The TOC response to correct this type of condition would be to elevate the constraint and optimize performance by providing all required resources to convert raw materials into components for finished jewelry production. This requirement for the highly reliable production of generic product with the best achievable quality shifts the model from TOC to Lean Manufacturing. In other words, a TOC constraint in Jewelry Manufacturing and Finishing is serviced and minimized at Stuller by the application of Lean manufacturing principles in the Metals Division.

Lean Manufacturing in Metals Processing Operations at Stuller

An obvious technique to eliminate waste to achieve lean manufacturing is to stop doing wasteful things. Many wasteful operations are performed in manufacturing operations out of simple habit. Habits are difficult to change. An organization has to identify wasteful habits for itself and develop its own methods and procedures for executing appropriate corrective actions. Some examples of actions to achieve Lean Manufacturing at Stuller will be described in the context of their capital intensity because manufacturing operations which use precious metals are so unique in this context.

Manufacturing companies invest capital to both acquire and optimize the value streams which create revenue and generate profits. Some of the results that capital investments are supposed to achieve include (1) reduction of unit costs (2) acquisition or expansion of capacity, or (3) acquisition of new or more efficient processing technology.

Using precious metals as a raw material in manufacturing adds an additional capital intensive dimension to the operations of a jewelry company. For example, fine gold ingot has cost approximately $275/oz over the past several months. This is the equivalent of about $8 million/ton. This is essentially the cost of raw material. As opposed to this, an aluminum ingot may be purchased as a raw material for a cost of about $1,000/ton. Investment costs for precious metals as work in process or product inventory require a great deal of thoughtful yet aggressive management for a company like Stuller.

With the previous facts in mind, it should be obvious that the application of Lean Manufacturing principles in Stuller's Metals Division has been pursued with some significant diligence. Operations within this Division are capital intensive on two levels. The first level is one of physical assets. Rolling mills, large melting furnaces and associated grain tanks, burnout ovens, wire drawing machines, heat treating ovens, draw benches, continuous casting machines, investment casting machines, etc., etc. are expensive to acquire and operate.

On a second level, the large, bulk quantities of precious metal that are entered into processing through this type of equipment represent very high concentrations of intrinsic value. Efficient operating performance is only achieved when these large batches of material are quickly processed into their final form and are available at the final staging location in a condition of superior quality for subsequent jewelry manufacturing operations.

Development projects at Stuller have been focused on:

1) reducing cost
2) minimizing precious metal work in process
3) maximizing the speed at which precious metal is being utilized in manufacturing operations
4) optimizing product yields in manufacturing operations and ultimately
5) optimizing usage of precious metal as finished product inventory.

Control Principles in Stuller's Metals Division

Focusing on the control of quality, cost, and precious metal accountability has helped to optimize operations within the Metals Division at Stuller. Some interesting synergism between these seemingly disparate elements has been used for some very valuable benefits.

Metal Accountability

An excellent system for precious metal accountability that is operated by Stuller's Material Control Department has been utilized to achieve traceability of material to specific parts while products are within Jewelry Manufacturing and Finishing operations. All melts are prepared and melted with identifying melt numbers. This melt number is retained with all clean, recyclable metal generated when the material is used in production. In casting operations, the melt numbers of the alloys that are used are logged for each day the metal is used. The date that a part is cast is also retained in production control records while parts are processed through the Jewelry Manufacturing Division. These date records are used to generate very accurate measures of quality levels on a daily basis. The date record also allows specific product items to be traced to a particular melt or lot of metal. Also, the genealogy of a particular melt can be constructed from the records of clean recyclable material and virgin components that have been used to formulate a particular lot of karat gold alloy.

The previous description may seem like a great deal of work. It is not. The benefits that have been achieved include a reduction in the number of individual melts prepared for use in production. A computerized database for all materials in production makes it possible to recalculate and reformulate recycled material to its original chemical composition every time it is melted to produce a new lot of production material. Every time a melt is prepared for production, the concentrations of all major alloying elements are recalculated and adjusted to assure that all alloying elements are at their original target chemistry. It is estimated that Stuller probably prepares only one-half as many melts as would be required if conventional jewelry industry practices were utilized. This reduction results in less assaying activity, and more positive control over precious metal inventory levels.

Manufacturing Cost Reductions

Investment Casting

To achieve lowest unit costs in capital intensive operations, maximum production lot sizes that are consistent with production scheduling and material control objectives are utilized. To accomplish this goal in the Casting Department, flask and mold sizes have been increased to the maximum size which will fit in a casting machine. In casting operations, a production "lot" is actually an individual mold. After effecting this change, the number of molds prepared for daily production declined by 30 per cent. Savings in investment material were also achieved in addition to the reduction in casting labor.

