WELDING Journal

The welder pictured above is shown welding on a tank. In the inset are front-end loaders on a truck.

Applying Lean to Welding Operations

BY VIWEK VAIDYA AND BRYAN GEORGE

This case study shows how the principles of Lean can be applied to welding operations in a plant producing front-end loaders (see lead photo). A systematic approach to measuring welding process parameters and welder skills was used to diagnose areas of applying Kaizen or the process of continuous improvement. Welder training and optimization of welding parameters resulted in a significant improvement in quality and reduction of waste. Design changes facilitating ease of welding and reduction of grinding were made. Weld process monitoring was used to measure deviation from optimized parameters and corrective action was implemented through welder coaching on the job. Welding duty cycles were

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Lean principles applied to the welding activity of a front-end loader manufacturing facility resulted in a productivity improvement

measured to justify robotics in specific areas. Annual savings of $400,000 were achieved in a shop employing 35 welders.

Introduction

Lean manufacturing is focused on eliminating waste in the entire manufacturing process. It deals with minimizing work-in-process, eliminating processes that do not add value to the product, making the process flexible enough to make products of different design without compromising quality or cost. Historically, many manufacturing companies have been able to maintain bloated or inefficient methods because of a protected market, strong brand strength, or huge profit margins. Global competition is forcing these manufacturers to change their methods to be less wasteful, and provide value to their customers through customization and reduced cycle or delivery times.

In the early 1980s, the Lean paradigm was invented at the Massachusetts Institute of Technology (MIT), and the Toyota Motor Co. was the first company to successfully apply it to automotive manufacturing. Lean philosophy is universal and can be applied to manufacturing, design, quality control, administration, order taking, accounts receivable, or any activity that needs to be improved. The process starts with a macro mapping of the activity called value stream mapping. It involves people at all levels in identifying areas of inefficiency. Once the problem is identified, groups of people work together for short periods of time in a well-documented activity called Kaizen to solve the problem. Building on small successes slowly embarks the entire enterprise on a never-ending process of continual improvement. Lean and Kaizen are work philosophies, requiring the commitment of the owner or CEO of the enterprise. Results are obtained through employee empowerment and are achieved over time.

This article describes how Lean principles were applied to the welding activity of a front-end loader manufacturing facility. The five key Lean principles were applied to the welding process as outlined below. The plant manager was the most visible promoter of the process and success was largely related to the appropriation of the continual improvement by the employees at all levels, specific to the welding activity.

Key Lean Principles

1. Perfect first-time quality through the quest for zero defects, revealing and solving problems at their ultimate source, achieving higher quality and productivity simultaneously, teamwork, and worker empowerment.
2. Waste minimization by removing all nonvalue-added activities, making the most efficient use of scarce resources (capital, people, space), just-in-time inventory, and eliminating any safety nets.
3. Continuous improvement (reducing costs, improving quality, increasing productivity) through dynamic process of change, simultaneous and integrated product/process development, rapid cycle time and time-to-market, openness, and information sharing.
4. Flexibility in production of different mixes or greater diversity of products quickly, without sacrificing efficiency at lower volumes of production, through rapid setup and manufacturing at small lot sizes.
5. Long-term relationships with suppliers and primary producers (assemblers, system integrators) through collaborative risk-sharing, cost-sharing, and information-sharing arrangements.

Perfect First-Time Quality

Welding is a multidimensional process and in-process parameters often determine the final quality of the weld. Besides the three dimensions of the welding nugget, the fourth dimension of time influences the final quality as it influences time-related parameters like welding speed, heat input, and timing in applying preheat and postheat, ultimately affecting the weld microstructures and distortion of the finished parts.

Fillet weld is the most common type of weld used in metal fabrication. Visually inspecting a fillet weld in two dimensions does not guarantee adequate weld penetration in the third dimension. Because fillet welds are usually taken for granted, they are mostly ignored by engineers and shop supervision. It is assumed that welders have sufficient skills to deposit quality welds to required sizes. However, failure analysis of many failed components often points to faulty fillet welds. For example, in a cyclic load application, fatigue failures usually originate from fillet weld toes. Large oil rigs and barges have capsized due to the failure of small, insignificant fillet welds. With this background information and some fatigue failure history with front-end loaders, it was decided that applying Lean would begin with making perfect fillet welds, every time, to print specification.

