FINAL REPORT

WELDING SUPERVISOR TRAINING AND CERTIFICATION

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1.0 Abstract

The front line supervisor plays a critical role in the improvement of welding productivity through direct interaction with the welders. A training program that focuses on critical variables of welding performance, with discipline and learning incentives stimulated through the recognition of a national certification program will empower welding supervisors to learn and apply the necessary knowledge within the production setting. The scope of this project is limited to the training and certification of individual supervisors, and the observation of improvements made by way of individual initiatives. Systemic improvements resulting from changes in manufacturing practices that are beyond the normal scope of a supervisor's job duties are not covered by this project, but represent fertile grounds for additional productivity improvements and research.

2.0 Survey of Shipyard Welding Practices (Pre-Training Evaluation)

2.1 Overview: A survey was conducted at the partner shipyard to ascertain the existing welding manufacturing processes and where significant improvements could be suggested. The survey covered the four critical functions of product design, process engineering, production and quality assurance as they relate to shipbuilding operations. Only those areas within these critical functions that are keys to quality, productivity and through-put improvements were covered in detail in the recommendations arising from this survey. This survey was conducted by the following Barckhoff and Associates engineers:

Jack Barckhoff, P.E.
Donald Lynn, P.E.
Kenneth Kerluke, P.Eng.

They worked closely with key Bender Shipbuilding and Repair Company personnel representing each of the four critical functions, and were very encouraged with the cooperation and positive attitude of people interviewed throughout the Company's facility.

2.2 Potential Savings: This survey identified several areas of Key Results and, for each area, resulted in recommendations that were judged to have the most return on investment.

The objective of the survey is to help shipyards recognize where, and how much, welding operations can be improved with respect to quality, productivity, through-put, or safety. In the survey, it is expected that full implementation of all recommendations will result in the actualization of annual savings of approximately $17,044 per welder.

The potential hour and dollar savings estimates used in this survey are based on the assumption that a shipyard will implement all Key Results Areas and projects identified for each of the five goals during subsequent implementation phases. Actual improvements and cost savings will depend largely on the quality of implementation, the effort expended, and management support.

Increasing welding productivity, improving quality and process control are vital tasks for personnel at all levels. To do so requires the identification of factors that adversely affect flow and cost, separating the "vital few" from the "trivial many" items of detail, and implementing and maintaining controls to obtain planned results.

To evaluate these factors effectively, the following five goals were examined:

1) reduce weld metal volume
2) reduce arc time per weldment
3) reduce rework and scrap
4) reduce work effort
5) reduce motion and delay time

The survey covered in detail each of these goals for the five Key Results Areas within each of the four critical functions of product design, process engineering, production and quality assurance. By evaluating the resulting 100 cell areas, it is possible to identify and report on those vital few items that will provide the greatest return on investment.

Although the emphasis of this work is technical, the people involved with the planning and implementation of the various projects really determine the success. Virtually any cost improvement project involves change. Even when people believe change will be beneficial, there is a reluctance to adopt new methods. Ignoring this very real human response to change often results in the failure of a project to achieve its goal. To implement change in the way people do things, it is not enough to show them how to do it - they must understand the "why," so they'll want to do it. Further, effective change requires teamwork, clear communications and proper follow-through. To obtain the productivity, quality, and cost improvements highlighted in this report, both the technical and motivation issues must be addressed.

The following illustrates the breakdown of the cost savings per welder that was determined by this survey. Through the observations and findings compiled with information obtained from the shipbuilding company personnel at various levels across the four critical functions, it is estimated there is a total potential annual savings of $17,044 per welder in labor hours and welding materials based on the 2002 fiscal year projections at the subject shipyard. This potential savings is realistic and obtainable, but caution must be exercised that it will take full support by management and a cooperative team effort and attitude across the critical functions for maximum results.

Potential savings, through-put, and weld quality improvements that can result from the following five welding goals are:

$3,319 per welder through the reduction of weld metal volume.

Savings in welding materials and associated arc time from specifying and controlling welds to the minimum practical number and length, and by eliminating excessive volume in fillet welds.

$4,281 per welder through the reduction of arc time.

Reduction of arc time per weldment by developing and ensuring the use of proper work-area layouts, setups, methods and welding procedures; for manual and semi-automatic welding operations that will increase productivity.

$3,244 per welder through the reduction of rework, scrap and rejects.

Reduction in documented, undocumented and integrated rework costs through the enforcement of weld sequence and placement; the use of meaningful welding procedures and quality workmanship performance standards to reduce weld defects; training with regard to the essential welding variables; good communications; correct input parts; an effective feedback program; and recognition of the fact that welding is an engineered science.

$6,200 per welder through the reduction of work effort, motion and delay time.

Reduction of work effort through better use of fixtures and tooling with quick change characteristics to reduce fatigue and time for assembly and welding of parts; the elimination and reduction of welds as well as their repositioning; and by empowering people through implementing sound welding management concepts of:

a) managing one's own area
b) taking responsibility and being accountable at all levels, and
c) guaranteeing one's own work.

Also by properly training and qualifying people, which will reduce start-up time and produce a more effective and efficient worker.

2.3 Management Considerations: The following discussion includes suggestions for systemic improvements that are beyond the scope of this project, but are included here for the benefit of the reader.

Two of the goals where significant savings can be achieved are to reduce welder fatigue and to reduce motion and delay. The savings are described in Section 2.4. Achieving these reductions will require the efforts of a strong manufacturing engineering function. There is a concern that the manufacturing engineering function may not be able to meet the challenges that must be overcome in order to upgrade the welding operations. The organizational structure must include all of the necessary subfunctions and the organization must include personnel who are capable and proficient in each of these subfunctions and who work and communicate smoothly and efficiently with each other. This function must contain all of the subfunctions necessary to:

- take a final design and successfully plan for, and implement, the manufacture of that design in production
- work closely with design during the creation of a new product, and
- support and train production personnel to manufacture the part.

To do this work effectively will require the grouping and cooperation of subfunctions that may not be thought of as needing to work closely together. These subfunctions require varying amounts of time and therefore several of them may be performed by only one individual, while others may require full time attention.

The following are subfunctions that typically need to work together to make an effective and efficient manufacturing engineering function:

<u>Process Engineering</u> - to evaluate, plan, develop, implement, document and control all processes necessary to manufacture products at the required quality levels and the lowest possible overall cost.

<u>Industrial Engineering</u> - to analyze, measure and improve the methods and sequencing by which labor, material, and capital are integrated to ensure the manufacture of products at the required quality levels and the lowest possible overall cost.

<u>Facilities Engineering and Maintenance</u> - to plan, engineer, implement, operate, and maintain the entire manufacturing facility, including its buildings, grounds, equipment, utilities and utility distribution systems, to provide full support to manufacturing operations while utilizing these resources as efficiently as possible within budgetary limitations.

<u>Tool Engineering</u> - to design and provide the perishable and non-perishable tooling necessary to manufacture products at the required quality levels and the lowest possible overall cost.

<u>Advanced Manufacturing Engineering</u> - to review designs for new products and new contracts for manufacturing feasibility; evaluate new processes and implement them into manufacturing departments; evaluate and specify new equipment; plan new or improved facilities; and conduct studies of product and manufacturing costs.

<u>Capital Resource Management</u> - to provide and maintain a program that ensures all activities required for effective Capital Resource Management are formally addressed and directed toward optimizing the utilization of capital resources.

<u>Facilities Layout and Material Handling Engineering</u> - to maintain an active Plant Layout and Material Handling Engineering Program that plans, designs and implements - in a timely manner - efficient plant, office and site layouts, and safe, efficient and economical material handling systems.

A second area of concern is the need for more follow-through, both within, and between, each of the four critical functions. These concerns are addressed in the Key Results Area sections later in this report.

Consider development of additional document guidelines such as application welding procedures, workmanship performance standards and methods sequencing, along with providing visual samples that will be accessible to each welder, supervisor and inspector.

Training will be a prime requirement for reaching the goals of increased through-put, improved quality and reduced costs. We recommend the expansion of the scope of work of the weld leader to include training responsibilities.

Consider training and designating certain personnel, such as the weld leader, as Internal Welding Trainer. These individuals will be the right arm of the Supervisor and help maintain welder qualification on the job according to print specification, application welding procedures, workmanship performance standards and method sequencing.

Consider re-evaluating the duties of the front-line supervisor since he plays such a "key" role that has so much impact on through-put, quality, costs and safety. What are his duties now versus what they should be in regard to managing his area, auditing and monitoring, and supporting his people per the Inverted Organizational Chart in order to consistently meet quality and quantity requirements?

Observations and Recommendations: Following are recommendations in the form of Prioritized Goals to achieve the results indicated in the previous section. First, the recommendations are listed by cells (Goals and Key Results Areas). Second, each recommendation is defined along with the requirements for achieving the anticipated results and the background facts which substantiate the need for the task. Some of these tasks will stand alone as projects and some must be coordinated with other tasks in the form of a project.

The dollar figures and the information contained in these Prioritized Goals and Key Results Areas are based on the work of one hundred and thirty-five (135) welders at the project partner shipyard. They are reported on a per welder basis with all observations and recommendations applying to all welding areas unless otherwise noted.

2.4 PRIORITIZED GOALS and POTENTIAL SAVINGS (Summarized by Broad Category)

Prioritized Goals	Potential Savings Per Welder
1. Reduce weld metal volume	$3,319
2. Reduce arc time per weldment	$4,281
3. Reduce rework, scrap and rejects	$3,244
4. Reduce work effort	
5. Reduce motion and delay time (included with #4)	$6,200
Total Estimated Potential Savings	**$17,044 per welder**

The Key Results Areas listed under each of the Prioritized Goals requiring action and/or control to obtain the above estimated potential savings are listed below.

2.4.1 Prioritized Goal #1 - Reduce weld metal volume

Estimated Potential Savings: **$3,319 per welder**

The thrust of this goal is to produce weldments with the minimum volume of weld metal consistent with the design standards. The design of a weldment is often a source of excess weld metal volume. Design must assure the performance of the product as a priority, but must also be careful not to add unnecessary costs. Production must then apply the specified weld size and length. Since arc time is directly proportional to the volume of weld metal deposited for a given current, applying the minimum acceptable volume of weld metal is essential.

In general the results that should occur - if the correction to the excessive weld volume is achieved - are the following:

- the fillet weld volumes, both for the horizontal and vertical, should decreased significantly,
- the length of the intermittent welds would be determined based on design requirements, and
- welding travel speeds should generally increase with the reduction of weld volume, also quality will improve and less spatter will be generated because the voltages and wire feed speeds used will be more consistent with the fillet weld sizes and the filler metal wire size.

