Title of manuscript:

"Developing Production Efficiency Through Lean Manufacturing"

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Structured abstract:

Purpose of this paper:
To report on the successful application of lean manufacturing principles at a large, international electronics company.

Design/methodology/approach:
Faced with increased global competition, this organization needed to improve the production efficiency of anvils, a critical component in its manufacturing of electrical connectors. Its traditional economies of scale operation was no longer competitive. Manufacturing engineers, plant leaders and machine operators collaborated to develop strategies designed to eliminate waste from the production system.

Findings:
Lean manufacturing can enhance flexibility, reduce lead times, increase profits and boost market share. Our experiences showcase the powerful benefits of these approaches, specifically as they apply to the electronics industry.

Practical implications:
Rather than investing in new technology or completely reorganizing corporate operations, our practical application demonstrates that successfully integrating lean approaches can result from new ways of conceptualizing the product as it flows through its value stream.

What is original/value of paper:
This paper offers practical assistance to managers of organizations that wish to become leaner. These findings can also be used as a pedagogical case study in operations management courses.

Keywords: Case study - Lean manufacturing, Process improvement, Electronics industry

1.0 Introduction

Womack, Jones and Roos (1991) coined the term lean manufacturing or lean production to refer to a set of innovative techniques developed at Toyota manufacturing plants in Japan. They chose the word “lean” since, quite simply, lean manufacturing initiatives use less resources as compared with traditional mass production approaches; namely, less on-site inventory, less product development engineering hours, and so forth.

Lean production entails teamwork, communication, continuous improvement and an endless quest for overall perfection. It represents a mean by which overall business and engineering processes are organized. It is typified by an enhanced emphasis on product quality and an integrated overall approach to the various aspects of manufacturing. As explained in Shah and Ward (2003), its fundamental thrust is to create a streamlined system that provides output at the pace of customer demand with little or no waste. In the end, successful applications of a lean manufacturing strategy ought to provide greater flexibility, reduced lead time, improved speed in order processing, smaller batch sizes and increased profits.

In this paper, we report on the experiences of a particular company in the electronics industry that underwent the transformation from a traditional, economies of scale operation to one characterized by lean manufacturing principles. As will be illustrated throughout our study, this improvement did not result from an expensive capital investment in new technology, nor did it require massive corporate reorganization. In reality, it involved a new way of conceptualizing the product as it flowed through its value stream.

The rest of our paper proceeds as follows. In the next section, we provide a review of pertinent literature detailing lean manufacturing efforts, and then offer a description of our company background in section 3. After that, we illustrate our respective improvement approaches for applying lean principles in practice, followed by the results of these efforts in section 5. We finish the paper with a few summary remarks.

2.0 Literature Review

To help facilitate an understanding of lean approaches, Womack, Jones and Roos (1991) established the International Motor Vehicle Program. This effort was created to conduct a thorough study of Japanese manufacturing techniques. Indeed, the authors felt that the American automobile industry was still using mass production techniques originally designed for early 1900's manufacturing systems. Such an approach was no longer competitive with highly innovative Japanese procedures.

They analyzed real-world manufacturing by surveying 90 automotive assembly plants in 17 countries, comprising about half of the entire world's assembly capacity. Their team of academic and industry specialists devoted five years to researching the differences between mass production and the "Toyota Production System". Ultimately, they described how organizations of all kinds (not just automobile manufacturers) could make the transformation from mass to lean production.

As lean manufacturing experienced its conceptual genesis in the automotive industry, it is not surprising that other researchers have explored lean applications in this area. Braiden and Morrison (1996) analyzed lean initiatives at a General Motors production facility in Oshawa, Canada. An important component of the manufacturing system improvement efforts in this study involved locating the bottleneck resource. Once it was pinpointed, a major cost savings resulted. They enhanced equipment uptime as fewer breakdowns occurred. Indeed, operations ran much more smoothly.

Klier (1995) showed that the increased use of lean manufacturing systems in the U.S. has precipitated a rearrangement of the geographical distribution of suppliers. He performed a detailed analysis of the supplier networks of eight U.S. auto assemblers and determined that suppliers are opting to locate in closer proximity to particular assembly plants. Presumably, this would facilitate closer relationships and more frequent interactions between these two parties.