Metal Fabrication

In Stuller's Metal Fabrication Department, all processing is done under an umbrella of "Best Metallurgical Practice." Strict melting procedures are used for the preparation of alloys and all processing of sheet, strip, wire, sizing stock, solder, etc., is done from instructions outlined on a "Process Sheet." Every shop order travels through production on its own process sheet.

This degree of procedural control has allowed the artificial inflation of lot sizes and a concomitant minimization of unit costs. In overly simplified terms, orders for similar products are "bundled" together and one continuous piece of material is issued for all the bundled orders. At the proper point in processing, quantities for individual orders are diverted to their final configurations. The Stuller workforce has become skilled in executing the preparation and the decision making required for this type of manufacturing. Everyone cannot do it and maintain the concepts of "Best Metallurgical Practice." While Lean Manufacturing methodology has been successfully used to mange operations within the Metals Division and its operating departments, a system derived from Theory of Constraints is used to forecast and schedule production to accomplish other management goals. It's appropriate now to review how a very universal application of the Theory of Constraints has been utilized in Stuller's manufacturing operations.

Theory of Constraints

Jewelry manufacturers achieving financial success focus outwardly on the customer while eliminating waste and reducing inventory. At the same time these manufacturers face many other internal and external pressures. Shareholders insist the manufacturer be cost-effective in terms of inventories, processes, and people. Manufacturing cycle times have been under relentless pressure for reduction without any diminishment of quality.

Stuller faced these conditions and improved performance by developing a synchronized manufacturing system that was a marriage of science and art using the Theory of Constraints and Lean Manufacturing principles. A synchronized, customer-focused manufacturing process was developed where the processes were streamlined by eliminating redundant manufacturing steps and unnecessary intermediate inventories.

As shown in the functional organizational chart in Figure 4, the Theory of Constraints system impacted both the investment casting and metals divisions. This chart identifies how the various manufacturing divisions are interrelated and must be controlled by one planning group.

Principles of Theory of Constraints

TOC defines a manufacturing system as a set of process flows. These flows contain variations and are dependent upon each other. Because of these variations, all systems contain bottlenecks. In order to have predictable results, the constraining process must be in a state of statistical control.

Traditional production planning used various tools to improve performance. Control charts were developed to determine what level of performance and what degree of variability a process could maintain over a sustained period of time. A control chart describes the way a process is behaving. From it, the stability of the process can be measured.

Variation in the process is in two forms:

- Controlled variation that is stable and consistent over time and due to common causes, and is therefore predictable.
- Uncontrolled variation, which is not consistent over time and may be caused by the process itself or by external factors.

Failing to identify the source of variation leads management to inappropriate decisions. Reducing uncontrolled variation is one method of achieving continuous improvement in the system. Without the ability to predict the outcome of a process, the process cannot be managed. Applying corrective action to a constraint can create predictability that can be managed with a high level of certainty.

When an organization identifies a constraint that is out of control, it must identify the causes of the problem, such as equipment failure, material defects, or employee errors. Once these are corrected, further improvements must come from a change to the process itself.

TOC is often referred to as synchronous management or drum-buffer-rope management. The "drum" is the constraint that paces the system. The throughput of the system can only be as great as the throughput of the bottleneck. Therefore the drum or constraint provides the pace at which the rest of the production processes need to be set. The "buffer" is the protection against the variability in the system. Usually this buffer takes two forms, inventory or time.

Inventory and lead times are increased (buffered) so the manufacturing process is not impacted by the variations in the system. Buffer inventory is located in front of the constraining resource. This is to prevent the bottleneck from running out of work if an upstream process changes. Time lost at the bottleneck is time lost to the entire system. The use of buffer inventory at the constraining process is used to provide smooth, constant production flows. By level loading the facility and generating a buffer stock in finished inventory, the company has a mechanism to aid in the variations in monthly demand requirements. The "rope" is the tool that is used to put additional work into the production process so that the constraining resource will not go without work (1).

Flow control, or TOC, has been applied successfully in plants where families of similar parts follow the same sequence of operations. This technique greatly minimizes execution by eliminating detailed scheduling. The requirements to make it effective are:

- Planned production rates for running critical operations
- Tightly controlled levels of work in process
- Well defined work cells so that work can move quickly
- Clearly visible identification and dating of work in process.