Key Results Area – Weld Size Determination

Weld size determination is a design responsibility. Three general methods apply to this effort.

A) Detailed stress calculations and tests can be used. This method produces the best confidence in the size and performance of the weld.

B) Rule of thumb sizes can be used to size welds based on the material thickness. This method is generally conservative since full strength welds are commonly applied. It also often results in excess volume because of a tendency to apply "a little more" than is needed.

C) The final method is by individual opinion either by guess or by consideration of past practice. This method often results in grossly undersized or oversized welds. Either condition is potentially bad due to possible part failure, or excessive cost.

Recommended Action

Overwelding resulting from the absence of welding symbols can be corrected by applying the required weld sizes on all engineering drawings. With the required weld sizes given on the drawings, every welder would know exactly which weld sizes to make and allow supervisors to better control and thereby eliminate the amount of overwelding occurring in the yard.

A second recommendation for removing excessive welding from the ship's design is to look at the use of intermittent welds. The use of intermittent welds has always been thought of as a cost saving measure, which in many cases it is. However, this judgment must be tempered with the knowledge that it is the overall volume of welding that must be the determining factor. To this end, sometimes the use of a smaller continuous fillet weld size may contain less volume, but have the same strength as a larger intermittent fillet weld. Added to this is the elimination of the need to mark off the intermittent welds by the welder, before the welding can begin. Although the engineers are constrained by the applicable code as to which welds can be used, this one degree of freedom is still available to them, provided the minimum fillet weld sizes are met.

Key Results Area - Workmanship Performance Standards

Workmanship Performance Standards can be a written document with the preferred features of the welds described, photographs or sketches of the welds, or actual weld samples. Production weld joint samples can serve as visual standards for controlling the resulting welds to meet productivity and quality requirements.

Workmanship samples are a very effective way to put the written words of a quality requirement into hardware. We recommend both the written document and samples to show the desirable weld features and locations.

Recommended Action

Design and build a physical production mock-up that represents the different weld joints and sizes used at the shipbuilding company. This sample becomes the visual reference for both weld quality, size and weld length depending on the type of mock-up that is used. The welds should be of acceptable quality but not necessarily be the best possible weld. A separate Workmanship Sample Board showing acceptable/non-acceptable weld criteria is recommended for display to welders, supervisors, inspectors, and customers. A completed production mock-up and workmanship performance sample board can be a part of the recommended shipbuilding company's process and quality center for the yard.

Part of the production mock-up should relate to volume control and use of fillet gages. Sample welds could be made that are slightly undersized, acceptable, or slightly oversized but within the targeted size meeting specification. This helps welders visualize the welds they should be making and helps with measurement and correction.

Key Results Area - Procedure Application

The welding procedures - whether written to an existing code, standard or modified as an application procedure for shop and yard use - will have a direct effect on the weld metal volume. The procedures should identify the variables that must be controlled to assure conformance to the design requirements. The procedures should specify electrode type and size, gas, amperage, voltage (arc length), technique variables, and other features.

Recommended Action

To resolve the above situations will require welding procedures with tight tolerances on amperages and/or wire feed speeds and voltages that will be strictly followed in production. These procedures will require input from shop personnel, and evaluation against expected acceptance criteria. Once they are established to produce the correct size and weld length in accordance with engineering requirements, they must be followed. In this way the volume of welding at the arc can be controlled to insure that drawing weld sizes will be maintained in production consistently.

In addition, the welding procedure in use must be able to maintain the quality and productivity in linear footage of welds being made while controlling the weld size. This can only be done through monitoring by the welding supervisors and corrective action by them, if welding procedures fail to achieve these goals.

Key Results Area - Personnel Qualification

To control the size and volume of weld metal deposited, it is essential that the supervisors and welders be capable of interpreting and applying the design specifications and workmanship performance standards as applicable. They should also understand what is expected, and how to produce welds that meet the requirements. Specific training will be required to make it happen. Further, the welding techniques as well as the resultant welds must be routinely monitored and audited. Welder training, supervisory control and inspection feedback will be necessary to ensure that welds are sized, shaped and located in accordance with specifications.

Recommended Action

The need to have a clearly defined standard and/or specification covering the fit up, tacking and welding, allows for everyone to have a distinct expectation of what is required. At the same time, this information would be included in the crew training that is given to both the fitters and welders to prepare them for the quality and productivity that are expected on a day to day basis.

This standard or specification would cover the allowable by either application, thickness, or material being fitted. The tacking would be covered as to size, length, and bead contour. The welding would reflect the acceptance criteria and the method for dealing with existing tacks that remain on the part as well as any fit up problems.

At the same time, this information would be included in the crew training for the supervisors and weld leaders, and both the fitters and welders. The training of the supervisors and weld leaders on this issue is critical to the monitoring and enforcement. To effectively reduce weld sizes and control tacks will require welding supervisors to check fit up conditions before welding starts, verify welding parameters during welding and check weld sizes and lengths when the welding is completed. The supervisors must do this often enough during the course of a work shift to assure that each welder is consistently following the weld size control requirements.

Key Results Area - Material Input

The welding operation often must deal with fit-up and dimensional problems that were created upstream in the design and fitting process. The corrections generally result in excess weld metal volume to complete the weldment. Excessive gaps require far more material to produce welds. The type of joint and the accuracy of the joint preparation also affect weld metal volume. It is important to use designs with the least possible volume for a given strength, and to keep joint preparations and fits as close as possible.

Recommended Action

Anytime excessive material gaps appear, it will result in added cost both for added filler metal and longer production time. The fitters and welders are aware of areas where they consistently have gaps, mismatches, and other poor fit conditions. This represents a ready source of corrective action. Check all areas with a history of excessive gapping and establish tolerances for joint fit-up. Ensure that welding supervisors are aware of the fit up problems and track through the welders and fitters to see that subsequent units do not show the same gapping problems.

Another much overlooked area is where welders and fitters have been taught to flame cut. In too many cases, unless the welding supervisor monitors the fit and trimming that they are doing in production, the quality will be less than desirable. This will lead to additional weld volume to close gaps resulting from poor cut quality.

Key Results Area - Inspection, Measurement and Reporting

The purpose of inspection can be:

1) to identify defects
2) to identify features that do not meet the quality standard
3) to determine if productivity requirements were met
4) to determine if the process variables are, or were, followed.

The reporting on deviations to the management production plan, so corrective action can be taken, is important to ensure long term improvement. There should be some level of inspection and reporting of compliance to weld size specifications, fit up, and other weld production concerns.

Recommended Action

The welder can be your first, last, and best inspector. If trained properly to "read the molten pool" during welding and understanding welding as a science, welders can be taught how to prevent making defective welds and maintain specified weld sizes and lengths. This inspection should also include the monitoring of fit up from both a quality and a volume concern. In the quality concern, any excessive gapping must have a properly sized fillet weld to compensate for the gap. The volume concern, of course, results when an excessive gap is welded properly and the increased volume from that welding occurs.

Supervisors should monitor the welders, understand welding as a science for corrective action of weld size and shape, plus the fit up to help maintain the welding procedures, workmanship standards and methods sequencing.

2.4.2 Prioritized Goal #2 - Reduce arc time per weldment

Estimated Potential Savings - **$4,280 per welder**

This goal requires the specification and control of welding processes and procedures, techniques, methods, equipment and tooling and the availability of supply items to reduce the arc time per weldment. Goal #1 – "Reduce weld metal volume," will directly affect this goal. The major differences that will be achieved by reducing the arc time are:

- changing from one welding process to another welding process that is capable of higher travel speeds will reduce the arc time in a particular welding operation, and

- an increase in the operating factor from the present 21.8% to 30%, though the use of mechanized and automated welding equipment will allow for one welder to do the work of two and possibly three welders.

Key Results Area - Process Selection

Welding process selection is an ongoing task for any welding intensive company. Changes in materials and equipment require evaluation both from a technical and user standpoint.

All shop applications with the exception of those with very small size and short arc time should be considered for semiautomatic, mechanized or automatic welding processes. Although there will always be some minimum need for manual welding processes such as shielded metal arc welding (SMAW), its use should only be considered where other more productive processes cannot be used.

Recommended Action

The FCAW process provides higher deposit rates and operating factor when operated in the horizontal and flat position. To optimize the use of FCAW, an effort should be made to determine its true capabilities by adopting welding parameters that will allow for the type of deposition rates that are possible when welding in the horizontal position. In addition, the use of semiautomatic welding processes should be considered in every application that still uses manual welding processes. This is especially true in the welding of piping whether in the shop or on-board ship. These improvements could range from something as simple as having the pipe welders use smaller guns that are more useful in tight access areas to orbital pipe welds that can increase the operating factor while lowering the arc time.

In the use of mechanized SAW, some thought should be given to using SAW on the circumferential welders on tanks and thrusters as well as heavy-walled pipe that can be rolled. This could include the engine exhaust pipe that requires a full penetration weld.

Another area that can be explored in areas where the welding is sheltered from the elements is gas metal arc welding (GMAW). Without the effects of wind and weather, this process could eliminate slag removal and improve deposition efficiency. In this instance, metal core wire may also find advantages in some areas. One important thing to consider is that the advantages of standardization on either welding processes or filler metals may not yield the same cost advantages as assigning the optimum welding process and wire.

Key Results Area - Equipment and Tooling

An important part of reducing arc time is to prepare welds for proper welding. This can involve the use of equipment to automate a process that is used to prepare weld joints for mechanized and automated welding processes. Not only can the use of automated equipment improve the productivity of the preparation time, it can also improve the quality of the welding.

Recommended Action

Use of equipment with fixturing and tooling can result in reduced arc time. This is especially true of cases like the pipe shop where so many manual and hand operations are going on daily. To combat this initially would only require that simple turning rolls for pipe spool assemblies be used. In addition, where hand cut to fit beveling is going on, the most common sizes could be done using a end prep hand held beveling machine. These machines, along with the small pipe rollers, are relatively inexpensive, but can be used over and over again for different jobs. Later, after all possible improvement has been achieved from these devices, automated equipment, which is more expensive, can be explored for additional improvements in the way of reduced arc time. Where possible, weld joints should be changed from vertical to flat or horizontal. The difference in deposition rates between welding out of position vs in position welds can be as much as 50%. A change of this magnitude could effectively lower the arc time by 30 to 35%.

Key Results Area - Procedure Application and Control

Increasing the current within an acceptable range will result in a definite and realistic increase in deposition rate, or reduction in arc time. This requires the correct welding process with procedures or set up sheets with optimum currents specified, training the welders and operators to use the procedures, and then controlling those procedures. It is necessary to control weld joint fit up to maximize welding quality and cost effectiveness.