Welders were using 0.035- and 0.045-in.-diameter wires to make ¼-in. fillets in the horizontal position in production. Sixteen welders were asked to make ¼-in. fillet welds on test coupons, alongside their production jobs, and all in-process parameters were recorded. These appear in Table 1. The welds were sectioned and quality inspected. Completely penetrated ¼-in. fillet welds with a 20% maximum overwelding were used as an acceptability criterion. Ten welders out of 16 were able to make ¼-in. fillets. Thirty-seven percent of welders failed to make good quality welds the first time (Table 1). This presented a great opportunity to perform a Kaizen event for improving fillet weld quality.

Table 1 — Kaizen Applied to Weld Monitoring Process Control: Starting Time Data

Process: GMAW   Weld metal type: ER70S-6, 0.045-in.-diameter wire   Shielding gas: Ar 90%/CO_2 10%
Type of weld: Fillet weld ¼ in.   Welding performed at the workstations, fillet welds made on 12-in.-long test assembly in horizontal position

Working Shift	Sample Number	Required Size (inches)	Over-welding %	Wire feed speed in./min	Voltage (Volts)	Gas flow (ft^3/h)	Welding speed in./min	Penetration Evaluation Acc./Rej.	Visual Evaluation Acc./Rej.	Overall Evaluation Acc./Rej.
Day	1	¼	0	458	30.2	27	22.2	Acc.	Acc.	Acc.
Day	2	¼	56	415	31.2	25	13.5	Acc.	Acc.	Acc.
Day	3	¼	25	466	30.3	40	17.6	Acc.	Acc.	Acc.
Day	4	¼	56	399	30.6	30	13.6	Acc.	Acc.	Acc.
Day	6	¼	0	402	29.5	17	17.6	Acc.	Acc.	Acc.
Day	7	¼	0	400	26.8	27	18.0	Acc.	Acc.	Acc.
Day	8	¼	0	494	30.1	30	21.2	Acc.	Acc.	Acc.
Day	10	¼	25	404	30.5	17	14.4	Acc.	Rej.	Rej.
Night	11	¼	25	454	29.5	27	18.5	Acc.	Acc.	Acc.
Night	12	¼	0	414	31.4	28	17.6	Acc.	Rej.	Rej.
Night	13	¼	0	385	29.4	40	16.9	Acc.	Rej.	Rej.
Night	14	¼	25	474	30.5	40	19.5	Acc.	Acc.	Acc.
Night	16	¼	–25	451	28.1	25	19.5	Rej.	Rej.	Rej.
Night	17	¼	–34	402	29.0	15	23.2	Acc.	Rej.	Rej.
Night	18	¼	12.5	406	30.4	22	16.0	Acc.	Acc.	Acc.
Night	20	¼	0	466	31.5	16	18.5	Acc.	Rej.	Rej.
Average	16 Welds		11%	431	29.9	27	17. 6	15 welds acceptable	6 welds undercut	10 welds acceptable
Optimized parameters after eight months of Kaizen		3⁄16 in.	30%	600	29.5	45	24	good	good	good

Waste Minimization by Removing All Nonvalue-Added Activities

Fillet Welds

As a general comment, shop welding procedure specification data sheets were difficult to read and did not clearly state the size of welds to be applied to specific components. A good rule of thumb while welding thick to thin materials is to equal the fillet size with the size of the thinnest member being welded. In the case of lap welds, the size of the weld should be equal to the plate thickness up to a quarter of an inch. Prequalified joints further indicate that the minimum size for dynamically loaded structures is 3⁄16 in. for plate thicknesses less than ¼ in. The minimum fillet size required for thicknesses between ¼ and ½ in. base metal thickness is recommended to be 3⁄16 in. per American Welding Society Standard D1.1, *Structural Welding Code — Steel*. Considering the base metal thicknesses being fillet welded at XYZ Ltd., it was confirmed that a 3⁄16-in. fillet would be more than sufficient to cover 90% of the work.