Excessive work in process results from lack of effective input and output control. This causes long and erratic lead times and increases in inventory. The drum-buffer-rope manufacturing system carefully controls the flow of materials into and through the plant in an attempt to produce finished goods in accordance with market demand while minimizing inventory and operating expenses. A synchronous manufacturing system is one in which there is a smooth and continuous flow of materials moving quickly through the plant with minimal disruptions (2).

The three key concepts to lean manufacturing are pull, flow, and the elimination of waste. The pull concept requires inventories to be available at various gateways throughout the management process. It also recognizes the fact that an order is required to start the process. The philosophy behind pull has been stated as "ship one; make one". The second concept, flow, is a theory of designing processes that allow an order to proceed without stopping once it is put into production.

Finally, the third concept is the elimination of muda or waste in the system. This is not restricted to the shop floor but starts with the engineering and design of the product and includes waste in the administrative functions as well. This process looks for waste at any location and seeks to eliminate it (3).

By examining Stuller's mission, to "Provide the jewelry industry with the products they want, when they want them", it is clear that adopting a pure lean manufacturing philosophy would not be effective for cast products.

For typical production orders, the goal of manufacturing is maximum utilization of capacity at the constraining operation. Within the same environment, discrete customer orders are placed. Here the goal is not capacity utilization but minimization of lead-time in order to improve customer satisfaction.

The lean manufacturing system eliminates finished inventory. When an order is received, it uses kan-ban cards to pull the order through the system. However, in today's environment that is not what the jeweler wants. The retail customers rely on Stuller's commitment to carry sufficient inventory so they can provide next day delivery to the ultimate consumer.

For Stuller, only 3.3% of the parts (SKU's) account for 50% of the sales. A majority of Stuller products has low and sporadic demand where 65% of SKU's account for just 10% of the sales volume. However, the customers assume these SKU's will be in stock for next day delivery. In order to meet their requirements, over 50% of the inventory is used to cover this 10% of the sales volume.

Accomplishing this mission on a consistent basis is what has defined Stuller as the performance leader in the jewelry industry today. This manufacturing style and commitment to overnight delivery became benchmarks in the jewelry industry. Other suppliers have developed their own version of overnight delivery based on the Stuller model. Keeping this promise defines the Stuller name in the mind of the jeweler today.

Theory of Constraints at Stuller, Inc.

Three years ago Stuller used a simple method to determine its production requirements. A targeted growth rate in gross sales for the following year was established. Once this was determined, the same growth curve was applied to all parts in the system. From this, a master schedule (MPS) for the year was created. The master schedule fed the daily production plan and it was assumed that if the MPS was manufactured, the correct product mix would be made and the customers would be satisfied.

Fundamental principles in inventory control were not recognized using this philosophy.

- The understanding that the key to inventory management lies in minimizing the number of errors made in the forecasting and replenishment process at the SKU level, not at the aggregate level. This error results in inventories that are too low or too high, and orders released too soon or too late (4).
- Evaluating inventory management performance on the basis of arbitrarily established financial growth rates is not sufficient for effective planning. Production scheduling was done based on economic order quantities, or re-order points. This system was more directly related to financial measures and time phasing of deliveries was not applied in inventory considerations.
- Also, the process did not demonstrate an understanding that the lowest total cost is achieved when replenishment quantities reflect the best tradeoff between the cost of obtaining and the cost of carrying inventory.

Because of these issues, the system frequently released orders that were not required, and was late releasing work that was already out of stock. This resulted in increased expediting costs, high out of stock levels, excess inventory, and decreased customer satisfaction.

A strategy was developed to allow customer orders to move quickly through manufacturing, and ensure the constraint was 100% utilized, and minimize inventory costs. Improving the effectiveness of the system and determining its constraints began by defining the requirements and expectations of Stuller's customers. The key was to identify customers, needs, and the services or delivery the customers are willing to pay for. This objective was accomplished through customer surveys and reviews of customer comment cards.

From this analysis, the primary constraint on the process was determined to be the overnight delivery commitment made by the company. This required that the right inventory mix be available to an account base of 40,000 customers each day.

Within the manufacturing process it was determined that the polishing steps were the most critical steps and often resulted in the longest delays. Although the facility was structured to have an even process flow, the bottleneck was identified as the polishing process.

The first part of the strategy to solve this problem was the creation of an accurate production plan based on a reliable forecasting tool. The second part of the solution was the implementation of a manufacturing method that would dramatically decrease production cycle times.