Observations and Comments

Throughout the shipyard, we observed and it was confirmed that most of the welding done using the FCAW process used 190 to 220 amperes. This amperage was picked because it would allow the welder to make welds in any position without the need to change the amperage. Using this setting, a welder could deposit approximately 6 lbs/hr. of filler metal. The 200 amperes represents an acceptable deposition rate for vertical welding, but is only about 60 to 70 % of the amount to be expected from welding in the flat or horizontal position respectively.

Recommended Action

The survey team recognizes the convenience and time savings that results from not having to change the amperage settings when changing welding positions. However, there exists, on the market, machines that will allow the welder to change the amperage at the gun and thereby switch back and forth between the settings for doing vertical welding and those for doing horizontal welding. Where this is not possible, training of the welders to handle higher wire feed speeds in the vertical position without making oversized welds would also help reduce arc time. In the case of .052" wire, some applications may allow for amperage settings of as high as 270 amperes. At this setting or a slightly lower setting, a welder could still get increased deposition rates in the flat and horizontal position that are not presently being achieved.

Develop welding procedures that will meet the weld size, shape and quality specifications for the various material thicknesses. Ensure that the conditions are acceptable for most welders. Train all welding personnel in the application of the procedures in the materials and positions used at the Shipbuilding Company. As was noted in separate calculations, the optimum speed for most weld application reviewed during the survey is 260 amperes. Note that for many of shipyard’s applications flat, horizontal, and vertical welding can use the same machine settings.

After training and initial floor application, monitoring the wire feed speeds and procedure compliance by the welding supervisors will be essential. The welding supervisors' involvement will help to insure that the higher amperages will not result in loss of quality or overwelding. Also supervisors should identify reasons for noncompliance (example: poor fit) and take corrective action as required.

Key Results Area - Qualification of People

Qualification covers the ability to perform the required tasks in the shipyard as well as the ability to pass the required formal welding skills tests. Training is a necessary part of the qualification process. This training can be informal in the shipyard environment, or a formal mix of classroom and hands-on work. Every facility has specific methods and details that are unique. Part of the qualification process involves taking a person experienced in a general welding process, and adding specific product knowledge to the basic experience.

Observations and Comments

The welders sometimes enter the yard with the ability to weld and are tested before sending them out to production areas. In other cases they need to be trained using a shipyard program. This program, however, requires a great deal of time, much more than management feels should be necessary. One reason for this appears to be that although the welders are shown how to make the type of welds they will make in production, their training does not efficiently use the welders training time on areas of significant importance. As already mentioned, overwelding is not specifically addressed, nor is welding to welding procedures that will yield the best productivity results. The prevention of defective welds and rework through a working understanding of the essential variables is not specifically addressed. A training program that addresses these issues in an organized fashion, where the instructors themselves are trained to instruct in this fashion, would not only result in a reduction of training time, but would also turn out better trained welders more able to meet the quality and productivity expectations. This was one of the supervisors' greatest concerns and needs.

Recommended Action

A welding training/testing program is needed so that a comprehensive approach to "crew training" can be given to quickly and thoroughly prepare a welder for the requirements in the yard. This will allow new welders to more effectively meet the productivity requirements without the need for additional training from welding supervisors and other welders to complete their training while on the job.

Training is one of the most important responsibilities that management has. It is also one of the most beneficial from the standpoint of aiding the company to achieve their quality and productivity goals. To facilitate this training in the welding area, properly trained trainers and welding supervisors are essential. A properly trained trainer also known as an Internal Welding Trainer or IWT is able to assist in all facets of the welders training from the time of hiring and through the use of procedures, equipment and new welding processes to see that welders are always prepared properly for the job they are asked to do. The same is also true of trained welding supervisors that are able to support the welders under their charge to make them the most effective production workers possible on a day to day basis.

2.4.3 Prioritized Goal #3 - Reduce rework and scrap

Estimated Potential Savings - **$3,244 per welder**

Rework includes any unnecessary work whether documented or undocumented. These hours can be controlled and limited by applying the best methods and standards to the production work. The objective is to assure that incorrect work is not done. This can best be accomplished by training and then making each person responsible for his own quality performance.

A reduction in rework and scrap is normally the result of some positive action in other areas, but it can often be used as a separate objective in order to focus efforts. Since virtually all rework is a direct cost, any improvement will affect profit. We also use rework and scrap reduction as a way to cover some details that don't fit other categories as well.

Rework and the subsequent repair can be difficult to estimate and usually requires the input from welding supervision and quality defect sheets to get an idea as to the magnitude of the problem.

Key Results Area - Manufacturing Feasibility

The design function primarily controls the manufacturing feasibility. Factors such as material type, size and complexity of parts, fits and tolerances, joint designs, accessibility, and restrictions affect the manufacturability. These factors affect the ability of the welders to produce welds of consistent quality. It is important to recognize areas where alternate joint designs, part arrangements or assembly sequence can improve access.

Observations and Comments

Throughout the survey, repeated examples of welds were witnessed where welders had to get into awkward or difficult positions in order to make welds. In some cases, the welders were unable, once the welding gun was in place, to make the weld while looking at the weld. In other cases, the welders were not able to hold the gun at the correct transverse angle to make the weld because of the restrictive position.

Recommended Action

Make it a priority to establish a means by which design, manufacturing engineering and production can quickly address and resolve these situations. This is a little like a "fire prevention" activity that initially is hard to justify because each corrective action generally requires more time and effort than "living with" the problem one more time. However, the long term payback is realized later when similar boats or similar type constructions are built with either reduced or eliminated accessibility issues.

In the subject shipyard, the design engineering group already makes a "cartoon" type series of drawings that show the sequence that the assembly should be done. The same approach could be used to incorporate the best order to do the welding work, and for the production department to identify those areas where an alteration in the design would facilitate the accessibility.

In any case, where personnel have been trained to recognize situations where welders are not able to follow one or more essential variables for performing a particular weld due to positioning, these situations should be evaluated to remove the problem. This is especially true for the supervisor when monitoring the welders to identify such situations as part of the continuous improvement effort for the welding program.

Key Results Area - Weldment Specification

The weldment specification is used to identify the weld requirements and the inspection and acceptance criteria. This information is the basis for training the welders and inspectors to examine the welds in the same manner. Welders that understand the difference between acceptable and defective welds are able to recognize when the weld technique or weld parameters are causing defective welds and correct this condition before additional welding is done. In addition, with the inspector trained to the same acceptance standard, the confusion that results from inspectors rejecting work that the welders have already accepted is eliminated.

Recommended Action

The design and production functions should develop a dialog regarding weldment specification. Where possible, cross-training of people would be of significant benefit. Production personnel need to be cognizant of design requirements related to the acceptance of welds, so that design, production and inspection will have the same understanding of what is a visually acceptable weld. In addition, designers could benefit from a better understanding of the types of information that the production functions need to produce quality welds first time, every time.

Key Results Area - Workmanship Performance Standards

All work must conform to an acceptance standard. The engineering drawing and welding procedure cannot cover all the requirements, so written quality standards are a requirement for many different industries. Any standard should accurately reflect the service requirements of the product and the demands of the customer.

All welders should inspect their own welds and guarantee their own work to an established standard. Quality Control then performs a random sampling and final inspection to the same standard. Workmanship mock-ups could be used to show the desirable weld features and locations.

Observations and Comments

Workmanship must meet the design requirements in order for the product to perform correctly and reliably in service. In addition, there are manufacturing and code standards that identify what a manufacturing process must do to make a product acceptable to the customer's expectations.

Recommended Action

The use of productivity/quality mockup and workmanship samples made from the standard contained in the weld specification would provide a visual image of both acceptable and unacceptable welds. These visual aids would also serve as a reminder of the types of defects that can occur when weld procedures and good weld practice are not followed.

Train and qualify all fitters that make tack welds to a procedure that will ensure all tacks are incorporated into the first weld pass without grinding. Fitters should also be trained in proper manual cutting techniques to reduce excessive grinding.

Key Results Area - Weld Procedure Application

Welding procedures contain all of the essential information and variables that a welder needs to know in order to make welds that meet all quality and workmanship requirements. However, for a procedure to fulfill this purpose, the ranges on wire feed speeds, voltage and travel speeds must be of sufficiently narrow range to hold all welders using it to the same performance standards. To ensure this, a welder must also know and follow other additional essential variables such as gun angles and contact tip to work distance.

Recommended Action

Welding procedures containing the essential welding variables should be developed and documented to minimize or eliminate the rework resulting from out of control essential variables. The procedures should be thought of as a living document that allows developed parameters to be conveyed to the welders, in clear instructions, followed by training. This will give them a accurate understanding of how they are to perform their welding assignments to achieve all of the desired results.

Key Results Area - Personnel Qualification

Training is a management responsibility, and should be regarded as an important part of any new project. The people who will be involved in making a project successful must understand what is to be done, why it is needed, and how they fit in.

Qualification refers not only to the testing and qualification of welders, but also to the training and verification of performance for all people in all functions. It covers the knowledge required for a job, as well as the practical experience and ability to apply that knowledge to the product or function.

Recommended Action

Fully integrate welding technology, welding application, and shop practices into training programs at the shipyard. The qualification testing can be structured to require demonstration of skills in all areas before a worker is released to the yard.

When more detailed rework documentation is available, it should be used as a training aid to correct errors as quickly as possible. Also use rework data to refine and improve the training and qualification testing.

The training for welders and fitters should include how to inspect their own fit ups and welds. This will reduce the amount of rework by allowing the fitters and welders to constantly improve by learning from past errors by themselves and others. This training should be done using the documents such as the workmanship standards that were generated for production's use so that both the fitters and welders will become familiar with this type of document and will use it for reference throughout the workday. Fitters and welders that are trained to recognize the difference between acceptable and defective tacks and welds at the time when they are made, can use that knowledge to identify what they are doing to cause the defect. The reason they can do this is because the technique and parameters that they used to make the welds are still fresh in their minds. When welders learn of their defective welds after the welding supervisors' or inspectors' examination, what was done to make that defective weld, and who made the defective weld, is often forgotten.

Key Results Area - Methods Application

This area includes all work methods including fitting and welding methods. Correct methods must be communicated to the yard and then applied and monitored by the welders and supervisors.

Recommended Action

A study should be made and combined with a review of the components to determine the best way for welding them to meet the engineering requirements. This method should be documented and taught to the supervisors and welders to ensure a uniform and efficient method of repeat welding.

Key Result Area - Inspection, Measurement and Reporting

Tracking rework costs is an effective way to measure the effectiveness of the quality control program. The objective of the program must be to reduce the long term rework. It is possible that a temporary increase in rework may appear until the total program is in place and operating.