A total of 77 welds were measured against a design requirement of 3⁄16 in. size. Weld leg sizes varied from 3⁄16 to ⅜ in. dimensions. The overwelding for the measured welds fluctuated from 33% to 206%, with the average at around 107%.

The excess weldmetal and effort in depositing the extra 107% nonvalue-added wasted manpower was a significant Lean finding.

An external design engineering team looked at all the drawings used to manufacture the final product. The shop drawings did not show any welding symbols. It was soon discovered that 90% of the plates used in the construction of the front-end loaders were less than ¼ in. thick, and 90% of shop welds were ¼-in. fillets. The design team determined that the fillet welds should be resized to 3⁄16-in. fillets.

Weld Design Changes

The design of the front lift arm assembly was carefully modified to change expensive flare groove welds to simple lap fillets between the wrapper plate and the structural steel channel. Fit-up was improved on the bushing welds and line boring was implemented to save assembly time.

Welding Wire Waste Measurement

The manufacturing facility was using both 0.045- and 0.035-in.-diameter solid E 70S-6 wires for most of the work. As the weld size was optimized to 3⁄16-in.-size fillets, it became necessary to optimize wire usage to 0.035 in. diameter and reduce the occurrence of undercuts. All the feeders were converted to feed 0.035-in.-diameter wire. These two changes resulted in a large improvement in logistics for consumable usage and preventive maintenance. Welder training and welding process monitoring were further simplified.

Welding Gas Usage and Optimization

Initial evaluation of welding macro sec-

Follow-up Actions for Applying Lean to Welding and Welding Management

The dilemma of prioritizing between passing quality audits and improvement in productivity is not new. A case in point would be to use very wide welding parameter ranges in a welding procedure specification (WPS) within code requirements, so that most welders would pass a welding audit by an ASME auditor, avoiding a serious nonconformance. On the other hand, to improve welding quality and weld penetration, higher wire feed speeds are usually required while using semiautomatic processes, as seen in this case study. The ISO 3834 quality requirements for fusion welding of metallic materials standards provides a good way around the dilemma by using specific work instructions (WIs). The WIs in a factory focus on productivity improvement, but are based on qualified WPSs. Thus, the WIs would need a tighter wire feed speed control for higher productivity; however, a nonconformance to WIs may not necessarily mean a nonconformance to the qualified WPSs.

The ISO 3834 standard has been widely used in Europe under EN729 series equivalent, and has now been adopted by Australia, Japan, and many European countries. It is a very good practical welding standard and provides many other advantages. For example, the standard requires the fabricator to disclose the size of the manufacturing facilities, including the capacities of press brakes, turning rolls, cranes, cutting equipment, etc., during the certification audit. It is used in Europe by purchasing departments in the tendering process to qualify subcontractors in their own countries and also from foreign countries.

The principal author has worked closely with the working group on ISO 3834 for the last three years and has been successful in bringing into focus the critical role of top management for Lean activities as applied to welding. The ISO 3834 Part 6 of the standard now recommends that top management review welding performance and allocate resources for welding technology selection, including implementation and performance monitoring of the welding processes. Figure 1 is an excerpt of a table from ISO 3834 part 6, and shows the use of the Deming process to welding and the role of top management in the continuous improvement process, as highlighted in this article. It is hoped that adopting the ISO 3834 standard by metal fabrication shops in North America will create the environment to foster Lean as applied to welding operations.

