# Portable Weld Inspection Management System Final Report

**Developed under**
**U.S. Government Contract No. N0014-03-C-0413**
**Subcontract No. 2005-323 Task Order No. 1**
**Via the Center for Naval Shipbuilding Technology**


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# Executive Summary

Visual weld inspections are performed manually by shipyard inspectors. Current weld inspection acceptance criteria specify absolute minimum requirements for structural fillet welds based on traditional workmanship limitations. The tendency in shipbuilding is to be over-conservative on weld size and inspection. The result is a culture of over-welding that deposits two to three times more weld metal than is needed for structural integrity. In addition, many welds are visually examined multiple times as panels are built into units and then into larger assemblies. Since visual inspection is somewhat subjective, welds which pass one inspection may fail subsequent inspections, leading to redundant and unnecessary inspection and repair cycles.

Over-welding and over-repair adversely affects cost, schedule, and performance. The cost to produce a weld is proportional to the amount of weld metal deposited, so over-welding adds directly to welding production costs. Additionally, the cost to repair a weld can easily exceed the original cost to produce the weld. Over-welding also causes excessive distortion which adds to the ship fabrication cost. The cost of flame straightening alone is estimated to exceed 11% of structure costs, the fitting costs for every assembly operation are further compounded by distortion. Over-welding, over-repair, and distortion mitigation also causes schedule disruption which increases delivery time. Finally, the performance of the ship is reduced as tons of excess weld metal is added.

An inspection tool is needed which performs quantitative, non-subjective quality measurements and then records the results in an easily accessible format. Such a system would offer the following benefits:

- Eliminate redundant inspections,
- Eliminate unnecessary multiple repair cycles,
- Eliminate repair of welds which meet minimum size requirements,
- Enable recording of weld size so that over-welding can be identified and reduced,
- Allow tracking of weld quality and statistical analysis of welding process capability to support lean/six-sigma continuous improvement initiatives,

The equipment evaluated has potential, but needs both hardware and software modifications before it can be used as a tool on a regular basis in a shipbuilding environment. As is, it will be useful as an audit tool to gauge the health of the visual inspection process and to further document the inherent variability of the visual inspection process.

# Introduction

The Portable Weld Inspection Management System (PWIMS) project received funding in November of 2004. The project team consisted of representatives from Bath Iron Works (project lead), Edison Welding Institute and Servo-Robot. The goal was to take an off-the-shelf inspection device (Servo-Robot's WISC) and determine what its capabilities were in terms of performing inspections in a shipbuilding environment.

Around the same time, a similar research project, Automated Weld Inspection (AWI) received funding from the Gulf Coast Region Maritime Technology Center. Lead by Northrop Grumman Ship Systems – Avondale Operations and collaborating with the University of New Orleans, the objective was to determine whether an alternative process exists that could combine flexibility, robustness, and versatility of human inspection with the impartial accuracy of an automated inspection system.