Observations and Comments

Control of rework must be at the shop floor level. Therefore, inspection by the operators in all departments is ideal, and monitoring by supervisors and auditing by inspection personnel will also be needed to ensure all standards are uniformly applied.

Rework reports provide data on the progress of the other projects designed to reduce total costs. Production, labor, and rework reports provide management with the information necessary to make informed decisions.

Recommended Action

The defect tracking chart is an effective method to track the level of quality as parts move through production. However, without a corrective action that not only addresses the deficiency, but also the root cause that leads to the deficiency the problem will most likely recur. This is where a well developed engineering function to provide follow up to the corrective action can make a significant difference, not only in dealing with the deficiency, but also with enacting permanent solutions as part of the corrective action.

Key Results Area - Corrective Action

Effective corrective action is the link that ties the final results to the initial weld. It must not only identify the right cause of a problem, but must also verify that the cure is effective. It requires the involvement of all parties who affect welding.

Recommended Action

Use existing personnel to apply more effective corrective action by improving reporting of recurring problems. A Leadman/Weld Leader and/or Internal Welder Trainer, if instituted, could be used wherever possible to help correct technique errors. The supervisors and inspectors must also be trained to recognize when a quality problem is a result of essential variables or incorrect technique as opposed to other causes that may require different solutions.

Ensure that corrective action is taken in addition to any rework that may be needed. This can be done by establishing an objective to reduce the number of repeat problems throughout the organization.

2.4.4 Prioritized Goal #4 - Reduce work effort

Estimated Potential Savings - Combined in with Prioritized Goal #5 - Reduce motion and delay time

Reducing work effort is a companion objective with reducing motion and delay time. The difference is that work effort projects focus on those elements that benefit the worker in performing a task. This includes any project that will reduce fatigue, and simplify or eliminate tasks. Some of the tasks that contribute to increased work effort are listed below:

-Fitting parts
-Reworking parts for better fit
-Positioning of people
-Slag removal
-Grinding
-Excessive pounding or hammering

Key Results Area - Process Selection and Application

The use of a welding process that reduces arc time per weldment and volume of weld metal deposited will by its nature decrease the amount of effort that a welder must expend to complete a unit of work. The application of a welding process that requires a lower skill level to ensure the same quality will prove less taxing to a welder and reduce the amount of fatigue he or she experiences. Welders, when they grow tired toward the end of the shift, are more prone to make mistakes in the form of weld defects, and they are prone to cut back on arc time thereby lowering their work output at the end of a shift. This is particularly noticeable with the use of extended work shifts and longer work weeks.

Observations and Comments

The overwhelming use of semi-automatic FCAW on most applications not only increases arc time over automatic and mechanized welding, but also increases welder fatigue. The use of mechanized welding equipment allows the welder to take an operator role toward welding which reduces the amount of tedium during welding.

The constant stopping and starting between intermittent welds and raising and lowering the faceshield requires more effort of the welder. Equipment exists to prevent this type of fatigue.

Welding using lower than expected amperages increases the arc time required to complete a horizontal or flat weld. One of the most tiring activities is the need in many cases to assume uncomfortable positions and then have to maintain them until the weld is completed. This is what occurs when a welder uses the same amperage to make both vertical and horizontal welds as previously described. Also, the use of gas-shielded FCAW where self-shielded would work adds more weight to the welders' gun and therefore more fatigue.

In the unit assembly area, many of the cramped hard to reach areas of the ship modules must be entered and re-entered by the welders several times to complete all of the welding in that area. This results in a great deal of fatigue. In a manufacturing sense this would be the equivalent of double or triple handling a part. All of the extra trips into these confined areas with their welding equipment is unnecessary and very fatiguing.

Recommended Action

Increase the use of mechanized and automated welding with such equipment as tractors with FCAW equipment and mechanized SAW "squirt guns." For example, for the horizontal base welds of the mud tanks, which are long and continuous, fillet welds would be good candidates for these types of improvements. This is another case of where an engineering group that is able to plan for the use of this equipment offline is so vital to quickly implementing projects such as this.

Other labor saving improvements would include autodarkening faceshields for welders doing intermittent welding to prevent the constant lifting of the welder faceshield. Also, when grinding is absolutely necessary, the welder can grind with the faceshield down and then begin welding again without having to raise the faceshield.

The potential changes of gas-shielded FCAW to self-shielded FCAW may be an option that should be explored. However, the elimination of having welders enter and re-enter these hard to reach areas would be one of the best fatigue eliminators. A more efficient planning of the fit up operations or a change in the approach should yield a solution that will correct this situation.

Key Results Area - Equipment and Tooling Application

To reduce work effort the proper equipment and tools must be available and in the right place. This applies to capital equipment, hand, or power tools. Availability and maintenance of shop services and facilities is also a critical part of this project.

Observations and Comments

During the survey it was observed that many welds are made out of position. When this is done either manually or semiautomatically, the work effort expended by the welder increases significantly and leads to a reduction of operating factor.

Recommended Action

The need to get as many welds as possible into position has already been stressed. The advantage to welders that work long days in hot weather will be noticeable.

A Preventive Maintenance (PM) procedure should be used with the welding equipment to deal with the issue of defective welding equipment. The procedure should include the welding supervisor taking control of all equipment that is reported as needing repair so that lost time due to equipment problems can be handled more efficiently. Additional thought could be given to the movement of welding equipment into and out of work areas. This could include labor saving devices such as smaller wire feeders, gun and cable assemblies and also push/pull guns for easier in and out of confined hard to reach areas.

The welding fixtures in the pipe and structural shop could be designed to rotate the pipe and large cylinders so that the welders could reach all of the welds with less effort.

The fixtures, where used, need to be identified and evaluated against the task that is being performed on them. All fixtures should have an engineering drawing; if an operation is identified as needing a fixture, a number is assigned for the building, tracking and maintaining of that fixture throughout its life. That fixture identification number is placed either on the engineering drawing or the routing to identify it for use on a particular assembly. A method describing the use of the fixture and training for the operator is required before the fixture is used in production.

One final recommendation in the area where welder fatigue may sometimes go unnoticed concerns the manual dropping and raising of the faceshield. The use of electronic autodarkening faceshields should be considered or reconsidered. The survey team is aware that some faceshields are in use. However, the following should be considered. During the survey we observed that the average welder using .052" diameter welding wire deposited 6.00 pounds of wire per arc hour.

If the average weld is two inches long, we assume an approximate weight of one fillet being .03 pounds. Given the welders' average deposition rate, this would result in the welders making on average 350 welds in an eight-hour shift. If two seconds were allowed for each faceshield lift, that would result in 11.6 minutes per eight-hour shift being consumed in the simple act of lifting the faceshield. The average time savings would be 0.194 hour per shift resulting in a savings of $8.26 per 8 hour shift, if $42.50/hour labor figure is used.

$8.26 X 135 welders X 240 work days/year = $267,750 per year. When the cost of the faceshields is factored into the savings, the savings for the first year with the cost of faceshields could be $254,000.

Key Results Area - Methods Application

Welding methods evaluations should include both the fit-up and welding work habits of the welders. The fabrication of interbottoms, piping, stiffeners, decks, engine rooms, bows and sterns involve many standard components. Although the size and configuration of these components may change, the basic concept remains the same. Building methods and operational sequences to reflect the most efficient manner in accordance with the quality requirements will reduce operator fatigue and thereby yield the optimum results in the long term.

Recommended Action

Some planning is needed to work out the weld sequences and thereby the effective amount of manpower that should be assigned to each area during the fitting and welding activities that are scheduled. The goal here is to not have the majority of the responsibility for this activity fall on the line supervision. Their ability to plan such things is limited by their other duties, and therefore they will not and cannot give the attention needed to effectively carry out the task. The welding supervisors can be much more effective supporting the welders in their charge and working as the eyes and the ears of management to help improve quality by implementing productive measures.

Key Results Area - Work Center Control

A thorough engineering approach should be followed in the development of manufacturing methods and associated tooling just as it is in product design. Too many shop and shipyard operations are based on trial and error and, even worse, there is typically insufficient time spent for trial.

The concept of work center planning is to provide the welder with everything he needs to accomplish the work with a minimum of delay.

You hire a welder to weld. The objective of work center planning is to improve the available arc time and then support the welder to minimize work effort (fatigue) and delay times due to parts input problems, maintenance problems and wasted motion. The objective of work center control is to see to it that the plan is working as planned.

Recommended Action

The use of a comprehensive plan and control in the unit assembly and completion areas as well as the other manufacturing and construction areas of the shipyard is one of the best ways to prevent excessive work effort, but the continued enforcement of this plan during each and every new module that is positioned will prevent work effort from returning to the job in the future. For no matter how well thought out the plan, if it is not documented and controlled within the work area, there is no assurance that the next time a welder is assigned a weld that all of the work aids, weld sequence and methods will be used. It is the work station control following the plan for building a module using the tooling and equipment assigned that ensures that the job is built as efficiently and effortlessly as possible first time, every time.

2.4.5 Prioritized Goal #5 - Reduce motion and delay time

Estimated Potential Savings - **$6,200 per welder**

This goal addresses the factors that cause "lost or unapplied" time on the job. The root cause of excess time is not always apparent. In most cases, the cause is not directly under the welder's control. Some action is needed to reduce the amount of delay time, for example. These efforts are to identify and control some of the following causes of excess time:

-Waiting for parts or assemblies
-Positioning parts
-Waiting for crane service
-Changing wire/electrodes/gun parts
-Availability and condition of equipment
-Delays in receiving work instructions or specifications
-Moving and handling parts
-Hand, foot and body movements during the weld cycle

Key Results Area - Equipment and Tooling

To reduce motion and delay, the right equipment and tools must be available and in the right place, and in good working condition. This applies to capital equipment, jigs and fixtures, and hand and power tools. The ready availability of shop support services, and the maintenance of the equipment and facility are critical parts of this project.

Observations and Comments

Fixtures and tooling should be built around the most efficient methods practical for the part. Fixtures should minimize excessive or unproductive motions or operations. Consider fixtures that "bring the weld joint to the welder" rather than the welder chasing the joint. This means less operations, less motion and handling time, therefore, more arc time. This is especially true in the shops and panel line and other areas where more of a manufacturing approach can be tried. In this approach, the need to address the welders' arc and non-arc time takes on new meaning. The emphasis is on reducing non-arc welding time so as to increase operating factor. In this way the maximum amount of welds is produced for every manhour worked.

In examples already cited, the large number of vertical joints vs horizontal and flat joints should be looked at from the standpoint of being able to rotate the part to bring more of the welds into position. This was especially true of modules containing innerbottoms and the engine room module where the use of profiles (transverse and longitudinal stiffeners) created an "egg crate" configuration that required welders to get in and out and make mostly vertical welds. The ability to rotate these modules at the most advantageous times would bring many or most of these welds into the horizontal position.