As the electronics industry forms the specific environment for this lean manufacturing case study, we note that others have explored lean applications in this industry. In particular, Mason-Jones, Naylor and Towill (2000) investigated the design and implementation of "leagile" supply chains. This term combines the separate - though related - concepts of leanness and agility. The former concentrates on eliminating non-value added activities, while the latter focuses on acquiring enhanced efficiencies via production technology breakthroughs. The authors showcased the manner in which such notions could improve real-world electronics product supply chains.

Our lean production case study investigates an item with particularly low volumes on an individual part number basis. The examination of lean principles in such low volume applications has been considered in previous studies. Lang and Hugge (1995) discussed these applications in the U.S. aerospace industry. In helping this industry adopt lean initiatives, the authors concentrated on the importance of concurrent engineering and tool minimization. The latter concept suggested that constraining product design to the use of common tools would enhance efficiencies. Jina, Bhattacharya and Walton (1997) further elaborated on the application of lean manufacturing principles in the high variety, low volume sector.

Lean manufacturing analysis would be incomplete without the actual execution of these principles in practice. To develop a broad understanding of implementation issues surrounding the use of lean or just-in-time manufacturing, White and Prybutok (2001) surveyed over 1,000 middle and upper-level managers with hands-on experience in this manufacturing environment. Such individuals possessed the requisite extensive perspective on their particular organization's activities and its associated lean implementation concerns. The authors found that repetitive production systems appeared considerably more progressive in their realization of just-in-time or lean practices than their nonrepetitive counterparts.

Shah and Ward (2003) examined the effects of three contextual factors (plant size, plant age and unionization status) on the likelihood of implementing various lean manufacturing practices. Basing their results on over 1,700 surveys of plant managers, plant leaders and manufacturing managers, the authors determined that plant size strongly influenced lean implementation. The impact of the other two factors was less pronounced.

In order to reap eventual success with lean manufacturing efforts, Lathin and Mitchell (2001) contended that one must carefully consider the underlying social issues within a production system. Indeed, managers must judiciously integrate an organization's social factors and the technical capabilities involved in lean approaches. The authors developed a Lean Implementation Planning Matrix, a tool to help determine those specific personnel or cultural factors that could be problematic in lean production initiatives.

Effectively managing the "human capital" component of any lean manufacturing endeavor is extremely important. Needy et al. (2002) identified those critical skills required for groups of employees to productively implement lean practices. Ultimately, successful recognition of such skills could help develop training initiatives, alter hiring practices, allocate workers, and establish compensation systems. To substantiate the value of their analysis, the authors implemented their approach at the Industrial & Commercial Controls Group of the Eaton Corporation (Beaver, PA).

Smeds (1994) explored the management of the evolutionary processes required in an organization's transformation towards a lean enterprise. Beginning with the articulation of an overall strategic vision, the author showed that a participative process is required to identify problems and opportunities and eventually implement desired changes.

We note the impressive results obtained with lean initiatives within several manufacturing industries. Nonetheless, it is rather encouraging to observe the robust applications of these principles in service sector operations. Womack and Jones (1996) provided a thorough analysis of the steps involved in transforming any organization, specifically those in service industries, into a lean enterprise. Swank (2003) reported on the successful application of lean principles at Jefferson Pilot Financial (JPF), a full-service life insurance company. Processing time (the interval between insurance policy application until new policy issuance) and cost per application experienced considerable variation within JPF's office locations. Errors in the policy creation process were especially problematic, as up to 10% of all applications required some level of reworking. Using lean initiatives, the company halved the average time from receipt of application to policy issuance. Labor costs were cut by 26% and the company's error rate fell by 40%.

3.0 Company Background

Tyco Electronics, formally known as AMP Incorporated, is the world's largest electrical connector company. The Global Application Tooling Division (GATD) is a department within Tyco Electronics. As the focus for this specific study, GATD is responsible for engineering and manufacturing machine equipment that permits customers to crimp electrical connectors onto wire. Customers who purchase electrical connectors depend on GATD to supply them with equipment that meets their specific wire processing needs. Such equipment ranges from hand tools to bench-sized equipment operated by a foot pedal to automated machinery capable of producing 4,000 wire harnesses per hour.

