Maritime Cast Shop Integrated Improvement Plan

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Prepared By:
WILLCOR Inc and the Best Manufacturing Practices Enterprise
4321 Hartwick Road, Suite 400
College Park, MD 20740
www.willcor.com

Michael Delaney
Albert Lang

Understanding future effects of today’s decisions
ACKNOWLEDGMENT

The Willcor Team would like to acknowledge the superb accomplishments of all of the team members that contributed to the overall success

MCS CAST SHOP PERSONNEL

MCS UP-GRADE SHOP PERSONNEL

MR. WILLIAM MANKINS

DR. SHAHRUKH IRANI

MR. DAN D’AGOSTINO

MR. ERIC COLLET

MR. NICK BOUCHAT

MR. DAN GALLO
EXECUTIVE SUMMARY

The Maritime Cast Shop Integrated Improvement Plan, sponsored by the Defense Logistics Agency’s Industrial Base Innovation Fund, resulted in significant increases in productivity, reduction of work-in-progress, and substantially reduced cycle times that will lead to reduced casting lead time at the participating Maritime Cast Shop (MCS).

Key company measures over the most recent six months (June-November 2009) of this project demonstrate the impact of the plant floor improvements described in subsequent sections:

- 20% Improvement in efficiency in Upgrade and Inspection
- 26% Reduction in work in progress (WIP)
- 28% Reduction in the close out report rate through the quarter ended Sep 2009
- 34% Value added capacity increase in Inspection (constraining department) resulting in reduced cycle/lead time
- 4.7% Scrap reduction from the same timeframe of the previous year

The Willcor Team developed a unique approach to improving operations for foundries. The Willcor approach varies from traditional tactics that target single cast components and improve performance ‘one casting at a time’. The Team’s methodology took a comprehensive system view and targeted improving foundry operation work processes and product lines.

The project was accomplished in two phases. The first phase being an assessment to tailor the plan to the unique needs of the MCS foundry and ensure an effective use of resources. A ‘menu’ of activities was presented to the MCS management. The MCS selected activities and the Willcor team formed action groups to accomplish those activities. Sites at which MCS improvement activities were conducted included the MCS upgrade facility and the MCS foundry operation.

At the MCS upgrade facility, the Willcor Team conducted projects centered on the principles of Lean Engineering and JobShop Lean. The first significant activity was to perform Lean engineering training. Brainstorming with the MCS on limiting constraints and desired improvement areas lead to a number of projects. These projects generally addressed constraints that limited capacity and also methods to reduce transportation and handling, both of which had a positive impact on cycle time and projected lead times.

At the MCS cast operation, the goal was to provide off-the-shelf cost effective tasks that would lead to improved 1st time casting quality. As efforts progressed, training in Lean Engineering principles was added to the scope of the work and resulted in the conduct of 5S shop organization efforts as well as the establishment of daily stand up meetings between mechanics and supervisors. Projects that successfully went forward included improved facilitation of scrap and revert, use of 3-D CAD drawings, and mold heating. Though not completely implemented at the time of this report, progress was made in the implementation of Manufacturing Resource Planning software, temperature monitoring and weight management at the melt station improvements.
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1 SUMMARY

1.1 INTRODUCTION

Under the auspices of the Maritime Cast Shop Integrated Improvement Plan this project provided significant improvements to a specialized maritime defense and commercial sector foundry.

The Willcor Industrial Base Innovation Fund (IBIF) proposal was a result of observations made while assisting General Dynamics Electric Boat to improve their supply chain which included critical casting suppliers. Shipbuilders periodically experience construction schedule delays with resultant cost increases resulting from castings issues. Casting issues in shipbuilding include the late delivery of components as well as the late discovery of latent quality issues. Costs of shipyard delays are typically vastly out of proportion with the actual cost of the casting itself.

During the conduct of previous efforts, it was noted that casting houses supporting U.S. Navy shipbuilding have several common characteristics:
- The manufacturing effort is typically high mix, low volume
- Radiographic casting upgrade processes and the subsequent defect weld upgrade, review and approval process is a cycle time driver
- The business is frequently small, often under one hundred employees
- Environmental policies discourage the development of new casting businesses or expansion of existing operation, and therefore most of the maritime foundry industrial base has been established for several decades
- The business has not made the investments to incorporate state of the art practices in:
  - Physics based finite element solidification modeling software tools
  - Technical process innovations and improvements
  - Continuous improvement techniques developed specifically to support reducing cycle time and waste in high mix, low volume manufacturing