Implementation - GAINS and Focused Manufacturing Cycles

Late in 1998, Stuller purchased software to assist in the forecasting and order replenishment process. This was the GAINS System. The selection of this software was the most critical step in the development of an advanced manufacturing planning system. GAINS is an integrated management tool providing forecast management, inventory replenishment plans, and service level optimization. GAINS software creates a forecast of production requirements using previous demand history and various statistical models. After the forecasts are reviewed and approved at the SKU level, an optimal replenishment plan is developed. This plan balances production efficiency, order-processing costs, and inventory carrying costs to produce the most profitable inventory level for each SKU, consistent with established customer service objectives (5).

The system optimizes the total of four costs:

- Procurement Cost, either manufactured or purchased
- Receiving Cost/Ordering Cost and/or Set Up Cost
- Cost of Carrying Service Stock
- Cost of Carrying Cycle Stock

Procurement costs are the cost of the item and remain constant or decrease if quantity discounts are offered. Receiving costs are the direct cost associated with ordering and receiving one shipment. Carrying costs for service stock increase as higher levels of customer satisfaction are required. This is because higher service levels generate larger quantities of service stock. The carrying cost for cycle stock is that part of the stock that satisfies demand. As replenishment quantities increase, the average cycle stock increases and the cost of carrying it.

The forecast optimization process is done by the system selecting the model producing the smallest MAD (mean absolute deviation). MAD is calculated by summing the absolute value of the forecast errors. A large MAD means that there is a relatively large forecast error. A low forecast error is indicative of a highly reliable forecast. Typically, the larger the demand for a SKU, the smaller the MAD, and therefore less service stock is needed.

With modifications made by the programmers, the system is updated daily instead of weekly. This provides the advantage of immediately identifying changes in inventory and adapting the manufacturing plan to these changes. Response time for customers has been reduced from 5 days to 1 day for significant changes in either sales or inventory.

A replenishment plan based on this forecasting methodology used in GAINS has several benefits.

- Actions are recommended at the SKU level based on inventory position and future demand projections.
- Constraint optimization and level production are developed based on customer needs.
- Critical inventory problems are highlighted and recovery plans are defined.
- Total system costs are minimized.
- Predetermined customer service levels are achieved so the jeweler can have what they want, when they want it at the least cost (6).

The goal of service level optimization is to provide a target level of customer service while simultaneously keeping inventory replenishment and safety stock investment to a minimum. The key used in GAINS to optimize customer service levels is the PIPE or Projected Inventory Position Evaluation. PIPE is the time-phased projection of each item's inventory stock level. This number is the inventory available at the end of lead-time for additional orders.

The system tries to maintain a balanced status. This means that all demand is satisfied but no excess or shortages exist. Under-stocked items are items with insufficient inventory to cover requirements. This condition will result in lost sales and increased expediting costs. Overstocked items have more material than is required. This will raise carrying costs. Balanced items are those where the stock meets the requirements, with no excess or deficit, and PIPE = zero.

This function provides the needed insight into the replenishment process by projecting future requirements on an individual item. The time-phasing process for the replenishment of orders was a significant improvement over the reorder point system.

Several developments were subsequently made in GAINS to enhance the scheduling of resources at the constraint. Advances in finite capacity planning, multi-supplier selection, price break optimization, and new item demand planning were introduced. These allow Stuller to maximize throughput and simultaneously minimize costs related to inventory pre-building in times of excess capacity, for future periods where insufficient capacity exists. Capacity is defined in terms of the constraining process, and the system defines lot sizes and supplier/production line mix that will optimize throughput and still achieve desired customer service levels.

It was recognized that producing and shipping non-stock items on a reduced cycle time was necessary for Stuller customers. Specific customer orders and non-stock items are now processed with a manufacturing sub-system called Fast Track. It was estimated that 95% of the total cycle time was composed of wait time. Reducing this provided the ability for Stuller to cut its cycle time on customer orders by ten days or 66%.

On a typical day about 95% of the pieces that are released to production are for replenishment or building of ready to sell inventories. The remaining 5% of the releases are for customer-specific orders. This relationship presented Stuller with the opportunity to develop the Fast Track Manufacturing system now currently in use. The lead-time for a finished mounting three years ago was twelve to fifteen days. This was unacceptable to the customer base. At the time it was not feasible to increase capacity sufficiently to reduce the cycle time on the entire product line. Under this concept, two cycle times for all SKU's were developed. One cycle for piece if it was being made for a stock order and a shorter, Fast Track cycle, if the piece was being made for a customer order.