This particular lean manufacturing case study focused on a specific piece of equipment called an applicator. Figure 1 offers a photograph of an applicator. These items have been engineered and manufactured by our division since the early 1960's. In the past 40 years, well over 3,000 types of applicators have been designed in numerous countries including the United States, Great Britain, Germany and Japan. An important part of the GATD production process, applicators contribute approximately 68% of the division's earnings before interest and taxes.

===== take in Figure 1 =====

An anvil is a critical component of each applicator. Anvil photographs are supplied in Figure 2. In the electrical connector manufacturing process, the two items that actually perform the crimping action to crimp an electrical connector onto a wire are a crimper and an anvil. The anvil is the most unique component of an applicator since it is specifically designed to match the profile of a particular connector, and therefore cannot be used on other connectors. Owing to the fact that the company has produced thousands of applicators, and since anvils form a unique component of each applicator, it ought to come as no surprise that there exist thousands of different anvil part numbers. Regrettably, as applicator and anvil production have evolved over the past four decades, there has been minimal coordination between different countries with respect to design standards. Each country designed their own anvils and had them manufactured locally.

===== take in Figure 2 =====

Since the anvil is the most distinctive part of an applicator, the delivery of the applicator most often depends on the anvil's lead time. The GATD ships approximately 660 applicators a month, while the factory manufactures approximately 1,050 anvils each month. Although the division keeps a small number of applicators and anvils in stock, the majority of our production is make-to-order.

Traditionally, our division's manufacturing philosophy involved an economies of scale approach to production. In reality, we evaluated the efficiency of each operation in a product routing instead of determining the efficiency of the entire value stream. This led us to manufacture only those anvils that had sufficient annual usage to justify the concomitant time investment in production control, engineering and factory floor operations. Essentially, we viewed our manufacturing process to be uneconomical for anvils with annual usages less than five units. As a result, the division only manufactured 256 specific anvil part numbers, while the remainder (numbering in the thousands) were purchased from outside vendors.

Our lead times for manufactured anvils was 5-6 weeks, while the lead time for those parts procured from outside sources was about 2-3 weeks. We relied on vendors to supply anvils that were needed for certain make-to-order applicators, as well as to provide spare parts orders. In the end, this contributed to the relatively large lead times observed for applicator delivery. We offered a 4-6 week lead time for make-to-order applicators, while newly-designed units could experience about an 8-12 week lead time. Since we comprised the largest connector company in the world, we felt comfortable that customers would accept our delivery times for tooling equipment.

A dramatic change subsequently occurred in our competitive environment. In March, 2000, a small European company began offering customers 2-week delivery on any applicator. The quality of the applicators was nearly equal to ours, while the costs were in the same range. Since lead times were significantly shorter with our competitor, we feared a loss in competitiveness. Indeed, our business office began receiving word from the European sales force that we were losing business to this new competitor. Loyal customers began asking our sales force why we were unable to match the new competitor’s delivery time. Apparently, many of our customers valued short lead times, even if it meant a little less durability and a little more cost. In truth, we needed to become lean and shed the vestiges of traditional, economies of scale production. The business office informed our division that we needed to reduce the delivery time on all make-to-order applicators from 4-6 weeks to 10 days. Moreover, the delivery times for newly-designed applicators were to be slashed from 8-12 weeks to 3 weeks. This translated into a lead time reduction for anvils to 2-6 days for every existing anvil part number. Since the vendor’s lead time was 2-3 weeks, our division needed to be prepared to make thousands of part numbers we had never previously manufactured, in addition to producing our original 256 anvil part numbers much more efficiently than before. Such directives from our business office spurred the development of various improvement approaches as reported in the next section.

4.0 Improvement Approaches

In order to make all anvils in 2 to 6 days, we required the cooperation of every function in our division, including production control, manufacturing engineering, product engineering, factory supervision and operators. In essence, we began to realize that the total efficiency of the entire process was more important than the efficiency of each isolated function and department. To reduce lead time, we had to reduce several forms of waste from our value stream; namely, waiting time, transportation time and wasted motion.