Based on benchmarking and other related work, Willcor conceived of an approach to improve foundry product lines beyond the traditional tactic of improving “one casting at a time.” The proposal included four elements integrated into a program designed to improve the upgrade process and first time cast component quality:
- Job Shop Lean - reduce production lead times on short-run, low volume, castings
- Physics Based Software Tools – off the shelf technology to improve mold design
- Technical Processes Assessment – deploy industry best practice technologies
- Computed Radiography – digital files to replace costly film and improve cycle time

Significant progress was made on these tasks with the exception of Computed Radiography. The delay of approval by NAVSEA for standards for the application of Computed Radiography on nuclear, Level I and SUBSAFE components, the primary products of this foundry, made the execution of this task problematic. (Note: The MCS foundry has decided to buy Computed Radiography equipment for preliminary quality
and information shots. The forward leaning thinking of this foundry will place it at the
tforefront of Computed Radiography use once these standards are approved.)

The MCS decided to partially implement the Physics based solidification modeling
capability as originally proposed by BMP. The MCS had questions on the cost benefit
equation given the very small production runs and the investment in Computer Aided
Drawings (CAD) which have not been made available from the customers. The portion
of this task that was completed was highly successful. The MCS hired an engineer who
was trained under this task in CAD tools. The CAD capability allowed the MCS to
outsource solidification modeling to an outside provider.

The success criteria of this project is the number of recommendations and projects that
are “transitioned” for use by the MCS. The Maritime Cast Shop Integrated Improvement
Project resulted in the implementation of numerous plant flow changes, concepts and
technologies with significant investments made by the MCS, all of which have
contributed to significant improvements in the manufacture of cast components and the
reduction of schedule and cost risk to submarine and aircraft carrier construction
shipyards. A summary is provided as Attachment A.

1.2 SUMMARY, RESULTS OBTAINED AND CONCLUSIONS
1.2.1 JOB SHOP LEAN

Typical lead times for maritime sector valve bodies are about 30 weeks. Larger castings
such as hatches and hull trunks are typically double this lead time. A cladding process
applied to a cast component can have lead times that approach two years. Job Shop Lean
(JS Lean) has successfully reduced similar lead times when applied by the DLA R&D
Enterprise Team (DLA-J339) and the Logistics R&D Branch (DLA-DSCP) to forges in
the aviation and land sectors. The Willcor team successfully applied JS Lean techniques
to maritime sector foundries during the course of this work.

The MCS upgrade facility (Upgrade) and foundry (Cast shop) are true job shops; they
both contain a number of “monuments” and job-to-job variation demands a high degree
of flexibility on the shop floor. The foundry and weld upgrade facility are integral parts
of the value stream. Upgrade is integral to the nuclear, Level I and SUBSAFE maritime
foundry castings and determines about 65-85% of product lead time.

The primary goal of this task was to reduce the average cycle time for castings that are
processed in the upgrade facility. Second tier objectives which supported the primary
goal were:
• To reduce the total time spent to complete weld/grind/inspect cycles for emergent
  repair on the castings
• To improve work-flow and reduce Work in Process (WIP) by improving the storage,
  control of workstation queues, and improving scheduling and tracking of active
  orders
• To identify and improve production constraints and bottlenecks
• To increase value-added utilization of resources in the work cells identified as
  constraints

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During early efforts the Inspection Department was identified as a critical constraint which, along with other intra-shop transportation and handling, contributed to a large amount of WIP present on the shop floor.

- To achieve these goals and objectives, specific projects undertaken were:
  Implementation of a manufacturing cell and associated area layout improvements which reduced casting transportation and handling.
  Implementation of a scheduling system between the constraint department (Inspection) and the non-constraint departments (Grinding, Welding and Radiography.)
  Improvements in the Inspection Department (constraint department) layout, supporting tool access/organization, which improves overall plant throughput.
  Analysis and identification of ways to improve throughput in shipping and receiving which was co-located with inspection.

Initial focus was placed on improving the overall plant constraint, which was inspection capacity. The Team initially found over production at several work centers in the upgrade facility. Inspection did not have the capacity necessary to increase throughput and therefore reduce cycle and lead time. Theory of constraint methods were applied to this bottle-neck and the team achieved a throughput increase of 34% at inspection.