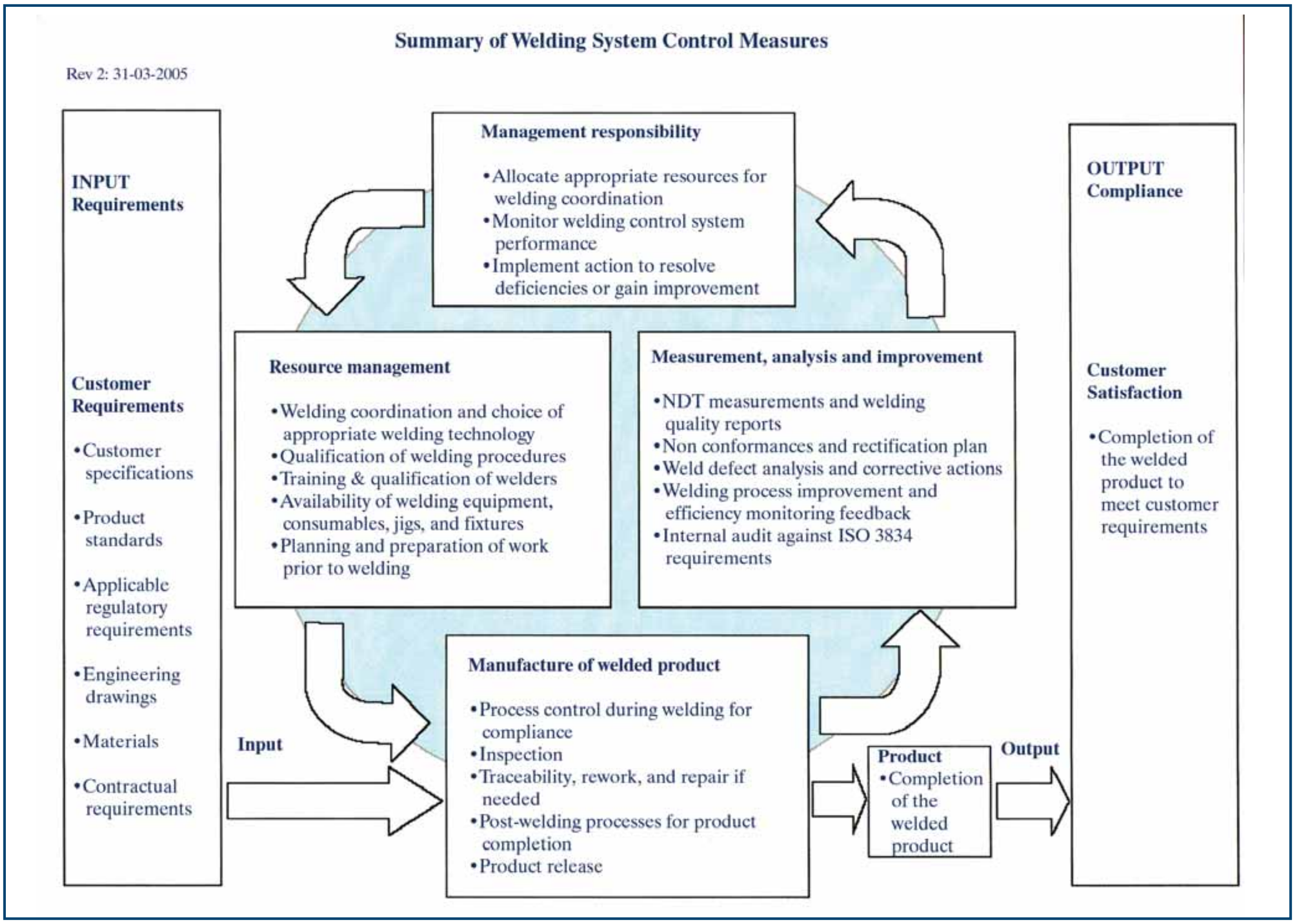


Fig. 1 — Summary of welding system control measures from ISO 3834 part 6 proposed diagram.