The left-hand column of Table I lists the 17 activities required in our traditional anvil production process. The largest contributor to the lead time of anvils was the heat treat operation, performed at another factory located two hours away in Virginia. This particular step in our process took two weeks since it required time to prepare and receive the shipment at each location and a one-day transit time existed to and from the Virginia factory. Further, the heat treat work center usually had a lengthy queue due to the large volume of parts it processes.

===== take in Table I =====

Perhaps our most significant change involved converting our current anvil production system to one that started with blanks that were already drilled, tapped and heat treated. Thus, we could forego many of the activities (shipping, receiving, heat treating at another factory) that previously consumed plenty of resources. Figure 3 provides examples of heat-treated blanks prior to the grinding operation, while Figure 4 illustrates partially completed units in the anvil grinding machine. Manufacturing all anvils from heat-treated blanks permitted us to store blanks in inventory that only required blank grinding, final grinding, blackening, laser marking and inspection before they were ready to be shipped to a customer or assembled on an applicator. We had resisted this method of manufacturing anvils in the past since it was felt that it prohibitively increased the cost of production, despite the dramatic reduction in lead time. In the right-hand column of Table 1, we provide the resulting steps in our more efficient, leaner manufacturing system. Where possible, we match particular activities in the lean column to its corresponding lead time component under the traditional process.

===== take in Figures 3 and 4 =====

After performing this initial conversion in our production process, the challenge still persisted to make the other operations flow as quickly as possible and to identify the remaining waste in our value stream. As an aside, we note that our improved process migrated to its present state in several stages. An important benefit of continuous, incremental improvement is that each advancement revealed new waste that could be targeted for elimination. The managerial and engineering knowledge obtained during a particular improvement step guided us to the next stage, which in turn propelled us even further in our progression. Indeed, this work of improvement continues to this day.

Before initiating our improvement project, it took approximately two hours to perform the task of processing an anvil part number in manufacturing engineering. The process involved creating two programs for the anvil grinding machine, as well as a tool sheet for the operator and a bill of material. In order to efficiently process hundreds of new anvils, we needed to simplify and standardize this engineering effort. We began by asking the operators for suggestions regarding paperwork reduction. Surprisingly, the operators informed us that they usually failed to use all the programs we were generating, since it caused them to input tool sizes for every factory order. Instead, they called down a particular program, left it in the machine and simply changed the dimensions for each new factory order by directly inputting the specific values from the print. We learned, consequently, that we did not need to create the new programs and tool sheets as we had previously. We worked with our talented group of operators to identify four categories of anvils. Then, we created a sheet that listed the program numbers that could be used to grind the four different anvil types. Eventually, this work spawned additional improvement as one of our operators combined all four of the programs into a single program that could be used for all styles of anvils. Paperwork reduction and process simplification reduced the setup time at each machine as well as processing time from two hours to just ten minutes. Quality was not sacrificed.

Another initiative involved drastically improving the process of getting a particular order to the factory floor. Traditionally, this required several days. The process of scheduling and printing a factory order, printing the quality inspection plan (QIP), pulling the parts and delivering them to the first grinding operation was too complicated and time consuming. Initially, we standardized the process routing and made blank copies that could be manually completed; we also developed a standardized QIP that could be manually prepared. This solution delivered factory orders to the first grinding operation in approximately two hours instead of two days. Admittedly, it was an extremely hands-on solution that required a great deal of our time, but it was the only way we could achieve the desired lead time reductions. Subsequently, we have learned new ways to manipulate our computer system to eliminate the need to write the factory orders and QIP's by hand. As it turned out, our willingness to process the factory orders by hand (as a first step solution) allowed us to achieve our delivery goals. Further, it showed us the issues that we had to solve to get the factory orders to the first operation as efficiently as possible.

We reduced factory lot sizes to less than five units. Many people in our division wanted to continue issuing factory orders involving our traditional lot sizes of five pieces because of apparent economies of scale, even though the customer may have ordered only two units. Indeed, they were solely examining the efficiency of the grinding operations while failing to consider overall system efficiency. Had we continued to issue five piece orders, we would have undoubtedly encountered the downfalls of overproduction (increased work-in-process (WIP) inventory, increased cycle time, and so forth). Although it took some time for our division to see the benefits of small lot production, we have successfully made the transition.