Based on analysis of a sampling of casting patterns, the MCS decided to implement a cell that would co-locate workstations for Grinding and Welding. The capability for grinding or welding technicians to perform self inspection using portable Magnetic Particle Inspection hand held units was also developed. This provides technicians the ability to self-inspect and reduces the number of surface defects found at the final ‘buy off’ formal inspection. The following benefits are realized with implementation of this cell:

- 26% - 42% reduction (part number dependant) in the total number of part moves throughout the shop and reliance on bridge crane and forklifts whose availability and slow speed of operation contribute to inefficiencies
- 20% - 42% reduction (part number dependant) in the number of intra-shop Grind⇒Inspect⇒Weld⇒Inspect loops

Personnel and resource limitations at the MCS required implementation of cell improvements to be accomplished in phases. Phase 1 is complete and additional phases are in planning.

Key company measures over the most recent six months (June-November 2009) of this project demonstrate the impact of the plant floor improvements described in subsequent sections:

- 20% improvement in efficiency in Upgrade and Inspection
- 26% reduction in work in progress (WIP)
- 28% reduction in the close out report (report shows planned to actual labor element per casting and any problems encountered) hourly rate through the quarter ended Sep 2009
• 34% Capacity increase in the overall constraining department, Inspection
• 4.7% scrap reduction from the same timeframe of the previous year

Theory of Constraints methods were applied which reduced WIP, an indicator of increased throughput through the plant and Inspection constraint. Increasing Inspector’s “value added” inspection time by 34% provided concrete evidence of additional capacity gains in the plant constraint. This improvement reduces cycle time and overall lead times of the castings, a key goal of the project. Improved quality of castings, another goal of the overall project, also contributes to reduced WIP as this causes less work content in Upgrade. Scrap rate trends during this six months show a 4.7% reduction from the same timeframe of the previous year.

Improved productivity measures such as reduced labor hours as a percentage of sales are being observed. This observation demonstrates success in removing non-value added activity in the Upgrade and Inspection processes. Initial casting quality also appears to be improving based on the company’s recent casting close out reports. These reports provide data on work performance against standard or planned hours. In a recent set of about forty close-out reports only one casting exceeded planning estimates.

1.2.1.1 Conclusions

Job Shop Lean has proven to be a flexible and adaptable methodology that is equally successful in the MCS foundry as it was in prior DLA forge applications. The MCS foundry and associated upgrade facility has improved in a number of critical areas as demonstrated by improving company measures which indicate capacity/throughput has been increased, which in turn reduces the lead time of critical maritime castings. JS Lean has proven to be an excellent precursor to other technically focused foundry process improvement methods.

1.2.1.2 Lessons Learned

1.2.1.2.1 Process Mapping

It is recommended that process mapping (and value stream mapping) which identifies areas of waste and improvement opportunity areas precede efforts focused on the foundry technical process. Process mapping helps the technology focused efforts get off to a faster start as the entire process has already been mapped out and viewed from a holistic “system” level. The methods/tools used in JS Lean and quality improvement efforts have many similarities and are often synergistic. Group technology approaches which are a cornerstone of JS Lean are an important starting point in a custom foundry such as this that has a high mix/low volume business or product base. The WILLCOR Team believes that the hands on approach taken with an engineer or engineer intern (with appropriate JS Lean training and ongoing mentoring) working onsite with the company accelerated the pace of adoption of the methods and improvements. Strong involvement and coaching of managers by the company President/CEO is essential to achieving the rapid success MCS has seen to date.
1.2.1.2.2 Customer Driven Hold Points

An ancillary issue observed at the MCS and by the WILLCOR team at many other component manufacturers is the untimely accomplishment of customer required hold points. Customer required hold points are essential elements of the customer’s supply chain quality assurance plan. These hold point requirements should not be diminished but should be better managed.

The untimely accomplishment of customer required hold points cause components to be stored as work in progress until the customer can accomplish the inspection. As with any WIP, cost and lead time is increased and instability in schedules is created.

It is incumbent on the shipbuilding industry to recognize this issue and take steps to mitigate its impact.

1.2.2 Physics Based Solidification and Computer Aided Drawing (CAD) Software Tools

During the Assessment phase, the WILLCOR team worked with the foundry managers and senior trade personnel to develop the information relevant to implement physics based software tools and 3-D modeling capability.