Table 2 — Actual Shop Conditions

Customer information: XYZ Ltd.
GMAW: ¼-in. 2F shop actual-19.5% overwelding

Welding position: Horizontal

Data	
Fillet Weld size in decimal inches	0.25 in.
Welding process	GMAW
Process efficiency	95%
Filler metal cost per pound	$0.75/lb
Wire diameter	0.045 in.
Wire feed speed in inches per minute	425 in./min
Calculated deposition rate at 100% shop efficiency	10.93 lb/h
Cost of shielding gas in dollars per cubic feet	$0.06/ft^3
Shielding gas flow rate in cubic feet per hour	20 ft^3/h
Shop charge out labor rate	$25.00/h
Fillet weld weight per linear foot	0.106 lb/ft
Fillet weld weight with 19.5% overwelding per linear foot	0.127 lb/ft
Calculated fillet weld cross section in square inches	0.037 in.^{2}
Calculated fillet weld size including allowable overwelding	0.273 in.
Welding arc travel speed in inches per minute	17.20 in./min
Measure shop duty cycle from CAP audit	20% observed from CAP audit
Effective welding speed reflecting duty cycle from CAP audit	17.20 ft/h
Shop effective deposition rate reflecting measured duty cycle	2.19 lb/h

Calculations and results	Cost per hour & repartition		Cost per pound & repartition		Cost per foot & repartition	
Labor	$25.00	92.71%	$11.44	92.71%	$1.454	92.71%
Wire or filler metal	$1.73	6.40%	$0.79	6.40%	$0.100	6.40%
Gas	$0.24	0.89%	$0.11	0.89%	$0.014	0.89%
Total	$26.97	100%	$12.34	100%	$1.57	100%

Welding cost calculator: Kaizen event for fillet welds. Customer: XYZ Ltd.

Table 3 — Optimized Shop Condition after Kaizen Event and Training

Customer information: XYZ Ltd.
GMAW: 3/16-in. fillet with 30% overwelding

Welding position: Horizontal

Data	
Fillet Weld size in decimal inches	0.1875 in.
Welding process	GMAW
Process efficiency	95%
Filler metal cost per pound	$0.81/lb
Wire diameter	0.035 in.
Wire feed speed in inches per minute	600 in./min
Calculated deposition rate at 100% shop efficiency	9.33 lb/h
Cost of shielding gas in dollars per cubic feet	$0.06 ft^3
Shielding gas flow rate in cubic foot per hour	45 ft^3/h (CFH)
Shop charge out labor rate	$25.00/h
Fillet weld weight per linear foot	0.060 lb/ft
Fillet weld weight with 30% over welding per linear foot	0.078 lb/ft
Calculated fillet weld cross section in square in.	0.023 in.^{2}
Calculated fillet weld size including allowable over welding	0.214 in.
Welding arc travel speed in inches per minute	24 in./min.
Measure shop duty cycle from CAP Audit	20% observed from CAP audit
Effective welding speed reflecting duty cycle from CAP Audit	24 ft/h
Shop effective deposition rate reflecting measured duty cycle	1.87 lb/h

Calculations and results	Cost per hour & repartition		Cost per pound & repartition		Cost per foot & repartition	
Labor	$25.00	92.14%	$13.40	92.14%	$1.042	92.14%
Wire or filler metal	$1.59	5.87%	$0.85	5.87%	$0.066	5.87%
Gas	$0.54	1.99%	$0.29	1.99%	$0.023	1.99%
Total	$27.13	100%	$14.54	100%	$1.13	100%

Welding cost calculator: CAP CONSULTANT. Customer: XYZ Ltd.

tions revealed uneven penetration patterns. A 10% CO_2 with balance argon mixture was delivered through a gas mixer. The uneven penetration profile of the welds indicated significant variation in the gas mixture. The mixer buffer tank had to be resized for a bigger capacity to stabilize the gas mixture.

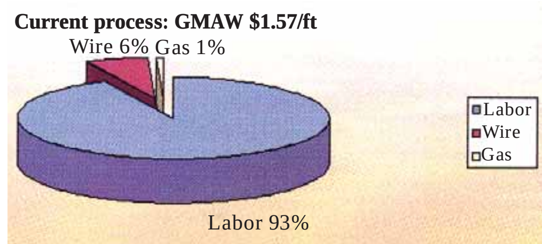
The measured gas flow rates in some parts of the shop were as low as 17 ft^3/h, which resulted in internal fillet weld porosity. Gas flow rates were standardized to 45 ft^3/h throughout the plant.