Other improvements implemented on the factory floor merely required convincing other departments in the plant to perform their jobs differently. As shown in Table I, the remaining activities after the two grinding operations involve blackening, laser marking and inspection. Due to the queuing times at each area, these operations could take as much as one day each to process. Anvils could not afford this waiting time, so we created boxes specifically labeled "anvils", and we placed them at each operation. We then told the operators not to let an order sit for more than two hours. Moreover, we informed the operators that they should transport a completed anvil order immediately to the next operation and never allow finished orders to stack up. Since these work centers operate two shifts daily, this resulted in orders traveling through the final three operations in approximately one shift instead of two days.

We also made subtle changes in factory layout. Originally, the factory order was delivered to a separate issue location whereupon a person pulled the blanks and placed them in the factory order. This wasted time and effort. Since the grinder only grinds anvil blanks, we moved the inventory bins next to the grinder operator. Now, the factory orders go directly to this operator, and he pulls the blanks from the bins that are only a step away from his machine. This saved several hours of queuing and transit time.

A relatively simple modification involved combining consecutive grinding operations occurring at the same work center into a single activity. Previously, these operations were written as separate procedures on the routing. Each operation required the operator to process two time cards, one for setup and one for run time. After the grinder operator brought it to our attention that he was getting buried in paperwork, we combined the activities. This further illustrates the importance of effective communication and teamwork in lean production applications.

We searched for redundant activities and made a concerted effort to eliminate them. One such candidate involved the in-process inspection that had originally occurred before the blackening operation. Quite simply, it added unnecessary queue and transit time. The “anvil maker” operators have a surface plate, a height indicator and a comparator at their work center to inspect anvils as they come off the machine. They were already performing 100% inspection of the anvils before they passed them on to the subsequent inspection operation. Eliminating this redundant inspection step was significant, because it reduced the cycle time to make a finished anvil.

To further reduce waste, we convinced product engineering to eliminate a specific design feature that existed on roughly 25% of our anvils. When a product like an anvil has been around for about forty years, many reasons for its original design are no longer known. However, people are very reluctant to change it since "it must be that way for a reason." After considerable information gathering, we determined that the feature was originally included to make the anvil easier to manufacture. The design feature was then copied over the years without being questioned. In today's manufacturing environment, the feature was no longer a benefit; indeed, it was a waste of time and tooling. Eliminating the feature allowed us to eliminate two extra grinding operations on the anvil maker, and to reduce the number of tools required.

5.0 Results

Our improvements to the flow of anvils have resulted in a flexible production process that it capable of efficiently producing small lots in a short cycle time at low cost. Perhaps the greatest benefit of achieving success in lean manufacturing is the ability to produce according to the customer's request. Since our cycle time is less than the delivery time for replacement anvils and anvils needed for assembly, we have achieved a situation where the customer is able to pull the product through the value stream. By producing what the customer orders in small lots, we are able to maintain low levels of WIP and finished inventory while still satisfying our customers.

We now provide customers with 10-day delivery on applicators, which our business office feels is giving us an advantage in this current economy. As Table II shows, we now have an anvil production lead time of 2-6 days, and we can produce an anvil in less than one day for customers in emergency situations. This has triggered new business for our factory. Now, we are manufacturing anvils that we used to purchase from an outside vendor, and doing so at a significant cost savings. We recently worked with our corporate shipping department to allow us to ship directly from our factory to Great Britain in 3 days. This means that Great Britain will receive their anvils 10 days after their order is placed with our factory. This recent improvement in delivery time has made Germany very interested in procuring anvils from our division.

===== take in Table II =====

6.0 Conclusions

We have investigated an application of lead manufacturing involving a department within Tyco Electronics, the world's largest electrical connector company. Faced with increased global competition, the Global Application Tooling Division (GATD) needed to dramatically reduce the production lead time of anvils, a key component of its manufacturing system. Through a number of improvement steps (such as beginning the process with heat-treated blanks, reducing paperwork associated with production, focusing on small lot sizes, modifying factory layout and eliminating redundant activities and product features), this division ameliorated its processes. We migrated to our present improved operational state in several stages. A benefit of continuous, incremental improvement is that each advancement revealed new waste that could be targeted for elimination. Under our traditional economies of scale operations, anvils experienced a 5-6 week lead time. Now with leaner, more efficient processes, this time has been cut to around 2-6 days.