Also, some notice must also be taken of the welding equipment and its condition. The gun and cable assemblies and their repair must be tracked to see if a problem with loss time due to equipment failure exists. Welders who are off the job because their equipment is not working or they believe it is not working will result in lost time. This condition can and should be addressed by the welding supervisors on a day by day basis. If an equipment problem exists, the welding supervisor, after the welder, should be the first person to know. Only when the welding supervisor is convinced that repair of the equipment is necessary should the welder exchange the defective equipment.

Recommended Action

The ability to build one time fixtures and stands to properly position modules to minimize out of position welds should be combined with positioners, manipulators and rolls for more repeatable tasks. All of these fixtures and equipment should be used in conjunction with the module manufacturing concept to allow for stations performing specific types of construction to be performed. This approach would justify the set up of positioning and rotating equipment to handle the types of modules and assemblies that would pass through that station. Construction assignments like the supply boats provide an excellent opportunity to set up production operations that more closely resemble manufacturing. Many more efficiencies result from that approach than the more traditional construction approaches used in shipbuilding.

All of the welding equipment presently in use should be evaluated to determine its ability to produce currents and voltages equal to the machine specification for the length of the duty cycle. Any machine that does not meet this goal could then be either repaired or replaced.

Training and follow up efforts in the yard could be initiated to change the welders' habits as related to the proper use and care of gun and cable assemblies.

In addition, a gun and cable exchange program could be initiated to reduce downtime from breakdowns of this equipment. This program would run through the welding supervisors, as they would have replacement gun and cable assemblies in their areas. This type of program would not only reduce loss time due to equipment, but would put the accountability back where it belongs.

Key Results Area - Work Station Planning

The concept of work station planning is to provide everything the welder needs to accomplish the work with a minimum amount of delay time. For example, tack welding operations should be evaluated to determine if the way they are presently done is really suitable.

Fabrication operations can and should be engineered to the same degree as the design of the product. This promotes better productivity and quality, and desired performance will be achieved much faster than through the use of trial and error methods.

An effective and efficient work station will be governed by a meaningful process plan that controls the five goals.

Observations and Comments

In order for any component or module to show realistic expectations of reducing the cycle time, a plan identifying the amount of arc time and non-arc time activities must be formulated. The companion of this plan is the fitter plan which allows for all fitter activities to be done in such time and fashion as to allow the welders to maximize their time. In order for a plan like this to work, the actual performance must be sufficiently documented to be comparable to the plan. This way, a comparison between a plan such as a module being completed in the time planned and an actual performance that lasted that long or longer can be made. If the work actually takes longer it is necessary to know what has gone wrong so that specific corrective action can take place.

The evidence of a work module plan is what is sometimes collectively called a process plan. Inside of this process plan are such elements as engineering drawings, methods including weld sequencing and welding procedures, fixturing and tooling where applicable and how they are used. In addition, there is documented information of the acceptance criteria for the welds and any additional information that the welder needs to know in order to successfully build a quality component or module in an efficient and effective manner.

Recommended Action

The work station control plan is designed to define how a work area is to perform the assembly, fit up and welding tasks assigned to it. The concept of modular manufacturing uses a workstation approach for modularizing the task in a sequential manner. The approach that the shipyard could use would involve clearly defining the type and number of workstations. Each station would contain a single module or assembly and have a specific number of tasks to be performed while in that area. The number and type would be the result of the need to prevent bottlenecking at any of the work areas where the modules or components must pass before final assembly in the hull completion area. Most work begins on the panel line which is capable of handling all of the work it has now and potentially a great deal more. Downstream work areas from the panel line should be configured to complete the task assigned to them in a time frame that can support that production level. The crews that are assigned to a given area should be of a size to complete these tasks in the time allotted. Several principles should be utilized for planning this modular manufacturing approach.

A. Avoid all double positioning of personnel - all tacking and welding should be combined as much as possible, so that two different individuals do not have to get into position for the same weld.

B. A once-though approach should be used that maintains that no module is allowed to sit out a shift without work being done on it.

C. No double positioning of material - all modules should have a planned method and weld sequence that allows the supervisors and welders to perform all welding in position before a part is repositioned.

The planning of these work areas to handle the modular manufacturing is an intensive effort requiring input from design, production, and management. The coordination of this job, of setting up the workstations is normally handled by the manufacturing planners or engineering.

Key Results Area - Machine Performance

Proper performance of all production equipment is essential for quality and productivity output. Welding machines are often capable of functioning even though they are not working as well as they should. Control of the welding variables, both by the welders and supervisors, requires accurate and well-maintained machines.

Recommended Action

To address potential problems will require the use of a truly effective preventive maintenance program, which consists of several levels of maintenance starting with the welders performing maintenance on the consumable parts of the gun and cable as well as the wire feeder. This may include tips, nozzles, wire liner cleaning, and replacement and drive rolls. At the next level is an effective gun and cable exchange program, to allow equipment exchanges before problems can develop and prevent lost time due to poor welding or delays. At the top level, the maintenance department will ensure that all welding equipment is kept in the same quality condition as when it was new. This is done through the use of diagnostic tests that will identify components of the power supplies and wire feeders that are not meeting specification and repair or replace the components before returning the equipment to production. This program should work on a preventive maintenance schedule which takes into account the projected time a machine can perform before maintenance checks are needed. This type of program is designed to eliminate “waiting for equipment breakdowns” before removing it from service.

As part of the process plan and training program, welders should be trained to understand and do daily maintenance checks plus perform periodic preventive equipment maintenance. Especially with semiautomatic equipment, if it is not properly maintained, will cause erratic wire feed resulting in poor quality and productivity.

Establish a gun and cable assembly exchange program, since about 60% of fluctuating wire feed problems come from this source. About 30% comes from the wire feeder and 10% from the power source.

In addition, establish a program to insure that welders know how the equipment works, so that they are able to properly operate it. In the case of the constant current power supplies and the dual type of wire feeder, the welders must understand that the power supply control adjusts the amperage and the wire feeder control adjusts the voltage. The reverse is true if the power supply is a constant voltage.

Key Results Area - Methods Application

The consistency of the shipyard procedures affects the cost and quality of the product. Where methods are controlled, it is much easier to identify and correct both cost and quality problems. Ideally, there should be method sheets prepared for each type of fabrication. Realistically, the best approach is to use the input of engineers, supervisors and welders to arrive at the best methods. In many facilities, the supervisors and foremen are too involved doing busy work. If this is the case, an evaluation of the supervisor's responsibilities and priorities is needed to allow more time for supporting and monitoring of the welders to improve and control the fit and weld methods. There are many good ideas, but as is often the case they are not incorporated into the documented methods without a system for using the supervisors and welders.

Observations and Comments

Welders seem to find out through experience what is expected of them and then, through time, learn how to perform the work. The supervisors, leadmen, and experienced welders are the principal teachers when it comes to the sequence for welding up a module component. To date, as explained, the work is arranged in packages, but the method in which the fitters and welders are to work together to accomplish all tasks inside of that work package has not been documented. Knowledge of the time required is beneficial to determining different welding sequences. Some of this is empirically done by supervisors when they assign welders to different tasks.

Some of the practices that were observed being done by the welders, resulting in lost arc time, were the grinding of tacks and rough flame cut edges and chipping of slag that was entrapped due to poor welding technique. The need to drag equipment in and out of confined spaces and up and down ladders is both time consuming and fatiguing.

One important thing that a method imparts to an operation is an expectation of what is to happen. This allows everyone that is to participate in accomplishing a task to have the same understanding of what is to be done and the allotted time for doing it.

Recommended Action

All of the major components of the ship should have a developed method that reflects how the work is to be accomplished in the allotted time. The method should include both the fitter’s and welder’s duties for coordination purposes and the manpower required during the manufacturing phase. A thorough study of this method may reveal some instances when the fitter and welder duties should be done by a single person instead of two. As pointed out during the survey some individuals have dual qualifications and can perform in both the fitter role and the welder role. From the standpoint of efficiency of movement and best utilization of personnel while following a method this may be the best approach.

A method can also reveal areas where excessive blocks of time are being consumed on a particular task. This consumption of time, when viewed in a general way with many other tasks all joined together, may go unnoticed, but as a single set of steps in a method, becomes quite noticeable.

The making of intermittent welds has been a standard part of the shipyard's methods or years. A significant number of manhours are used chalking for weld locations. This time could be eliminated if the laser is used to mark these intermittent weld locations as part of the cutting operations or welders were trained to "eyeball" their starts and stops. Automatic darkening lenses in the faceshields could be used to lessen moving the faceshield up and down reducing fatigue and increasing productivity.

In the pipe shop, the use of fixtures, positioners, and mechanized as well as automated welding equipment, would be made a part of the welding method. This would eliminate a number of inefficient practices such as shielded metal arc welding (SMAW) when FCAW would be better. Also, the cutting of tubing for manifolds could be done with mechanized equipment instead of manually. The use of a method detailing these work instructions and equipment to be used as well as the training to the method would reduce significantly motion and delay.

The implementation of methods that are developed, documented and taught to welders before production on a part is started, is an effective way to reduce or eliminate many of the problems that welders encounter. These problems cause loss of time, additional effort and quality problems, and can be traced to the use by a welder of an incorrect method. One important point with the methods application is the need for buy-in by the welders, and the need for training. The buy-in comes from having welders and supervisors assist and provide input during the creation of the method. Training must occur before the method is used in production. At no time should the documented method be substituted for training. The documented method should only provide reference for the instructor or welder after the training is completed.

Key Results Area - Work Station Control

This is a companion project to work station planning. Work Station Control is the action phase of Work Station Planning. It involves proper control of such things as planned and implemented methods, tooling, equipment, material preparation and welding booth layout.

Effective work station control includes all activities and materials in the welders' work environment. This means controlling the following items to plans, specifications and standards:

- Welder skills and knowledge
- Communications
- Equipment and tooling function and availability
- Work place arrangement
- Methods, techniques and procedures
- Quality of materials and workmanship
- Time requirements (methods)

You hire a welder to weld. All other tasks and motions cause unnecessary and unproductive hours. The objective in this area is to improve the welder's part cycle time and support him/her to minimize work effort (fatigue), delay time, equipment maintenance problems and wasted motion.

Recommended Action

The implementation of a Work Center Control Plan that contains all of the elements of the process plan along with process control and training of the personnel will correct most of the motion and delay problems. The plan will also put in place the mechanism that will allow for corrective action and continuous improvement. These aspects will not only help to prevent improvements from being lost in time, but will also allow for modification and change as the needs in production warrant.