Leaks in the gas manifold system were verified. The ratio of amount of gas used to deposit one pound of filler metal was targeted at 4.5 ft^3/lb. This is a good ratio to monitor gas waste.

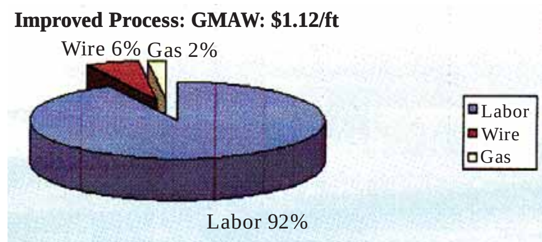
Table 4 — Cost Calculation Spread Sheet

CAP Audit: Cost calculations for XYZ Ltd.

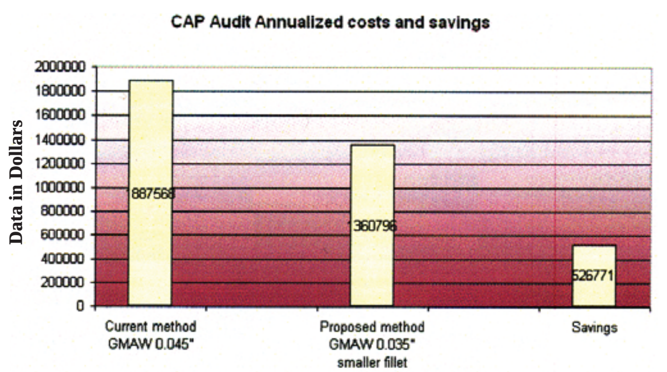
Current method	
Cost per foot of weld	GMAW 0.045 in.
Labor	$1.45
Wire	$0.10
Gas	$0.01
Total	$1.57
Effective arc speed, ft/h	17.20



Improved method	
Cost per foot of weld	GMAW 0.035 in.
Labor	$1.04
Wire	$0.07
Gas	$0.02
Total	$1.13
Effective arc speed, ft/h	24.00



Annualized calculation	
Number of welders	35
Annual footage calculation:	1,203,670 ft
Welders needed with new method	25 welders
Extra capacity	10 welders



Annual footage for steel welds (mono pass)	1,203,670 ft
Current method: GMAW, 0.045 in.	$1,887,568
Proposed method: GMAW, 0.035-in. smaller fillet	$1,360,796
Savings	$526,771
Increase in productivity in %	39.56%

Lean Resources Needed for Kaizen Applied to Welding

In order to carry out a satisfactory welding-related waste measurement, it was necessary to use various measuring devices and instruments. Without going into too much detail, a simple list of items is provided to understand what is needed to make a nonsubjective welding assessment.

Human resources:

- Motivated CEO or plant manager interested in pursuing opportunities for cost savings
- Internal or external experienced welding engineer/technician team with excellent, analytical, training, and people skills.

Material and software resources:

- Calibrated length-measuring instruments
- Stopwatch
- Wire feed speed measurement device
- Calibrated ampere and volt meters
- Shielding gas flow measurement devices
- Gas saver devices
- Gas leak detection equipment
- Duty cycle measurement device capable of data acquisition, storage, and download over 24-h measurement periods, for continuous improvement
- Fillet gauges, manual, or electronic systems
- Ability to test fillet welds quickly with destructive tests
- Ability to produce weld macrographs for quality feedback to welders
- Digital photography equipment
- Annualized gas and wire consumption data and pricing
- Cost calculation software to validate improvements of Kaizen activities.

Continuous Improvement through the Dynamic Process of Change

Welding Wire Size

Once the initial welding parameters were recorded, as shown in Table 1, the task of continuous improvement began with plant supervision. All welders were using water-cooled welding guns of European design. These guns never leaked any water; however, a lot of undercutting was noticed on fillet welds. Arbitrarily used in production were 0.045- and 0.035-in. diameters. The welders on the floor had implemented a “smart” solution to this problem. On a four-drive roll feeder system, two rolls were 0.035-in. and the other two were 0.045-in. diameter, so any diameter of the wire could be fed. As a corrective action for undercutting, the front end of the guns was changed so that the contact tip could be properly positioned for spray transfer. All 0.045-in.-diameter wire was removed from production and standardized to 0.035-in. diameter.