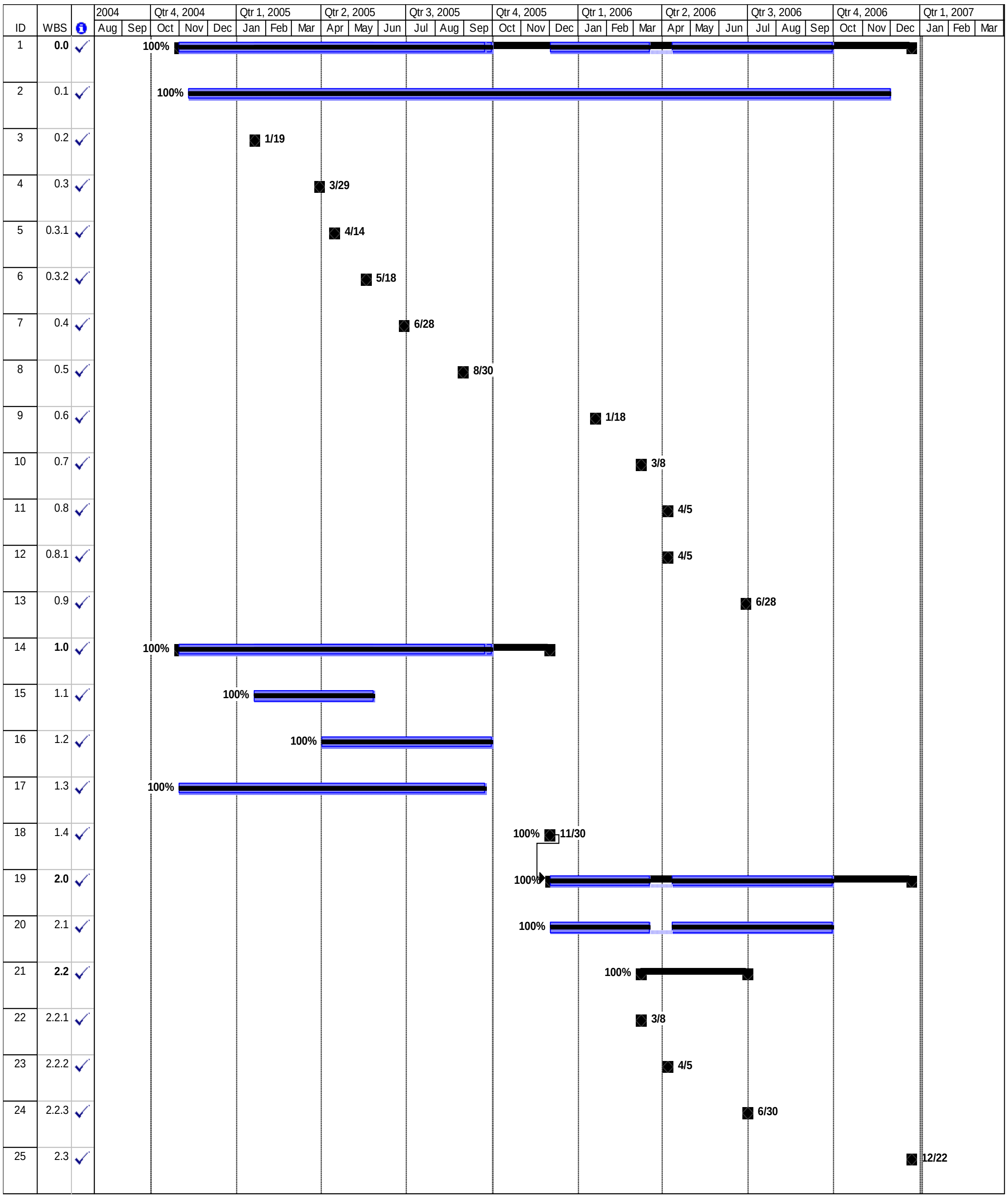
The two teams, PWIMS and AWI, met in January 2005, and agreed to work together to test whether the Servo-Robot WISC could be integrated into the shipyard environment to create a better weld inspection system.

# Acknowledgements

The investigator would like to thank the Center for Naval Shipbuilding Technology for their wisdom and foresight in funding this project. Thanks also goes out to the participants for their effort in developing and executing this project; Chris Conrardy for his project management experience; Connie Reichert LaMorte for her invaluable programming experience; Jeff Noruk for his background with laser sensors and Jeff Dumais for his exhaustive testing of the system. The investigator would also like to thank Allegra Treaster for sharing her findings of her project (AWI) which have been a tremendous help in fine tuning the capabilities of the final inspection unit.

# Project Schedule

This project was originally funded in November 2004. A kick off meeting was held on January 19, 2005. Phase 1 was completed in September of 2005 and a GO decision was made to fund Phase 2. Phase 2 began December 1, 2005 and completed on November 30, 2006. An overview of the project schedule follows:



# Project Tasks

## Task 1.1 – Specify Detailed Requirements for PWIMS

The purpose of this task was the development of the functional specification to ensure that all team members understood the requirements for the PWIMS prior to customizing the system software. The overall goal of this project is to demonstrate improved resolution and repeatability of weld quality measurements and better management of inspection data, as compared with current visual inspection practice. The selected hand-held laser-based inspection tool was not capable of measuring all features that are required by BIW for visual inspection. At the successful completion of this project, additional work will be required to expand the system capabilities (e.g., resolution and field of view of the sensor) so that other features can be measured.

BIW identified the best way to use the PWIMS. Immediate applications discussed include the following:

- Benchmarking Tool. The PWIMS can be used by BIW Welding Engineering as a benchmark to settle disputes regarding acceptable weld quality. This would improve consistency in the visual inspection operations by providing an unbiased "referee".
- SPC Tool. The PWIMS can be used by process-improvement teams to collect detailed data to support SPC analysis. In this case the PWIMS would be used for spot-check sampling in order produce reports on first-time-quality, defect types, repair rates, degree of over-welding, etc. The data may also be useful to designers in developing "fitness-for-purpose" design approaches.

In the longer-term the system may be used as follows:

- Quality Control Tool. The PWIMS can be used by the trades' inspectors to perform the inspection and to identify areas requiring repair. In this case the PWIMS generate a report for the supervisor indicating repair areas. A potential benefit of this would be a reduction in redundant inspections by producing reports of components which have "passed" inspection and should not be re-inspected. To accomplish this goal, the PWIMS will need provision for manual data entry so the inspector can collect information on all defects found, even if the PWIMS can not measure them.

All of the above potential uses were considered in the development of the functional requirements. Appendix A is a copy of the functional specification and Appendix B provides the Data Repository Architecture.