The Willcor Team developed an incremental plan to build aptitudes and skills necessary to deploy 21st Century software tool implementation. The plan identified and enabled the ability to develop critical knowledge and capabilities essential for the successful deployment of commercially available physics based solidification tools. The critical steps identified were:

- Identify MCS personnel with credentials and background suitable to learning and using sophisticated engineering software tools
- Train MCS personnel in the use of 3-D CAD software tools supported by physics based solidification suites
- Put the 3-D CAD software into regular use in the mold engineering processes
- Develop the ability to use the 3-D CAD software as the foundation of the development of Computer Numerically Controlled (CNC) machine code for the manufacture of patterns
- Train the MCS personnel in the use of a commercially available physics based solidification software suite
- Validate the physics based solidification software in the cast shop though the use of test pouring
- Make process changes
  - Bidding and marketing operations request digital renderings of cast components
  - Integrate software tools into the core operations of the cast shop and the marketing operation

After reviewing this task, MCS management decided in March that the costs and resources associated with conducting this task would be large and might not be offset by savings over the typical small quantity production runs. As such, it was decided that the
immediate implementation of the physics based software tools was not feasible based on present realities of the cast shop operations. All other elements of this task such as the training in CAD tools were conducted. To support activities in this area, the MCS hired an engineer with appropriate computer bona fides. Key cast shop personnel joined Willcor Subject Matter Experts to form a team to execute activities that would enable the 3-D modeling capability.

1.2.2.1 Results

To familiarize the new-hire engineer with casting operations, the team developed a process map for the cast shop. This dual use document was employed as a training aid as well as an overview of operations for the targeting of process improvements, discussed in the next section.

The new-hire engineer had basic knowledge of the 3-D CAD SOLIDWORKS software package and initiated use of this tool to generate digital renditions of patterns. MCS engineers attended training provided by TRIMECH Solutions, an authorized reseller of the SOLIDWORKS software. The foundry then used the SOLIDWORKS software tool to generate digital renditions of patterns.

Both the MCS marketing personnel and the Willcor SME requested digital renditions of cast components to facilitate the use of 3-D CAD software. Customers were either unable or reluctant to provide digital renditions of components.

The MCS has, on a limited basis, started contracting for solidification studies of their more difficult or problematic castings by a third party source. The third party used the 3-D CAD drawings produced by the MCS and evaluated mold design using physics based solidification software. The MCS use of the third party evaluations has so far produced successful castings on two occasions.

The MCS has also stated they would use the 3-D CAD drawings to explore the use of CNC routines with their suppliers.

The MCS ultimately decided not to conduct this task as originally proposed due to concerns of overloading the staff and questions surrounding the return on a substantial investment given the small production runs of each mold modeled. The task was partially completed and successful in that MCS hired an engineer with basic CAD tool skills that were enhanced through training. This placed MCS in a position to use Physics based tools on their more challenging castings with an a third party provider on an as needed basis and positioned themselves to develop the capability in the future if determined cost effective.

1.2.2.2 Lessons Learned

A methodology or partnership approach needs to be developed that would support making the business case for a foundry to justify purchasing and use of these mature yet expensive tool capabilities. Elements of this methodology would include investments in CAD renderings by the design house (shipyards have not yet provided electronic CAD design in this case), and training an engineer or technician to use the CAD and
solidification modeling tools. If, as in this case, a business case can not be established, then outsourcing of part of the work or forming a consortium to share the fixed costs may be the appropriate alternatives.

Shipyards and 1st tier shipyard suppliers need to share digital renderings of components with foundries. For several decades, shipyards and 1st tier suppliers have used software packages such as CATIA for overall ship design. These ship design software packages require digital renditions of valve bodies and other components. Component manufacturers require digital renditions to generate CNC routines. Making these items available to foundries will facilitate the use of 3–D CAD drawings in the foundry environment, minimize the cost of pattern manufacture, and facilitate the use of physics based solidification packages.

1.2.3 TECHNICAL PROCESS ASSESSMENT

The MCS produces quality castings for markets that accept only the best available cast parts for use in the most critical, nuclear, Level I and SUBSAFE, applications. Observations from visits to the MCS cast operation and upgrade facilities show that high quality products are being manufactured and shipped.

The goal of this operation must be to make defect-free castings; the first time and every time. The careful selection and application of commercially available off-the-shelf technologies and training will improve first time quality of as-cast components and facilitate meeting customer specifications without extensive upgrade activities.

Production of castings with surface and/or internal flaws requires the defects be identified by inspection, ground-out, occasionally weld repaired, and inspected again. Typically, this is an iterative process. Lack of 1st time quality can be responsible for significant amounts of process time and production costs. It is a well established principle that it is not possible to inspect in quality.