Weld Monitoring

Much monitoring and skills training were required to break old habits and assimilate new ones. Every week, the Kaizen team recorded production welding parameters of wire feed speed and welding speed, including quality and extent of overwelding. The results were reviewed with the welders not performing to the new standard. To help the welder acquire the required skills, on-the-job training was provided by the Kaizen group. This process was repeated throughout the plant until desired results were obtained. The feeder speed potentiometers were physically marked with a sticker to indicate the optimized position for the wire feed speed in order to help everyone use the standardized parameters.

After eight months of training and on-the-job monitoring of welding techniques, the average welding speed increased by 6 in./min, an impressive 39% improvement. These results are summarized in Tables 2 and 3. Welders were able to produce 3⁄16-in. fillet welds in the horizontal position, with 90%Ar + 10%CO_2 gas mixture at optimized wire feed speeds of 600 in./min at an average of 24 in./min of welding speed with practically no undercut.

Cost Savings

The average welding cost per foot for a 3⁄16-in. single-pass fillet weld was reduced from $1.57 to $1.13 per foot. On an annualized basis, a potential annual savings of $526,771 was calculated (Table 4). In the first year alone, the company was able to realize more than $400,000 in savings. By reducing waste and increasing welding speed, more welding capacity was added, requiring further work balancing on the production line in the following years.

Flexibility in Production

Management was keen to go to robotics for flexibility of production. However, when the process audit was carried out, actual welding duty cycle measurements were made. Further attention was paid to the existing accuracy of fit-up.

Duty cycles were measured in the various areas of manufacturing. The following weighted-average duty cycles were observed during the audit over a three-shift time span. The high duty cycle numbers were for areas where the operator was not interrupted. An average duty cycle of 20% was calculated for the shop for cost calculations by the Kaizen team.

- Lift arm assembly average: 22.7%
- Attachments average: 16.1%
- Transmissions average: 17.1%
- Mainframe assembly average: 28.5%
- Quick attachments average: 13.5%
- Tanks average: 22.3%

The overall throughput of the plant was eight units per day. In order to improve this performance, the initial survey showed that the shop floor layout would have to be significantly improved, reducing a very large amount of work in process. Robotic welding was discouraged at this stage, as part fit-up was less than acceptable and the floor layout was inadequate to feed the robot parts and then remove the finished parts efficiently without creating further work-in-process pileups.

The overall operation needed to be more balanced. It was found that even if the welding operation could be significantly improved from a productivity point of view, the bottleneck was still frequent at the final assembly of the machines. More Kaizen needed to be done for the logistics of all electrical, mechanical, and hydraulic systems. After the initial year of welding improvements, it was decided to defer the automation projects until other operations could produce a pull effect on welding to really make flexible robotic welding worthwhile.

Long-Term Relationships with Suppliers

Further to the initial process audit, the president of XYZ Ltd. was very keen to implement corrective actions through focused Kaizen activities. The process was supported with a long-term four-year contract with the local gas and welding products supplier, who could provide not only consumables, but also welding engineering expertise.

The first Kaizen activity was focused on wire feed speeds and reducing undercuts.

The second Kaizen activity was focused on welding speeds and fillet weld sizes.

After the first eight months of assistance from the external welding engineering support, the plant inspectors were taught to measure and report key parameters targeted by the two Kaizen activities to ensure that the higher productivity standard was maintained over the four-year period.

Conclusion

While applying Lean principles to a metal fabrication facility employing arc welding in the manufacture of front-end loaders, a dramatic improvement in productivity was achieved over a 12-month period. The key to success was the keen interest of the management team to succeed in the continuous improvement process.

The auditors performed similar audits in more than 100 metal fabrication shops with good results whenever the plant manager or the CEO of the corporation was keenly involved in the results.◆

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- Canadian Patent pending CA 2434537 : System and method for improving the productivity of a welding shop.