This process allowed the majority of the work to process at a normal pace but it also separated the customer pieces to run through special handling and be completed quicker. These teams inspect their own work and thus eliminate several administrative steps in the process, as well as reducing wait time. With the Fast Track manufacturing, customer orders are completed in five days instead of fifteen days.

One of the strengths of Stuller is flexible resource planning and control. However, the price of achieving the flexibility needed by the customer is a higher level of inventory. Adhering to this system is contrary to the principles of lean manufacturing but has proven effective for Stuller. The Fast Track concept provides a tool to achieve the conflicting goals of maximum capacity utilization and selectively reduced lead times for specific orders. The Fast Track or focused factory concept integrates and synchronizes people, processes, and systems with the principles of flow manufacturing. It enabled Stuller to manufacture at lower costs and provide a variety of products in a very short delivery cycle time.

Results - Metal Working

Product quality is under continuous scrutiny, observation and evaluation at Stuller. Quality reporting is done in two time frames. Daily reporting is done to provide a "snap shot" of quality. The number of pieces rejected for operator or process failure are monitored and reported as a percentage of the total number of pieces entered into work that day. This is an average measure of what is happening in manufacturing.

After all pieces that were submitted on a particular day are completed, a more refined evaluation of product quality is performed. For investment cast product, the date that a piece was cast is used as a reference point. All data for product failures that occurred on that day are collected, summarized by department and cause for failure. In this manner, product failures are linked to a particular lot of metal, changes in process parameters, or unusual changes in manufacturing conditions due to unexpected, external conditions. Rejected product represents waste, and causes for product rejection are under continuous review so appropriate corrective actions can be taken.

Unit production costs for batch operations decline as batch size increases. This suggests that process lot sizes should be as large as possible, consistent with production demand, equipment capacity, and the carrying costs of precious metals inventory. In casting operations, for example, trees should be made as large as is practical.

Practices that result in products of superior quality are routinely used at Stuller. Efforts to develop new practices, which improve quality, are ongoing. The waste that is contained in a rejected item represents wasted labor, material, and manufacturing capacity.

As a consequence of efforts to eliminate waste in metals processing operations, practices used for preparing and processing karat gold alloys for production are different from practices used throughout the jewelry industry.

As a result of superior metal tracking and monitoring, only about one half as many melts are formulated, weighed and melted at Stuller, as compared to the number which would be required if more traditional jewelry practices and procedures were used.

Investment casting has been under the most intense scrutiny in the jewelry industry at Stuller. As a result of this scrutiny, a grain refined 14K yellow gold casting alloy was developed in September 1999. Many companies in the US jewelry industry use silicon deoxidized alloys that are not suitable for grain refined alloy practices. Besides impacting manufacturing, grain refining resulted in a 14K yellow gold alloy that was 25% stronger and 45% more ductile when evaluated by standard mechanical testing, compared to silicon deoxidized 14K yellow gold which contained only 200 - 300 ppm of silicon.

Casting Operations

Internal measures of performance are useful, but the ultimate judges of performance are Stuller customers. Each month, a questionnaire is sent to seven percent of the customers who received a shipment of product from Stuller during the past month. Customers are requested to answer a series of 13 questions.

This measurement reflects customer opinion rather than management's perspective of its own performance and tracks what the customer wants to receive, not what the company wants to offer. Measurements in several key areas of the questionnaire are identified here

Chart 1 reflects the customer's opinion of our performance regarding next day delivery. Figures for 2001 show results