In the Melt Shop, all procedures must be written and followed for every casting produced to ensure the consistency of process. Melting alloys requires that chemical compositions are to specifications and, as importantly, furnace operations and practices must be replicated each time a heat is made. Molding and casting procedures must also be adhered to for every part that is cast. To support failure analysis and quality record keeping functions, appropriate data must be recorded and archived.

The MCS cast shop operation produces a wide variety of alloys, including steels, stainless steels and cupronickels, in a wide variety of sizes. This exacerbates process control compared to a foundry that produces the same grade of steel day after day which is cast it into similar sized molds. The changes recommended in this report, especially those that are procedural, are for the purpose of creating processes that can be duplicated irrespective of the alloy being melted and cast. It can not be over emphasized that each alloy has its own metallurgical properties and the procedures used to produce it are specific for that material, and the written instructions for that grade of alloy must be satisfied.
A critical improvement is the frequent and accurate measurement of temperature. Temperature control is important to achieve the desired chemical composition and to consistently produce the technically acceptable castings.Weights of charges, amounts added, the quantity of material in the furnace or AOD vessel are essential because the rates of reaction are dependent on composition, temperature and time.

The following recommendations made were primarily procedural and require a minimum amount of capital expenditure. Adoption of the recommended practices and providing additional training to both managing and operating personnel should produce benefits in product quality and delivery.

- Purchase optical infrared pyrometers. A high temperature range to unit for measurements in the 3000°F range and a low temperature range instrument for measuring temperatures less than 1000°F.
- Evaluate commercially available crane scales for suitable for use in conjunction with ladles containing molten metal. A heat shield is required to protect the electronics in the scales.
- Establish a mold heating station using existing mold heating ovens to pre-heat to approximately 250°F molds after closing and prior to setting them in place for casting. After proof of the utility of mold heating, explore other commercial mold heating solutions capable of heating multiple molds to supplement the existing ovens.
- Establish melt shop practices and written procedures that will determine actual weights and chemical analysis of revert. Establish a routine that will consume all scrap and revert at the same rate that it is generated to prevent accumulation and the building of inventory. Utilize the maximum amount of revert material to make up all furnace charges instead of using raw materials, such as punchings, which must be purchased and added. Punchings add new dollars to the melt costs whereas revert has already been purchased and is essentially “free” material in the charge.
- Provide additional training in the metallurgy and physical chemistry of the Induction Melting furnace and the AOD vessel to management and operating personnel. Praxair is a source of this service on the operation of the AOD vessel as well as the reactions that occur in the vessel. Instruction on the theory/practice of the Induction furnace can be taught by a qualified metallurgist.
- Observations and recommendations were provided in the following areas:
  - Operation Sheet development
  - Process conformance quality
  - Casting Foundry Floor Observations
  - Finishing Operations Foundry Floor Observations

Personnel and expertise were provided to coordinate recommended changes with the following results

1.2.3.1 Results

Optical Pyrometers – Contact pyrometers were determined not to be a viable option for this application. Two brands of pyrometers were used on a trial basis. Neither brand was successful. Both the accuracy and the precision of instruments came into question. The MCS used two distinct pyrometer types, the first type measured the intensity of the
infrared emission. The accuracy and precision of the intensity style of parameter will be significantly affected by the smoke and particulate associated with a pour and was rejected. The second type of instrument was a ‘two-color’ device that is not affected by smoke and particulate. Operations with the ‘two color’ device still resulted in problems with accuracy and precision.

The cast shop uses a bottom pour ladle for teeming molds. On further study, it was determined that mechanics of the bottom pour requires personnel to continually move around the mold and ladle. Signal interference caused by this personnel movement caused the two-color pyrometer to have accuracy and precision issues. The use of a pyrometer is considered essential for process control and failure analysis efforts and the Willcor Team recognizes that a solution which works for this application is still required.

Scales for in process weight determinations – The MCA cast shop is still actively pursuing this technology. They have experienced issues with the size of the scale and heat shield. The ladle and associated crane that services the Induction Melt Furnace have space limitations that have made the purchase of a scale with appropriate heat shield problematic. The MCS is continuing to pursue solutions for this.

Mold Heaters were installed in late-November on a trial basis. The MCS reported that their first use of these items was successful. In mid-December, the Willcor Team traveled to the Propeller Foundry in Philadelphia Pa where these items were demonstrated. Successful pours using this technology were accomplished in late November and early December.

A one day training course conducted by Praxair experts was accomplished. Attendees included cast shop management team as well as the melt work station personnel.

1.2.3.2 Lessons Learned

The Willcor Team developed an understanding of the special issues surrounding a bottom pour operation. Work needs to be accomplished to develop these ideas into a set of best practices.