Serious thought should be given to setting up in the modular manufacturing areas a working arrangement which results in the fitters and welders working more closely together. Possible alternatives are composite crews of fitters and welders, individuals that are fitter/welders working in crews to fit and weld. Another possibility is methods that are designed for both the welders and fitters and prescribe what both are to do and at what time in the schedule the work is to be completed. In this case the workmanship standard defining the fitter and welder requirements will be necessary if the methods of coordinating their outputs are to work effectively.

Key Results Area - Auditing, Monitoring and Reporting

To effectively achieve results in this area, many previously held practices in the shop will change. Each of the four critical functions will contribute to this change. To ensure that all the functions as well as the welders, operators and fabricators carry out their duties; an auditing, monitoring and verification system will be needed. The result of this effort should show that quality has continued or improved, and that productivity has risen. However, these changes will not happen automatically just because a new work station plan and control have occurred. The auditing, monitoring and verification will give visibility, ensuring that old practices do not slowly return once the system is in place. The reporting portion of this cell is used to keep management informed not only on the progress of this effort to eliminate wasted motion and delay, but also to track its on-going performance. If unacceptable performance is found during the auditing from any of the functional areas, the reporting is used to call attention to the deviation and to prompt corrective action.

Observations and Comments

In any manufacturing operation, there must exist a way of measuring the performance of the workers and the equipment, in terms of both quality and quantity, so that modifications, changes and continuous improvements can be identified, implemented and verified for return on investment.

The strongest need in this area is to develop the welding supervisor as the monitoring arm of management auditing, monitoring and control. Too often the welding supervisor is given duties that will not allow the time necessary to work with and monitor the activities of the welders on a shift to shift basis. No other representative of management can better afford both the time and the opportunity to impact the day to day quality and productivity as the welding supervisor.

Recommended Actions

There is a standard rule in manufacturing "if you cannot measure it, you cannot control it." This is going to be very true regarding the implementation of work area planning and control. To make significant improvements in reducing motion and delay time, and work effort, it will be necessary to establish a method to measure the change and gage the improvements as the planning and control are put into effect in the weld stations. To accomplish this, the auditing and monitoring for reporting purposes could take the form of measuring performance against documented work plans, audits of weld quality against engineering acceptance criteria and monitoring of welder performance using a documented welding procedure. The purpose of these measures will be to determine if the changes made in the work booth are having the desired effect, and to quantify the results, thereby giving objectivity to the continuous improvement process.

3.0 Design, Content, and Conduct of Welding Supervisor Training Course

Several considerations influenced the design and administration of the training program for welding supervisors. Subject areas to be covered under the certification requirements had to include the subjects specified in the governing qualification standard AWS/ANSI B5.9:2000, *Specification for the Qualification of Welding Supervisors*. These subjects are delineated later in this report. The training subjects also had to satisfy training needs identified in the pre-training survey as well as cover subjects specific to shipyard manufacturing.

The delivery of the training to a large number of supervisors in an active shipyard presented challenges in the scheduling of the training sessions as well as the workload of the supervisor students. The training sessions were conducted after working hours on two consecutive Thursday-Friday-Saturday sessions. The supervisor students also organized themselves into additional study groups to review the material. Due to the intense use of mathematics to solve the welding economics problems, many of the supervisor students needed additional mathematics tutoring to bring their skills back up to par.

It was also recognized that many other personnel categories might benefit from exposure to parts of the training program. The Bender Shipyard management arranged to bring in personnel involved in design, engineering, detailing, and purchasing to benefit from selected portions of the training program.

The following outline details the design and delivery times of the training program:

3.1 Welding Supervisor Training Curriculum

Introduction Module

- CWS Program (45 Minutes)
    - How Training will be conducted
    - Supervisor Certification
- Training Objectives
    - Improve Weld Quality
    - Improve Throughput
    - Improve Productivity
    - Improve Safety
    - Improve Knowledge & Understanding

- The Science & Art of Welding (15 Minutes)

Total Welding Management Module

- The Barckhoff Welding Management "System" ™ (45 Minutes)
- Using the "Barckhoff Method"™
- Welding Work Center Planning and Control (30 Minutes)
- Use of Welding Mock ups & Workmanship Samples (30 Minutes)
- Quality Process Centers
- Supervisors Role (30 Minutes)
- What the Line Supervisor, Manufacturing/Industrial Engineer should know about welding
- The In-Plant Welder Training (20 Minutes)

Welding Training Module

- The Requirements of a Weld (90 Minutes)
- Welding Symbols (120 Minutes)

Productivity and Quality Improvement Module

- The Five Welding Do's/Goals (45 Minutes)
- Cost Effective Welding (150 Minutes)
- Welding Economics (150 Minutes)
- Economic Welding Variables (120 Minutes)
- Welding Process Selection & Cost Considerations (90 Minutes)

Welding & Cutting Process Module

- Flux Cored Arc Welding (90 Minutes)
- Submerged Arc Welding (90 Minutes)
- Laser Cutting (60 Minutes)
- Proper Use of Meaningful Welding Procedures (30 Minutes)
- Effect & Control of the Welding Variables (240 Minutes)

Quality Standards & Inspection Module

- Welding Discontinuities and Defects (90 Minutes)
- Inspection of Welds (45 Minutes)

- Visual Inspection to an Acceptance Standard
- Welding Process Control (120 Minutes)
- Training & Qualification of the Operator (30 Minutes)

Welding Health & Safety Module

- Welding Health & Safety (120 Minutes)

Base & Filler Metals Module

- Welding of Metals—Part I. (60 Minutes)
- Welding Various Metals—Part II.
- Fundamentals of Shrinkage & Distortion (45 Minutes)

Auditing, Monitoring & Reporting Module (60 Minutes)

- Welder Shift Sheet
- Welder Shift Summary Report
- Supervisor Monitoring Sheet
- Supervisor Report
- Manager Monitoring Sheet
- Manufacturing Audit
- Pareto Chart

Welding Codes and Standards Module (60 Minutes)

- Welding Codes & Specifications
- AWS D1.1 Specific Applications

Total 35.3 Hours

The welding supervisor students were provided with an extensive set of study materials that were produced by the project partner, Barckhoff and Associates, Inc. The materials are intended to serve as a continuing reference for the welding supervisors to assist them in their supervisory roles. In addition to the training materials, the American Welding Society furnished additional references to support the training program. These references could be studied by welding supervisor candidates outside of the standardized training program to assist them in taking the certification examinations.

3.2 Welding Supervisor Course References

AWS Welding Handbook 8th Edition, Volume 2, *Welding Processes*
AWS Welding Handbook 9th Edition, Volume 1, Chapter 7, *Residual Stress and Distortion*
ARE-7 AWS Resources for Engineers, *Residual Stress and Distortion* (alternate to Ch. 7 reference)
AWS Welding Handbook 9th Edition, Volume 1, Chapter 12, *Economics of Welding and Cutting*
ARE-12 AWS Resources for Engineers, *Economics of Welding and Cutting* (alternate to Ch. 12 reference)
AWS B5.9, *Specification for the Qualification of Welding Supervisors*
AWS QC13:200X, *AWS Standard for Certification of Welding Supervisors* (draft)
AWS B1.11:2000, *Guide to Visual Examination of Welds*
Z49.1:1999, *Safety in Welding, Cutting, and Allied Processes*
AWS A3.0:2001, *Standard Welding Terms and Definitions*
AWS A2.4-98, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

4.0 Design, Content, and Conduct of the Welding Supervisor Certification Examination

The American Welding Society is actively engaged in the delivery of third-party certification examinations to provide assistance to employers in determining the qualifications of employees and to provide an avenue of recognition to individual practitioners to demonstrate their knowledge and skill sets. The procedures and control mechanisms necessary for the administration of certification examinations reside within a volunteer standing committee within AWS, the AWS Certification Committee. The examination questions are reviewed for applicability to the required subject matter, correlation to the training program and reference materials, and for difficulty and understandability. Approved examinations are then considered to be confidential and protected documents and are subject to extensive controls to prevent their dissemination.

Representatives of all of the project partners met several times to agree on the weighting of the subject areas defined in AWS/ANSI B5.9:2000, *Specification for the Qualification of Welding Supervisors* and to formulate examination questions for each of those subject areas. The AWS Certification Committee gave permission to conduct a trial examination at Bender Shipbuilding and Repair Company in October 2002.

The trial examinations that were administered in October 2002 were in two parts. Below are listed each of the examinations and the subjects that were covered in each examination and an approximate weighting for each of the subjects. Candidates seeking certification in these trial examinations were allowed to use any references (open book) during the examinations. Each of the examinations lasted two hours. A minimum overall score of 70% was required for passing the examinations.

4.1 Welding Supervisor Certification Examination Composition

Part 1 – Fundamentals of Supervision	50 questions	
Knowledge of welding supervision	5%	weighting
Understanding drawings/specs	10%	“
Base materials/welding materials	5%	“
Welding, brazing, cutting, theory, and application	5%	“
Safety	10%	“
Welding instructions	10%	“
Welding inspection	5%	“
Work reports and records	5%	“
Understanding general applications of welding standards	5%	“
Part 2 – Welding Practices and Economics	30 questions	
Welding practices and production controls	10%	weighting
Welding productivity	30%	“

Although the certification examination is confidential, a number of questions were released to serve as sample study questions.

4.2 Sample Welding Supervisor Examination Questions

The following questions are illustrative of the types of questions that will appear on the CWS examinations.

1. Slag inclusions can occur because of the following cause?
   A. the electrode has no flux
   B. low amperage
   C. high voltage
   D. A and B only
   E. None of the above

2. Of the following answers which is an advantage of the shielding metal arc welding (SMAW) process?
   A. versatile in application
   B. no smoke
   C. continuous wire feed
   D. doesn’t require a face shield
   E. requires a shielding gas

3. Once a weld process has been selected, what other production requirements should be considered?
   A. material handling and fixturing
   B. ease of inspection
   C. set-up time allowance
   D. A and C only
   E. None of the above.

4. In gas metal arc welding (GMAW), the terms narrow beads, shallow penetration, low heat input, and good-in-all-welding-positions describes which type of welding arc?
   A. spray arc
   B. globular arc
   C. buried arc
   D. short - circuiting arc
   E. series arc

5. In gas metal arc welding (GMAW), what is the purpose of the shielding gas?
   A. Prevent smoke from forming around the arc.
   B. Make the welding arc easier for the welder to see.
   C. Prevents atmospheric contamination.
   D. Helps to reduce spatter.