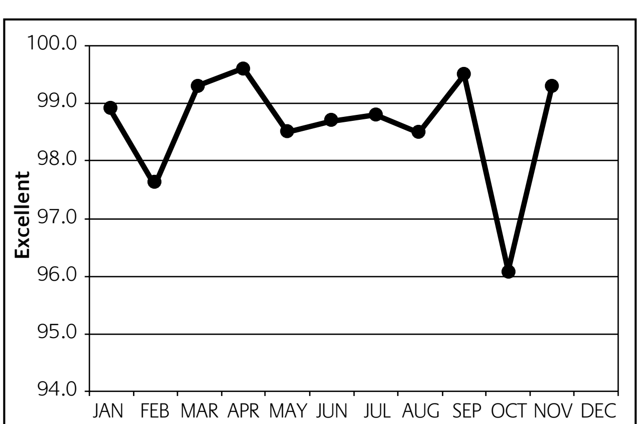

Chart 1 - Customer survey on-time delivery

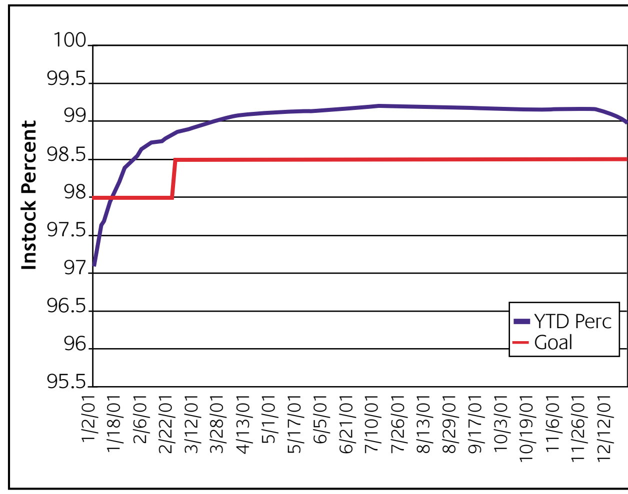

Chart 2 - YTD average daily instock position

consistently above 98%. The 98.6% YTD average is above our target of 98.0%. With the introduction of the Fast Track Manufacturing system, the average time a SKU is out of stock is three days. On time delivery for the SKU's that comprise the top 50% of sales are typically above 99.5%. Because of this, customers can rely heavily on Stuller and thus rank them very high in this area.

Chart 2 is Stuller's internal measure of in-stock performance for inventory. These results are consistent with the customers response and the 99.02% achievement reflects the synergism of the Sales, Logistics, and Manufacturing groups at Stuller. The Logistics group has classified the SKU's into ABC categories in order to focus activities on those SKU's the customer requests most often. A weighted average for this group places five times the emphasis on a class A item for example than a class C item.

The in-stock position shows that if 98.5% of the SKU's in our inventory are in stock, it would expected that 1.5% of the customers who call would be told that the item they requested would not be available for over-night delivery.