Many sources of technical help and advice exist for the foundry industry. Searches of references did not find a comprehensive foundry specific “maturity model” which a foundry could use for self assessment of key process areas or a buyer of foundry products use to benchmark a foundry operation.

1.2.4 COMPUTED (DIGITAL) RADIOGRAPHY (CR)

NAVSEA standards for CR of Nuclear, Level I and SUBSAFE systems were not completed as anticipated for this task. The Team decided not to pursue this task due to lack of necessary customer standards. The MCS has recently procured the Virtual Media Integration CR equipment for “informational quality” shots, as opposed to formal customer buyoff. These capital purchases enable the organization to be well positioned for the future.
2 IN-DEPTH ANALYSIS AND DISCUSSION:

2.1 JOB SHOP LEAN

As discussed above, lengthy lead times are associated with maritime shipyard castings. The longest lead times are associated with nuclear, Level I and SUBSAFE components; the specialty of the MCS. Pressure to compress “span” or build time of submarines in order to reduce the cost has been flowed down to key suppliers such as the MCS. To meet Navy shipyard requirements, the MCS needed an approach to reduce the cycle time associated with key components. This was the case for existing promised deliveries and future commitments for customer driven reduced lead time in a multi-year shipbuilding procurement. JS Lean which had been applied by the DLA R&D Enterprise Team (DLA-J339) and the Logistics R&D Branch (DLA-DSCP) to forges in the aviation and land vehicle sectors was applied as part of the overall solution. Differences in the MCS foundry setting included different Naval Sea Systems Command (NAVSEA) quality and part “sell off” criteria.

The foundry and upgrade facility are housed in different buildings but are integral parts of the same value stream. Upgrade is unique and integral to Level I/SUBSAFE maritime foundry castings and is the predominant factor in product lead time. Primary components of lead time as measured by the customer include:

- Administrative (proposal, quote, purchase order,…)
- Foundry cycle time
- Upgrade cycle time (including in process inspections)
- Final Inspection and Shipping

Because the upgrade component of lead time was larger and appeared to have more opportunities for improvement, most of the JS Lean efforts were focused there. Projects reducing non-value added activity such as improved location (point of use) of tools and mold components were conducted at the foundry but are not included here.

Upgrade cycle time is driven by a number of lower level elements which were discussed with MCS for short term/focused improvement efforts. Since Upgrade cycle time can not be measured until a number of months after the casting is poured, improvements in these areas were considered indicators of progress toward the overall goal of reduced cycle time and casting lead time. These lower level elements included:

- Increasing value-added capacity at the plant constraint operation in inspection area (operator time conducting an inspection vs. in set up)
- Reducing the total time spent to complete multiple weld/grind/inspect cycles for emergent upgrade on castings
- Reducing WIP (work in process) by improving the storage, queue size/location and part flow control, and tracking of active orders

To positively impact these supporting elements of overall lead time, specific projects were decided on with the MCS. Initial focus was on improving the overall plant constraint which was inspection capacity and throughput. There was over production in
work centers of the Upgrade facility while inspection did not have the capacity needed. Initial projects included:

- Implementation of an upgrade manufacturing cell which combined weld, grind, and as feasible hand held MT inspection operations. This facility layout and process improvement reduced non-value added transport and handling time.
- Implementation of a scheduling board that was located between the constraint department (Inspection) and the non-constraint departments (Upgrade & Radiography). The intent of this visual communication system was to limit the inspection queue to about one days worth of work thereby limiting interference in inspection. This allows inspection to pull in just the castings they can work on in a given time frame.
- Improving the inspection (constraint department) layout, supporting tool access/organization, and work analysis and process improvements. This targeted increased inspection throughput which in turn would improve overall plant throughput. Improved inspection throughput was measured by “percentage of hands-on inspection time” of inspectors to non-value added set up and other operations.
- Work analysis towards identifying ways to improve throughput in shipping and receiving which was co-located with inspection.