As we demonstrated throughout this application, our production improvements were not the result of massive corporate reorganizations, nor were we required to purchase expensive, new technology. Rather, we facilitated improvements as we discovered a new way of conceptualizing our particular product as it progressed through its value stream. We can truly echo the sentiments expressed by Womack, Jones and Roos (1991) that some Western companies have attempted to become lean by "pushing the traditional mass-supply system to its limits under pressure, rather than fundamentally changing the way the system works." (p. 167, emphasis added). We also confer with Smeds (1994) that participative processes can effectively identify opportunities for improvement and provide the basis for implementing desired changes. Through communication and teamwork involving manufacturing engineers, plant leaders and machine operators, our division discovered sources for improvement and made eventual implementation much more practical.

We realize that our pursuit of perfectly satisfying the customer will never end, because we are always gaining new customers while the needs of our current customers are constantly changing. We are convinced that lean manufacturing efforts have given our company a competitive advantage in the application tooling market that will result in new business and increased profits in the future.

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Figure 1: Photograph of an applicator

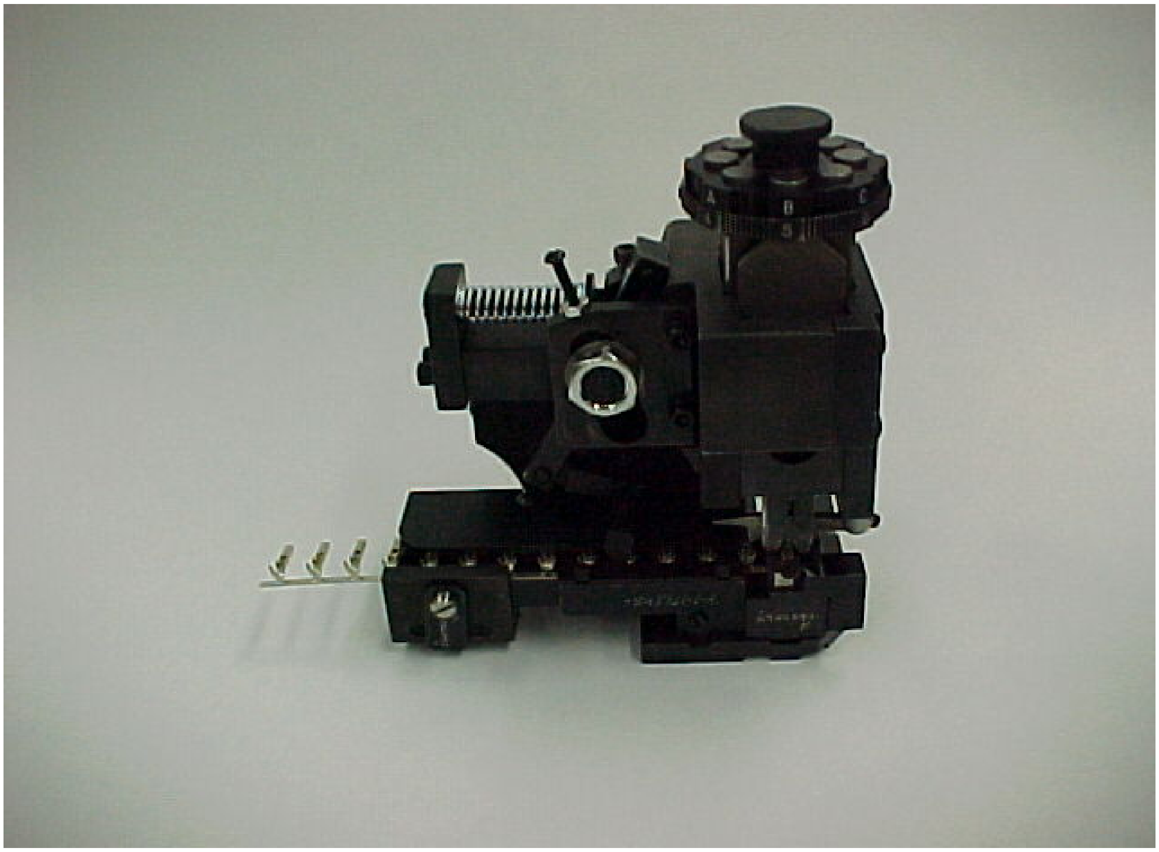

Figure 2: Photograph of different anvils (coin is shown for size comparison)