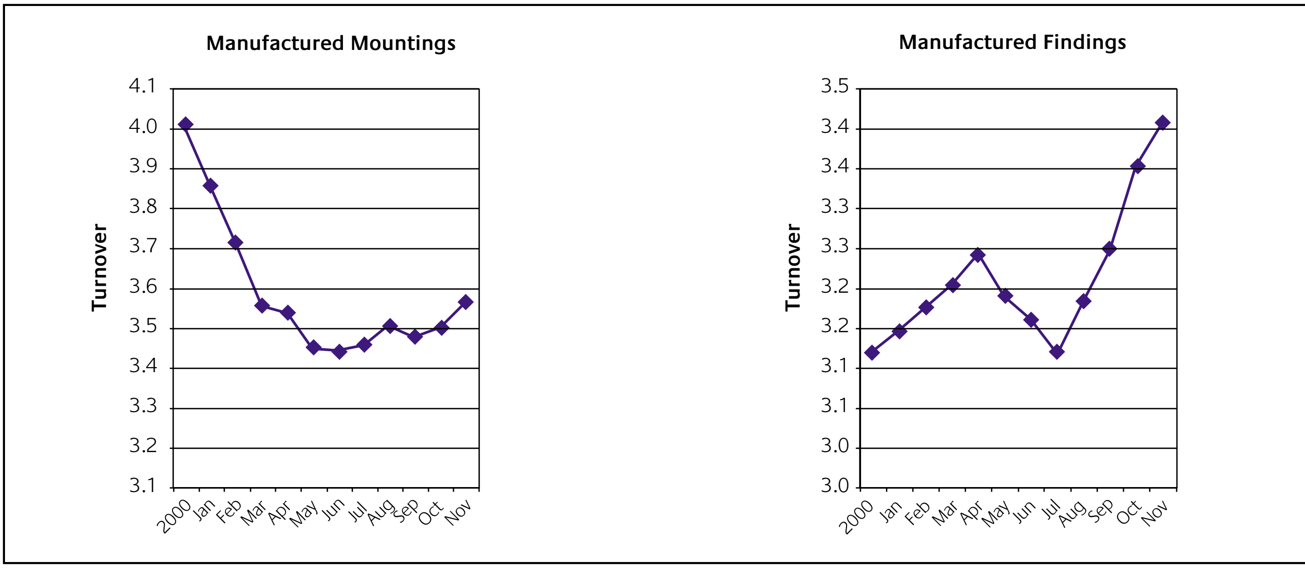

Chart 3 - Inventory turnover

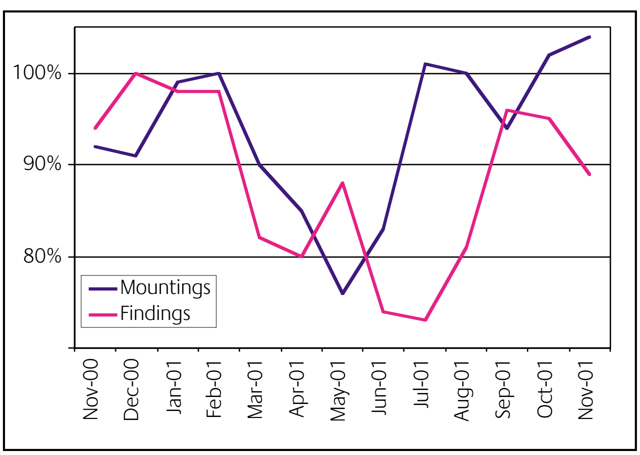

Chart 4 - Plant utilization

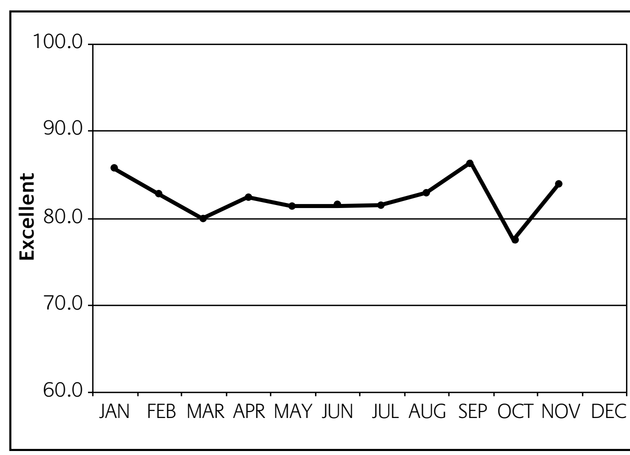

Chart 6 - Value for money

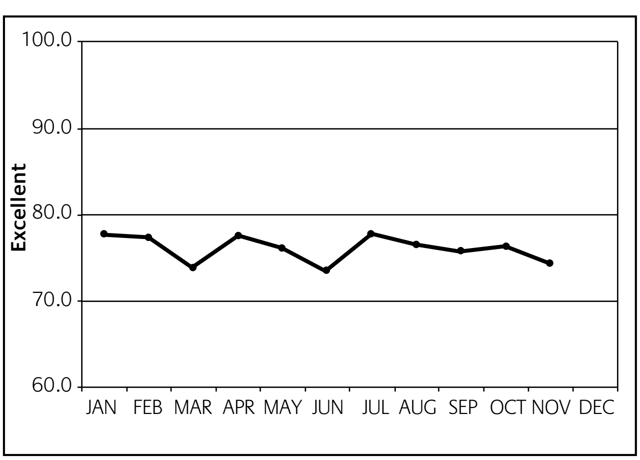

Chart 5 - Product quality

Expediting has also been reduced with the introduction of these processes. Costs for this group reduced 12% in 2001 with the implementation of the Fast Track system. This was a dramatic improvement for the customers. Sales improved and customer satisfaction increased due the introduction of this process.

The next chart, Chart 3, shows turnover rates for mountings and findings. The 2001 recession caused inventory turnover in mountings to decrease until excess inventories could be consumed. Inventory was reduced sharply through the end of 2001 due to improvements in GAINS forecasting. Even with this reduction our ability to meet customer needs improved this year. In fact our in-stock position was 3.2% better at the end of December 2001 than at the end of December 1999.

Through the use of accurate forecasts and focused manufacturing principles, Stuller was able to move quickly back to acceptable in-stock levels after the 2000 Christmas season. It now only takes 14 days to return to the 98.5% in-stock goal compared to 45 days just three years ago.