## Task 1.2 – Integrate PWIMS and Incorporate Shipyard Requirements

The overall deliverable in this task was to assemble the prototype PWIMS. The following tasks were accomplished:

- Development of data management software for the tablet computer
- Development of a central database
- Development of data reporting software

The Functional Specification and Data Repository Architecture documents created in Task 1.1 were used to form the basis of the PWIMS design. Appendix C provides a detail description of the PWIMS and its major components.

## Task 1.3 – Develop Data Analysis and Reporting Tools

PWIMS data analysis and reporting software made use of MS Access ™ and supporting visual basic code along with SQL Server database views and stored procedures. MS Access ™ was selected because the shipyard had familiarity with the software and could modify or expand the reporting tools as necessary. A variety of forms were developed based on the shipyard data analysis requirements. Appendix C describes the interface modules and different forms developed.

## Task 2.1 – Field Test and Refine PWIMS

A detail evaluation was conducted on the prototype system by having a VT Level III Examiner use the system during his surveillance of visual inspection personnel. This allowed for the collection of data both in terms of weld attribute data and equipment operational data. The evaluation was conducted on actual production welds under production conditions.

A detail report was developed and refinements to the system (within the limitations of the project) were made. Appendix D describes some of the refinements to the system.

## Task 2.2 – Demonstrate PWIMS and Report Findings-

A final demonstration of the unit was held at BIW for team members and CNST. Several presentations on the capabilities of the unit were given to various audiences (DD(X) LIPT, NJC TAB, NSRP Welding Technology Panel, SNAME). Appendix G is a presentation given SNAME and represents the type of presentation given as part of the Technology Transfer Activities. Appendix H is the paper published as part of the SNAME Ship Production Symposium. Appendix I is the article that appeared in the Welding Journal.

A PWIMS system was purchased and provided to the Navy Joining Center (NJC) so that a second system could be developed for use in other shipyards and industries.

A PWIMS User Manual was created that includes specific instructions for the user on how to use the PWIMS system. The User Manual is attached as Appendix E.

A document which describes the system architecture was developed to identify and divulge how the hardware and software parts of the PWIMS interact with one another. This document is included as Appendix F.

This report represents the final report of the project.

# Recommendations

The equipment evaluated has potential, but needs both hardware and software modifications before it can be used as a tool on a regular basis in a shipbuilding environment. As is, it will be useful as an audit tool to gauge the health of the visual inspection process and to further document the inherent variability of the visual inspection process.

The WISC portion of the PWIMS needs to be updated to make it more efficient and user friendly. Specific recommendations include:

- As a minimum the unit needs to be wireless. Wireless technology would allow the sensor to get into confined areas better.
- Reduce the weight of the WISC head to relieve the inspector from carrying and manipulating a heavy device.
- Make it possible to maneuver the WISC head around smaller radiuses while using the dynamic mode with the wheels. The entire sensor and PDA interface needs to be miniaturized to the size of a cordless drill. The device should be capable of being carried on a belt hook.
- Capability for portable printing of inspection forms should be explored. (Concept such as rental car return agent printers)
- Develop capability to measure welds that come to an intersection where the tie-in weld is 90 degrees from the other.
- Develop and/or improve some of the existing algorithms to handle:
    - Two welds in the same field of view
    - A tee weld with a sharp radiu in the field of view which does not match existing template
    - Partially ground butt and tee welds
- Battery life should be a minimum of 8 continuous hours.
- The PDA interface needs to be upgrade to allow for the use of a memory card. Consideration should also be given to using a Windows ® based PDA that will allow a much smoother interface and data transfer to the lap top. This could allow incorporation of all PWIMS functionality on the Tablet into the WISC package thus eliminating the need for a Tablet or a control box.
- The unit needs to have some way to apply a mark on the work piece when a defect is detected. It is recommended that this be manually controlled by the operator.
- The unit should have capability to be operated with an extension in order to reduce having the operator crawling on their knees and to reduce shoulder fatigue while inspecting overhead.
- The use of English units and terminology should be seriously considered for marketing the unit in the US.
- Improve editing functionality such as copy and paste in order to allow for easier modifications of joint tolerances in the joint libraries.

The software side of the system needs a few tweaks to make it more user friendly in order to produce reports that can be distributed (via email and presentations) to management. Specific recommendations include:

- All programs should have reports can be exported to (i.e. Excel)
- There needs to be a way to file inspection data by hull and a way to easily delete data from the Analyzer module.

# Conclusions

The PWIMS can be a powerful inspection tool but needs to be made more ergonomic in order to be used as an effective tool for visual inspection tasks and statistical process control analysis on a routine basis in a shipbuilding environment. As is, it will be useful for VT examiners to efficiently audit visual inspectors' performance and objectively resolve varying interpretations on the acceptability of a weld between two parties.