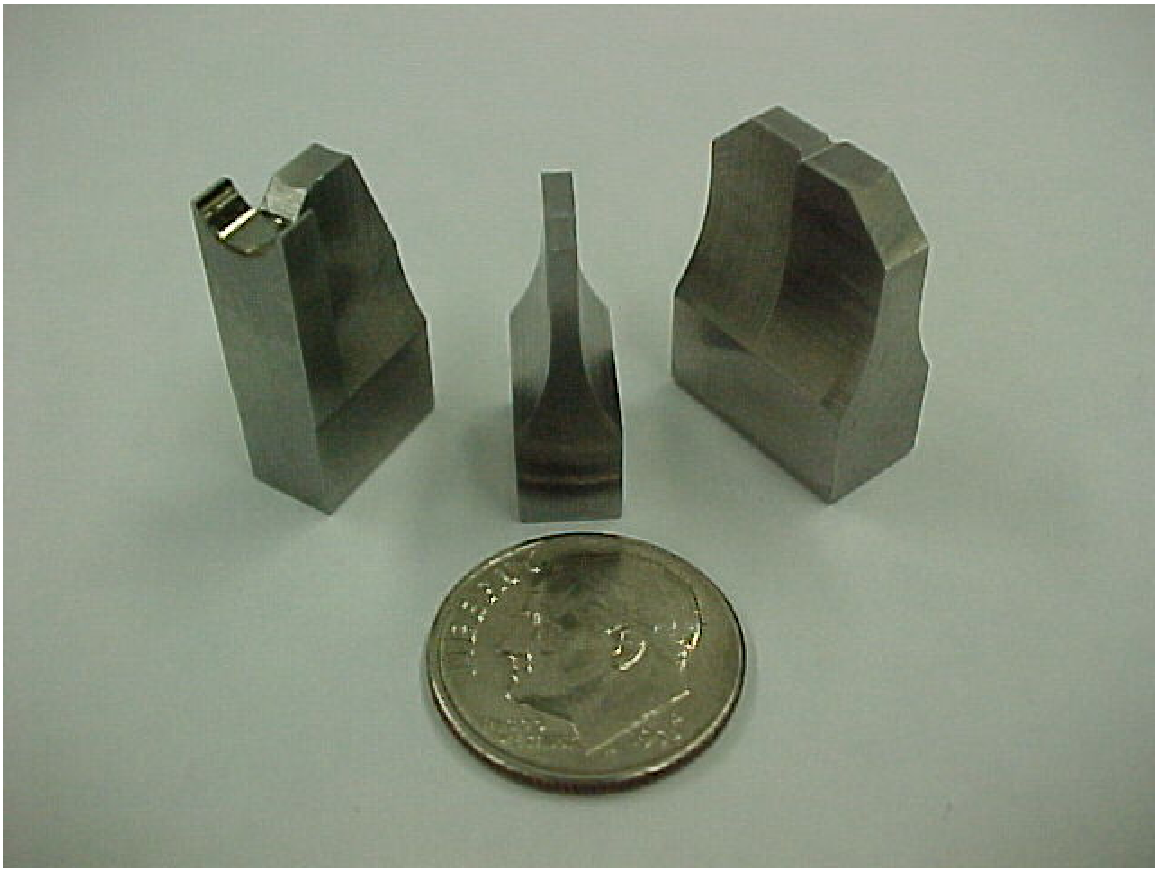

Figure 3: Photograph of blanks prior to grinding operation

Figure 4: Photograph of partially completed units in the anvil grinding machine

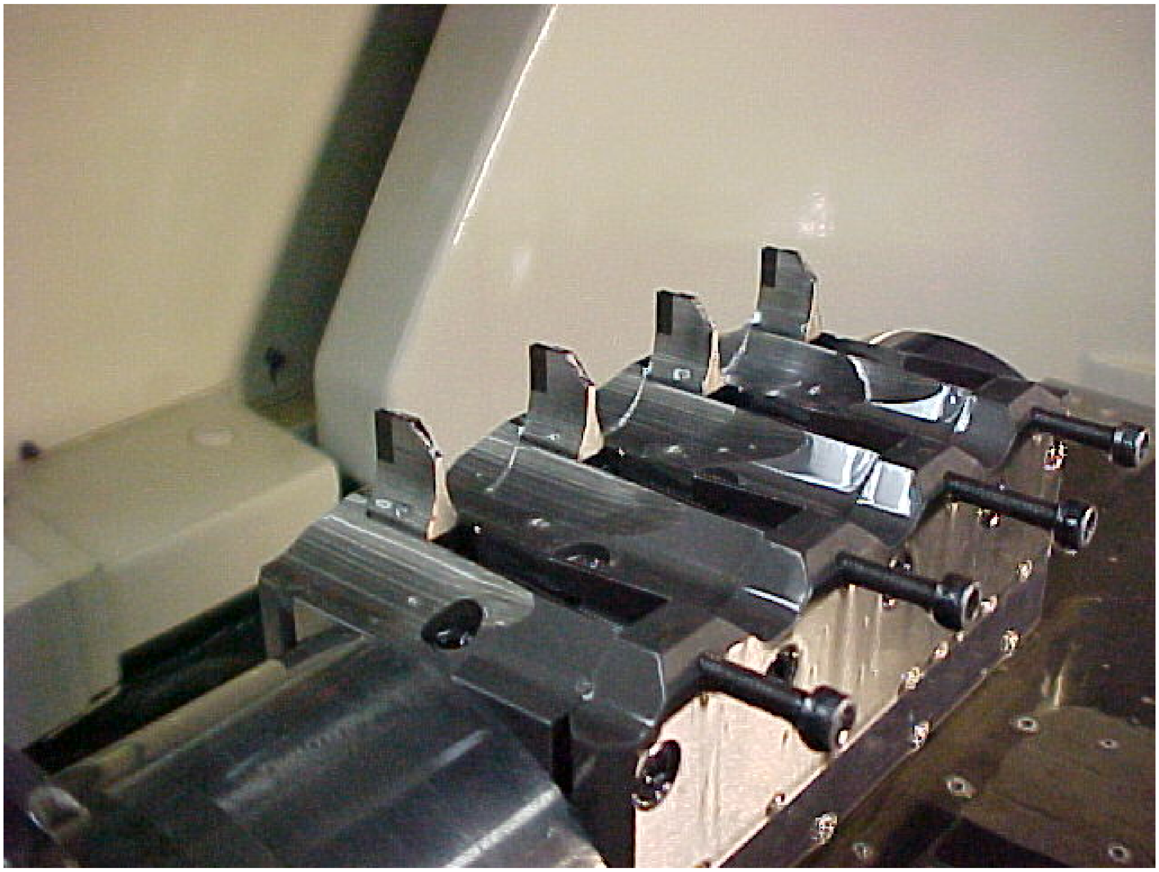

Table I: Lead time components

Traditional Process	Lean Process
Pull Blank	Pull Blank
Mill Width	
Drill & Tap Hole	
Shipping	
Receiving (Virginia)	
Heat Treat (Virginia)	
Shipping (Virginia)	
Receiving	
Grind Thickness	Grind Blank
Grind Square	
Grind Height	
Grind – Anvil Maker	Grind – Anvil Maker
Inspect – In Process	
Blacken	Blacken
Laser Marker	Laser Marker
Inspect – Final	Inspect – Final
Stores	Stores

Table II: Summary of improvements

	Traditional Method	Lean Approach
Applicator Delivery Time	Up to 8-12 weeks	10 days
Anvil Production Lead Time **	5-6 weeks	2-6 days
** Able to provide anvils in less than one day for customers in emergency situations		