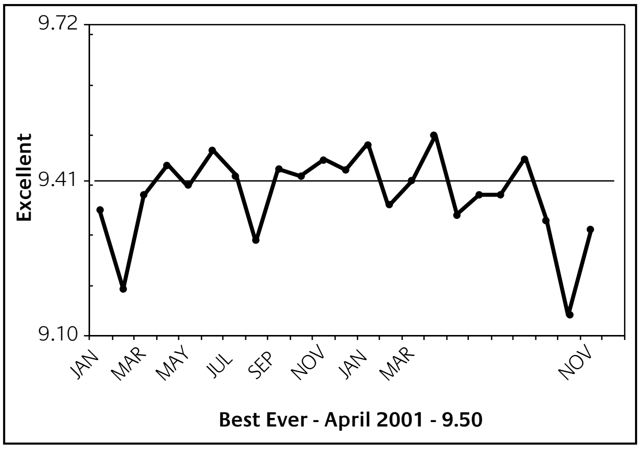

Chart 7 - Customer satisfaction

Utilization for the factory is shown in Chart 4. The drop in the second quarter was a strategic decision to reduce inventory balances. Overall the 94% and 87% averages reflect the ability of the GAINS system to maximize throughput while still working to minimize total system costs. A combined utilization for the factory is running at 97% for the December and January of 2002.

Chart 5 indicates the customer's perception of the quality of the products offered. This question asks respondents to rate Stuller quality as poor, fair, good or excellent. During the period January 1999 to October 2001, between 72 and 80 per cent of respondents rated Stuller quality as good or excellent. In October 2001, over 98% of respondents rated Stuller quality as good or excellent.

Chart 6 is the customer's assessment of the value of the products offered by Stuller compared to the price paid. This helps to determine if the customer believes the prices meet their expectation for the quality, service, and overnight delivery offered to them. Often a customer will rank Stuller company less than excellent in a specific area and yet perceive the company as an excellent value on an overall basis.

Last, in Chart 7, is the overall satisfaction index of Stuller. The 9.37 weighted average for 2001 is significantly greater than other firms using the same index. This index seeks to determine an overall assessment of Stuller's performance from the customer's viewpoint.

Conclusions

Market forces and corporate policies created a unique set of opportunities for the manufacturing group at Stuller, Inc. The marketing philosophy of the company is let you order with the expectation that you will have delivery the following day. In order to meet this challenge, inventory must be available in the finished form in order to ship immediately. This approach is contrary to the principles of lean manufacturing.

Lean manufacturing is broad in perspective in that it requires you to work to remove waste throughout the company. TOC requires you to focus on only waste at the bottleneck. At Stuller, Inc., concentrated effort is focused on eliminating waste at the bottleneck. The prioritization defined by the TOC system allows Stuller to effectively use its resources to optimize throughput. While the TOC system sub-optimizes financial results for cost centers other than the bottleneck, it optimizes the entire chain by assuring maximum utilization of the constraining resource.

Lean manufacturing works best in a market with relatively stable demand that is largely for replenishment. In contrast, a Fast Track manufacturing system recognizes that variation may be inherent in certain environments and makes itself available to meet that demand. Looking to the future it is probable that the marketplace is moving toward more specialization and individually tailored products which will require the Fast Track response in manufacturing.

Lean manufacturing is applicable in the metalworking operations that are capital intensive and not contingent upon a single customer order. Preparing casting grain melts is done with a lean inventory system. Inventory is minimized and often turns in less than a week.

In cast production, operations are labor intensive and grouped in small lots. The demand is comprised primarily of stock replenishment and to a lesser degree, customer orders. A push system is best suited for this process. Forecasts can be determined for the production required and a production-planning tool can be used to monitor releases. With the adoption of the Fast Track system, the company can react to customer needs and provide a superior level of customer service.

The model developed at Stuller has become the standard in the jewelry industry for others to achieve. It has created a habit for success in the organization and fosters what Matthew Stuller calls "a passion to serve" and a "desire to delight the customers".

Stuller, Inc. is a world-class manufacturer of precious metal jewelry and fabricated metal products. By using a combination of the best of lean manufacturing and the Theory of Constraints management systems throughout the organization, these have improved customer satisfaction and reduced manufacturing cycle times. Stuller applies the best concepts of Lean Manufacturing and TOC in one operation to be the benchmark for quality and delivery in the jewelry industry today.

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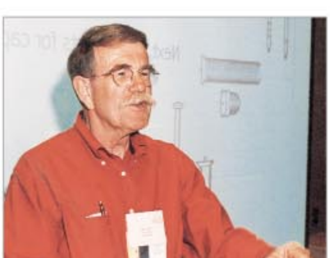

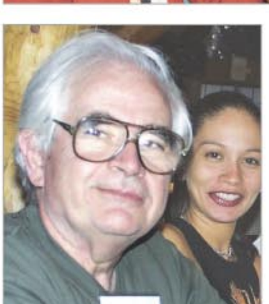

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