6. Which of the following is <u>not</u> a factor that affects the amount of shrinkage and distortion?
   A. mechanical properties of the base metal
   B. size and shape of the weldment
   C. welding sequence
   D. welding process
   E. None of the above

7. To reduce shrinkage forces when welding, which of the following should be done?
   A. Make the largest practical weld.
   B. Minimize heat input.
   C. Design weldments to avoid the use of subassemblies.
   D. Pick welding processes that give shallow weld penetration, so as to use larger fillet welds.
   E. None of the above

8. If a welding symbol on an engineering drawing calls for a 3/16” fillet weld and the welder makes a ¼” fillet weld, approximately how much overwelding will this result in?
   A. 25%
   B. 50%
   C. 75%
   D. 100%
   E. None of the above

9. Which of the following joints would prove most economical when welding a T-joint 12 inches long?
   A. Weld the joint for 6 inches using a ½ inch fillet weld size.
   B. Weld the joint for 9 inches using a 3/8 inch fillet weld size.
   C. Weld the joint in two – 3 inch long fillet welds using ½ inch fillet weld size.
   D. Weld the joint continuously 12 inches using a ¼ inch fillet weld size.
   E. They are all the same.

10. A welder using the FCAW welds for 18 minutes out of every hour, what will be the welder’s operator factor?
   A. 10%
   B. 15%
   C. 25%
   D. 30%
   E. 35%

11. If the labor time to perform a welding task is 1 hour and 45 minutes and the total arc time is 30 minutes, how much of the time is non-arc welding time?
   A. 2 hours and 15 minutes
   B. 1 hour and 30 minutes
   C. 1 hour and 15 minutes
   D. 1 hour
   E. None of the above

12. A welding task that requires 10 lbs. of filler metal is being done using SMAW, with an E-7018 electrode with a deposition rate of 4 lbs./hr. If the welding process is changed to use Innershield FCAW, with an E-70T-4 electrode with a deposition rate of 12 lbs./hr. approximately how much total arc time will be saved?
   A. 100 minutes
   B. 75 minutes
   C. 150 minutes
   D. 50 minutes
   E. 200 minutes

13. A welding job takes 50 minutes to weld using FCAW to make fillet welds using a procedure calling for 210 amperes with a deposition rate of 6 lbs/hr. The welding procedure is changed to call for welding the same fillet welds at 300 amperes with a deposition rate of 10 lbs/hr. Approximately how much time will it take to weld the fillets using the new amperage?
   A. 20 minutes
   B. 30 minutes
   C. 40 minutes
   D. 50 minutes
   E. 60 minutes

14. IDLH is an acronym for:
    A. "identification of low hydrogen" in a welding electrode.
    B. In a confined space is a warning which symbolizes "interior design / low headway."
    C. "Immediate danger to life or health" and is a condition which imposes an immediate threat to loss of life.
    D. "Illumination design for lighting heights" in areas where good lighting is required for safe working conditions.
    E. "Instrumentation Design for Liquid Hydrogen" in cryogenic tanks.

15. Supervisors shall determine what flammable and combustible materials are present or likely to be present in the work location. They shall ensure that such materials are not exposed to ignition by taking one or more of the following actions:
    A. Have the work moved to a location free from combustibles and away from hazardous areas.
    B. Have the combustibles moved a safe distance from the work or properly shield against ignition if the work cannot be readily removed.
    C. Schedule welding and cutting so that such materials are not exposed during welding and cutting operations.
    D. Adequately hose down the entire area to be affected prior to welding or cutting operations that pose a danger of fire ignition.
    E. A, B and C only

16. Welding helmets with filter lenses are intended to protect users from:
    A. arc rays and from weld sparks and spatter which impinge directly against the helmet.
    B. foreign objects to the eyes.
    C. grinding wheels and discs.
    D. falling objects.
    E. All of the above

17. In terms of welding and cutting economics, manufacturing costs include:
    A. expendable equipment
    B. overhead costs
    C. direct materials (base and filler metals)
    D. direct labor (welder's labor)
    E. All of the above

18. The term "arc time" refers to:
    A. the length of time the arc is maintained while making a weld.
    B. the length of time to prep the joint, make the weld, clean and grind.
    C. the welding process amperage times the wire feed and travel speed.
    D. the deposition rate of a known process and electrode at a set amperage.
    E. the duty cycle of the power source.

19. The term used to determine labor costs that is a calculation of the ratio of arc time or actual weld deposition time to the total work time required of the welder or welding operator is:
    A. labor time
    B. operator factor
    C. arc time
    D. nonarc time
    E. direct labor (welder's labor)

20. Residual stress in weldments can ___________________.
   A. produce distortion
   B. cause premature failure
   C. result from external forces
   D. both A and B
   E. both B and C

21. High local stress in weld regions of low notch toughness may initiate brittle cracks that are propagated by any low overall__________ that is present.
   A. stress
   B. fusion zone
   C. heat input
   D. yield strength
   E. austenite

22. If metal is heated unevenly, _______________ develop.
   A. thermal stresses
   B. inherent stresses
   C. stress risers
   D. plastic flow
   E. Charpy V notches

5.0 Evaluation of Certification Results and Testing Improvements

The results of the trial examinations administered at Bender Shipbuilding and Repair Company were evaluated by AWS staff in accordance with established protocols for analyzing test results. All of the responses to all of the distractors were tabulated. Any question (or distractor) which accumulated a large number of incorrect responses was highlighted and referred for review to a panel of subject matter experts. Based upon that review, the question was either discarded, rescored, or left unchanged. After the review of the identified questions, the test papers from the candidates were rescored and the results recalculated. Candidates scoring at the minimum 70% correct answers received certification as AWS Certified Welding Supervisors. The final results of the welding supervisor examinations were as follows:

5.1 AWS Certified Welding Supervisor Certification Results

Candidate	Score%	Pass/Fail
DCA	70%	Pass
DLB	84%	Pass
LJB	88%	Pass
RLB	54%	Fail
VLB	82%	Pass
JDC	80%	Pass
JLC	81%	Pass
LSD	84%	Pass
GAE	69%	Fail
GAE	51%	Fail
CHO	89%	Pass
PRJ	73%	Pass
CRM	73%	Pass
RRM	85%	Pass
GWM	86%	Pass
GRM	66%	Fail
JLM	85%	Pass
CLM	90%	Pass

JWM	93%	Pass
LEP	80%	Pass
ASP	80%	Pass
GDP	69%	Fail
GRS	69%	Fail
RST	85%	Pass
RAW	69%	Fail

At the conclusion of the staff evaluation of the CWS certification examination results, the examination bank and examination results were turned over to the AWS Certification Committee for final review and improvements. The committee met in Miami, Florida on June 24-25, 2003 and were assisted in their review by subject matter experts from Barckhoff and Associates and Bender Shipbuilding and Repair Company. Several questions were improved and additional questions relevant to welding fundamentals were added. It was also agreed that the program would be limited to in-company presentations where the defined training program would be mandatory until such time as additional study materials could be developed. The availability of those study materials to the general public would allow the examinations to be made available to individuals who would not be exposed to the training materials used in this study.

6.0 Post-Training Evaluation

Approximately nine months after the initial CWS training at Bender, a post-training supervisor evaluation was made to ascertain what effect the training had on the activities of the participants that took the test. This post evaluation was conducted on June 18 and 19, 2003.

The purpose of the post-training evaluation was to document what effect the CWS training had and to seek out examples of quality improvement and productivity increases or improvements that are traceable to the knowledge gained during the training.

The post-training evaluation conducted Don Lynn and Ken Kerluke over a two day period of time and was divided into three segments.

1 Survey of the shipyard operations to observe productivity changes.
2 Questionnaires and interviews with CWS candidates
3 Review of documentation in support of all productivity activities by the CWS candidates.

As part of the productivity improvement emphasis during the training the five welding goals to achieve cost-effective welding were identified. These goals are:

-Reduce overwelding
-Reduce arc time per weldment
-Reduce reject, rework and scrap
-Reduce work effort (fatigue)
-Reduce motion and delay time

Reduce overwelding – the reduction of overwelding for example can be measured by comparing the size and length of welds to the engineering prints. During the pre-training evaluation in September/October, 2002, it was observed that none of the engineering drawings had any welding symbols on them. The post-training evaluation showed that the CWSs were successful in getting engineering to put the welding symbols on the drawings. In addition, weld fillet gages had been distributed to the welders and CWSs and daily checks of weld sizes and lengths were being made to confirm that they were to print specifications.

Another way to reduce overwelding is through proper material fit-up of the components being welded. In this case, the CWSs who work closely with or who supervise the shipfitters have began to identify poor fit-ups occurring on different ship modules and are working with the fitters to correct these occurrences.

Due to the CWS training, the way welding productivity is measured in the shipyard has changed. Before the CWS training productivity was measured in footage; it is now measured in weld metal volume deposited. With this change the true effects of overwelding can be measured and assigned a value to better justify the effort needed for corrective action.

Before the post evaluation one of the individuals that took the CWS training and works as a planner for the new construction was checking weld volumes instead of footages. He discovered that the shipyard's outside engineering contractor designated the wrong fillet weld sizes. The sizes specified were 5/16" when a ¼" could have been specified and ¼" when a 3/16" could have been specified. In the case of the 5/16" fillet weld, the overwelding could have resulted in a 58% increase in filler metal and labor hours required over what was needed. In the second case of the ¼" fillet weld the overwelding could have resulted in a 78% increase in filler metal consumption and labor hours. As a result of the increased attention to weld metal volume resulting from the CWS training, thousands of pounds of filler metal and manhours have been saved.

Reduce arc time per weldment - This goal involves the reduction in the amount of arc time required to weld a unit volume or length of weld. To this end the welding procedures and especially the wire feed and/or amperage to be used with any specific size and type of weld is critical. Before the training welding procedures were loosely observed, if at all. Welding procedures were believed by the welding supervisors to be mostly for the benefit of the outside inspectors and for code or standard requirements. The welding procedures were not viewed as a productivity tool to increase the filler metal deposition rate and thereby reduce the arc time per unit volume of weld required for deposit.

Following the training several changes occurred. The first was in the training school which trains and prepares new welders to begin working in the shipyard. This area is staffed by two of the new CWSs and through their efforts the training was changed to reflect the drive for more productivity. The shipyard primarily uses flux cored arc welding (FCAW) with gas and .052 inch diameter electrode for most welding applications. During the training the school basically used 200 amperes for all welding positions. After the CWS training and what was learned, the welding school now uses 260 to 270 amperes for flat and horizontal fillet weld position with a goal of increasing this to 300 to 320 amperes. The welds being made in the vertical position were increased to between 225 and 250 amperes, while the welds in the overhead are being done at 250 to 260 amperes. At the lower amperage of 200 the deposition rate is about 6 pounds per hour. At the new amperage the rate is from 8 pounds per hour for vertical to 9 pounds per hour for overhead and almost 11 pounds per hour for flat. This represents a 33% to 80% improvement in deposition rate and for any given size of weld a comparable arc time reduction. These changes were also coupled with a new grading system by the welding school trainers where they graded the quality of the welders at the required amperage settings for each position. Before welders are released to the production areas they have to demonstrate they can deposit acceptable welds using the required amperages. Another example of an improvement resulting from increasing the amperage was on the panel line where the travel speed due to the increased amperage rose from 23 ipm to 36 ipm for the stiffener welding.