Some of the methods applied during this project included:

- Product Mix Segmentation: Product/Part-Quantity analysis and From-To Charts to understand and reduce transportation associated costs.
- Product Mix Rationalization: Detection of and process-re-engineering to eliminate “misfit” routings, detection and elimination of exception operations in manufacturing routings, part family formation for identification of potential for shared machines.
- Facility Layout: Product-Process Matrix Analysis, design of a cell to produce any clear-cut stable part family, flexible facility layouts that are part-Process Layout and part-Cellular Layout, impact of travel distance on use of Transfer Batch instead of Process Batch, etc.
- Material Handling and Shop floor Control for Inter-Cell Flow Management: Visual communications, locations for inventory buffers, queue management at constraint work centers, etc.
- Cross-training and teaming among machine operators: In this case between welders, grinders and inspection. How well is operator and machine time optimized. Are there other plant floor, machine layouts, cells, or cell derivatives which will improve flow and optimize the operation.
- Finite Capacity Scheduling: In what order and at what times should jobs be released into the job shop? In what order to sequence jobs in queue for processing at constraint work centers? Which processes are the bottleneck/s?

2.1.1 Specific Job Shop Lean Analysis, Improvements and Recommendations

Process Improvements in Inspection Department
At the beginning of the project it was determined that the Inspection department was the constraint limiting capacity and the ability to improve delivery times. Indicators included the number and size of casting queues in front of/in Inspection and also in the management time spent identifying and ensuring the most urgent hot jobs got through inspection on a priority basis. Given that this department was the MCS system constraint, numerous improvement projects were explored and suggested for implementation. Capacity improvement in Inspection was made through a series of improvements in workspace layout, tool accessibility, and unskilled labor support to keep the Inspectors doing inspections and minimizing their time on setup and other non-value added tasks.

These improvements resulted in inspectors increasing the time they actually spend on inspections (as opposed to set-up or other activities) from 33% to 50%, or a 34% Inspection capacity increase. These measures were based on inspector work timesheet records between July and November.

Ultimately the MCS decided a second Magnetic Particle Inspection system was needed to meet new submarine multi-year procurement order delivery requirements. Based on analysis of casting work flow it was determined that in the short-term, the purchase of a second Magnetic Particle Inspection booth located in the Upgrade department where the layout table was located would provide needed capacity in the best location and mitigate the problem of WIP build-up at Inspection. Based on analysis of the “From-To” chart discussed in the “Analysis of Factory Flow Alternatives” section below (Table 3), 56% of the total material flow in the MCS occurs between the rest of the facility and the Inspection department through a narrow portal that requires transfer between various casting transportation and handling systems. Assuming that the current Magnetic Particle Inspection booth remains in the Inspection area, having the new Magnetic Particle Inspection booth located in the Upgrade department would reduce the traffic into the Inspection department from the rest of the facility by 10%-20% which is the direction the MCS has decided to take. Additional analysis and recommendations on how to optimize utility of the new Magnetic Particle system are outlined in the following section and can be applied in either location, to the new or existing system.

**Magnetic Particle Inspection and Parallel Operations**

A time study was performed on the wet magnetic particle inspection station constraint of the MCS facility. Figure 2.1 shows the steps associated with the Magnetic Particle Inspection process and time taken to perform a typical task in this booth from start-to-finish.
The total time the part was in the booth was 1 hour 42 minutes. This means that not only is the booth occupied for 1 hour and 42 minutes, but also the inspector doing the work is occupied doing the tasks listed in the histogram. If the work is divided as shown in Figure 2.2, an unskilled material handler can perform the tasks listed in red, while the inspector (whose skills are needed to perform the tasks in green) would do only those tasks shown in green. If this resource can be shared across two or more work areas in the Inspection department, then the material handler and inspector could work in parallel. As the inspector is finishing up inspecting a part, the material handler can begin setting up the next job the inspector is scheduled to work on. Thereby, the inspector would be occupied for only 60 minutes rather than the 1 hour and 42 minutes (due to his working at a single station). The Cost-Benefit analysis for this new approach can be summarized as: Is hiring an additional material handler and setting up an additional work station adjacent to the Magnetic Particle Inspection booth worth the 42% reduction in cycle time (or increased capacity) at a workstation in a department that is currently the bottleneck for the entire shop?
In order for work to be done in parallel, the layout of the Inspection department must be altered to suit the change in work procedures. This layout change decision should be made in conjunction with other strategic changes in the facility layout, such as opening of the wall that separates the Upgrade and Inspection departments and the implementation of more Grind⇒Weld⇒Inspect cells in the future.

If future ferrous orders support a second Magnetic Particle Inspection booth system it is recommended that this be installed near the Upgrade weld/grind areas, potentially between these and Radiography. Proximity to the weld/grind booths would reduce movement and handling of large castings that require this inspection as discussed in the previous section. Different layouts and casting part flow alternatives can be analyzed and compared in more detail using software tools such as PFAST, STORM and ARENA. Consideration must also be given to what some of these “brick and mortar” changes will have on associated roles, responsibilities, and cross-training of employees.