Once in production, the welders are continually monitored by the new CWSs and their foremen to verify that the welders continue to make welds at the required amperage with acceptable weld quality. This reinforces the new welders training program so the productivity levels can be maintained without concern that the welders will inadvertently revert back to lower amperages or begin making unacceptable welds at the new amperage settings. In addition the new CWSs realize that the exiting welding force would also need to have additional training to raise their welding skills to use the higher amperage settings. This was accomplished through a one day training session to improve their knowledge and skills of understanding the application of the seven essential welding variables that makes it possible to achieve the ultimate wire feed speed.

Another innovation that was started by the CWSs was the use of a remote current control. This device placed on the wire feeder box allows the welders to change their amperage in addition to their arc voltage at the wire feeder. It provides the welders the ability to adjust their amperage as they change welding positions and thereby take advantage of the higher amperages when in the overhead and flat positions, while still using the correct amperage when welding in the vertical position.

Reduce rejects, rework and scrap – This goal involves the ability to identify weld defect conditions that are occurring. And not only fix the discrepancy, but also identify the root cause and effect corrective action. One of the important points taught during the CWS training was the effect of this goal to not only impact weld quality, but also impact the positive affect on productivity. Normally making improvements in quality and productivity through this goal is difficult without an organized effort. This organized effort at Bender was in the form of a welding committee staffed for the most part by the new CWSs. One of the things this committee began doing over the last several months, before the post-training evaluation was conducted, was to begin to track some of the more troublesome and costly rework occurrences. These occurrences are being tracked for corrective action on a "Welding Process Improvement Matrix" which has evolved into a "Rework Matrix" that is presented to the welding committee each week. The committee assigns and tracks rework occurrences to see that corrective action is taken and a solution is implemented.

Reduce work effort (fatigue) – This goal, along with reducing motion and delay time, involves the non arc welding time. The goal seeks to eliminate the unnecessary effort needed by welders to perform their daily tasks. These unnecessary efforts can involve having to get into awkward and difficult positions to weld. It can also involve trying to make welds located at inaccessible positions, where the welders cannot position their welding gun to make an acceptable weld. In other cases the welds are positioned in such tight areas the welders cannot position their heads so that they can see the molten pool and hold the welding gun at the same time, forcing them to virtually weld blind.

The new CWSs realizing that conditions such as these can be harmful have sought to identify and correct these conditions. In one case a request was sent to the engineering department to chamfer the corner end of a stiffener to allow better access to a weld that is located behind the stiffener. In another instance, the welding supervisors have begun identifying and recording the equipment movements made by the welders during the course of a working shift. This information is provided to the welding committee, who then institute a project to find ways of reducing or eliminating these movements thus reducing the welder work effort.

Reduce motion and delay time – To achieve this goal from an external approach all input materials, methods and weld sequencing, welding procedures and training to carry out the welding operation must be in place. From an internal sense the reduction of wasted motion and delay is a matter of minimizing or eliminating as many hand and foot movements as possible from the welders' task while producing the required welds. In short, this and the previous goal are about reducing the welders' non arc time to the lowest possible value.

The welding committee comprised of the CWS-trained welding supervisors have been identifying activities that the welders engage in that is inefficient. One change that has already been made is for all welding filler metals and welding consumables to be kept in a welding supervisors' area. This prevents the welders from having to go to the central stores to get these types of materials. The reduction in lost time has been significant. In addition the welding supervisors have begun to monitor the number of ins and outs that welders make into compartments of ship modules. In the past to complete a compartment the welders might have to carry their equipment and wire feeders in and out of an area several times before the welding was completed. The goal now is to have only one in and out where all welding is completed in a module during the welders one set up.

Another action which was taken by the welding supervisors' was spending more time with the welders to anticipate their support needs. Things such as having tools and equipment brought to the welders instead of them having to stop welding and get the materials themselves. This initiative was followed up by monitoring of welders to establish their day to day operating factor. Before the CWS training, the welding operating factor was about 15% on average for all areas. The new monitoring rate varied in different areas, however in some studied instances the rate was found to be between 25 and 32%. This improvement in operating factor can only be attributed to a reduction in the non arcing time of the welders allowing them to increase the arc on minutes that they have available during each working shift.

6.1 Post-Training Conclusions:

The Bender Shipbuilding and Repair Co. Inc., has demonstrated an interest in increasing their welding productivity while improving and maintaining acceptable weld quality. One of the ways that this interest has manifested itself was in the training and certification of welding supervisors at their Mobile, Alabama facility. Since, that time Bender management has continued to support the CWS welding supervisors in their effort to use the training they received to institute projects and tasks that will address and correct productivity problems in their welding operations.

These improvements have centered on the five welding goals taught in the CWS training program. The reduction of overwelding through the redesign of welds and the application of the specified weld sizes and lengths has reduced the arc time needed to make the volume of weld required. The same is true of the second goal where the amperage and therefore the deposition rates where increase through qualified application welding procedures and training to reduce the arc time for the weld metal volume required by specification. Through the welding school's training and monitoring by the welding supervisors and foremen the number of rework and repair instances have been reduced. This not only improved the quality of the welding but the production output though the reduction of time spent rewelding.

The welding committee made up of CWS welding supervisors has taken a "Welding Process Improvements Matrix" approach to address the last two goals of reducing welder work effort and motion and delay time. This has already resulted in significant reduction in non arc time. Before the CWS training program, ship modules on a large twenty ship order were showing reduction of two to three hundred manhours in welding time with each repeat module. The first wholly built module after the training showed a six hundred hour reduction in welders' time. The next module after that showed a one thousand hour reduction in welders' time. The shipyard management has attributed most of this reduction to the improvements in the welding cycle time effected by the work done by the CWS welding supervisors and use of the training they received.

7.0 Metrics for Verification of Effectiveness

The following sections correspond to the Prioritized Goals and are offered as tools for the monitoring of improvements made to the welding management system.

Verification of Reduced Weld Metal Volume

To measure progress in the area of weld size control, it will be necessary to have a system for checking to see that welds are being held to size. This can be done through a monitoring program by the welding supervisors and audits by QA or other personnel where a statistical number of welds made during a shift are measured for fillet weld size or weld reinforcement to assure that they are within + 1/32" of the engineered size. Where welds are found to be consistently outside of the acceptable tolerance, corrective action can be taken through on-site instruction and retraining.

Verification of Reduced Arc Time

The largest reduction of arc time is made possible through the use of optimum welding procedures. A monitoring program by the welding supervisors is required. If the welding machines have meters this can be done by having the supervisors compare the operating settings on the machines with the applicable welding procedures, if not the supervisor must carry a calibrated meter. The information gathered in this manner will assure that the maximum deposition rate is being achieved. This data is then combined with the data collected under the Priority Goal of the Reduction of Weld Metal Volume. Together they will show that weld size is being held, while the maximum deposition rate is being used. This will insure the greatest linear footage or travel speed for every minute spent welding. This in turn will lead to the lowest arc time.

Verification of Reduced Rework and Scrap

Reduction of rework is one of the most difficult goals to verify. Since, welders are able to correct their defects, and will be expected to correct clearly visible mistakes from earlier manufacturing operations without documentation, the amount of this work is seldom known. In most cases, this work is included in with the normal welding tasks, and is then just a part of the cost of making a welded component. However, as part of a comprehensive welding management system, welders could be required to fill out a welder shift sheet. The welder shift sheet would be completed at the end of each shift. This shift sheet among other welder inputs would be used to identify any rework that was performed by them during a work shift. The determination of what constituted rework can be determined by the company and taught to the welders. The rework occurrences and the time they consumed can then be addressed for corrective action. This will aid in preventing the cause of future rework. In addition, the amount of time for reworks can be tracked over time and compared to previous time periods as a measure of the improvement.

Verification of Reduced Work Effort

To document reduced work effort requires that the welders supply feedback on the type of difficulties that they encounter on a day by day basis. Many operations that contribute unnecessarily to the welders' fatigue in a shipyard have long been a part of the normal routine and operations in shipbuilding. To identify and remove these activities that reduce productivity requires the welders and supervisors to report these occurrences on the shift when they occur. This is another use for the welders' shift sheet that will allow welders to report lost time due excessive work effort activities. These occurrences would also be tracked along with rework for corrective action and comparison with past results for tracking the improvements to this goal.

Verification of Reduced Motion and Delay Time

As already discussed, the Reduction of Motion and Delay Time comes primarily from methods and work station control planning and execution. The primary responsibility for verification is the welding supervisor with the input of the welders. This is verification that should be tracked on a shift by shift basis by the supervisors using a monitoring sheet that reports the welders' conformation to the work center control plan and methods. This sheet should also report any occurrences that interfere with performance to this plan. These occurrences along with occurrences from other goals will be documented and tracked for corrective action. This feedback should be continually monitored by company management against past performance for confirmation of continuous improvement.

8.0 Conclusions

The Certified Welding Supervisor (CWS) Program was undertaken in recognition of the fact that the position of welding supervisor was an overlooked resource aimed at achieving the goal of improving weld quality and increasing productivity in the welding operations. For many years management has neglected the valuable contribution that a welding supervisor can make to the four most important metrics in the welding operations: Quality, Cost, Productivity and Safety. Without these and the key role of a welding supervisor, welding productivity is greatly diminished. This report will detail how much in dollars and time.

The underlying cause of this loss of the welding supervisor's input to improving productivity can be traced to inadequate knowledge and minimal amount of time that a supervisor actually spends with welders. Most welding supervisors have been given a significant number of tasks to do which diverts their attention away from the welders and what is going on in their workstations, which ultimately affects the welder's ability to produce quality goods in the most cost effective manner possible. Unfortunately, the perception of management is that supervisor time with the welders does not directly affect welding productivity. Often individuals who have little or no knowledge and training in the welding field are placed into supervisory roles.

The Certified Welding Supervisor Program was created to rectify this condition by offering welding supervisors and their companies the opportunity to put the welding supervisor in a support position for the welders to make them the most productive and best they can be. The Certified Welding Supervisor Program identified a body of knowledge all welding supervisors should know and understand how to use to increase productivity and improve weld quality.