Based on additional analysis MCS management has considered adding an electric lift pallet truck, a jib crane, and expanding existing cranes in Upgrade and Inspection to minimize wait and handling time. Management should discuss with employees optimal use of these handling devices. Feedback should be obtained on the following sample guidance policy for prioritizing bridge crane and other handling equipment use;

- Bridge crane used for loading/unloading castings in the Grinding, Welding, Inspection booths and
- Bridge crane used for transporting the castings between the Grinding, Welding, Inspection booths.
- Pallet truck or other floor mounted mobile devices for other lineal travel to lower crane usage and associated crane waiting time.

Manufacturing Cell for Improved Material Flow

Figure 2.3 shows the “Spaghetti” diagram for the routing of a single representative casting. Currently, the representative casting must be moved a total of 270 times to complete all the operations listed in its associated work traveler. Due to the size and weight, the only material handling equipment capable of moving these castings are the overhead bridge cranes and forklifts in the Upgrade and Inspection departments.
Not only does this casting make a total of 270 moves but it must travel 95 times through the narrow 9 ft.-wide opening separating the Upgrade and Inspection departments. Further, 55 times out of the 95 times this casting traveled in an “internal loop” across the building between the Grinding (W/C #6), Welding (W/C #11) and wet Magnetic Particle Inspection (W/C #8) departments, as shown in Figure 2.4.

Figure 2.5 shows that the Grinding, Welding and Magnetic Particle Inspection operations contribute to 53% of total time spent upgrading the casting. Figure 2.3 shows these work centers are distributed throughout the MCS and separated by large travel distances. These travel distances, in combination with the multiple internal rework loops, result in excessive material handling costs and delays order completion. The “spaghetti” diagrams for four other castings showed similar frequencies of occurrence of the “internal rework loops” and large travel distances. The large inter-work center travel distances not only contribute to an increase in cycle time for order completion, but also complicates order tracking through visual management due to the lack of direct Line Of Sight (LOS) between key work-centers. Furthermore, the build-up of excessive WIP queues in front of work centers increases inventory carrying costs, as well as decreases the efficiency of floor space utilization.
To combat the issues discussed above, a work cell was implemented that co-locates Grinding, Welding and hand held Magnetic Particle Inspection. The cell co-locates multiple consecutive operations in the routings of many castings into a single work area that can be shared by cross-trained employees who provide all the necessary resources to process that family of castings. By combining operations in one work area, reducing the inter-operation travel distances/handling, and allowing quick feedback between operators on quality-related issues, this cell delivers significant performance benefits. The MCS is investing considerable effort to change the culture of their employees and cross-train them to work in a cellular workspace. Two approaches were examined for setting up the cell:

- Dedicate each side of the cell for welding or grinding:

  Each side of the cell can be dedicated to be either a weld area or grind area. For either operation, the layout can be optimized for ease of use. The hand-held Magnetic Particle Inspection unit is portable, so the inspection operation can be done on either side of the cell. The major concern for this approach is that parts still need to be moved from the dedicated grind area to the dedicated weld area and vice-versa. However, the worker/s in either area will not have to move their tools and equipment to the other side of the cell.

This leads to the question: Is it better to move the parts or move the workers? For example, when the grinder finishes Part #1, he will have to wait for the welder to finish Part #2 before Part #1 can be transferred from the grind area to the weld area in the cell. In essence, this would tie up both work areas because the cell is designed with grinding and welding in separate areas. However, the grinder could be working on the next part, Part #3, and put the finished Part #1 in the welders queue.
If the grinder can complete 2 parts before the welder completes 1, the cell will not be balanced. Therefore, this approach will work best if the process times for grinding and welding are relatively equal. Observations were that welding and grinding times varied considerably and could not be counted on to be nearly equal.

- Perform grinding/welding/inspection as needed in same location without disrupting part set-up:

The alternative to Option (A), as described above, was to have two flexible work areas able to support the weld, grind and inspection operations using quick changeover fixtures, redundant, or easily moveable tool setups. The two work areas would be a mirror image of one another with easy access to weld machine, grinding station tools and sharing of the hand-held Magnetic Particle Inspection unit. The part would always stay fixtured on the work table, re-oriented if needed, and have all three operations done on it without removing it from the work table. This would eliminate internal rework loops that the typical part needs as it travels between Welding, Grinding and Inspection departments.

The question this raises is; would it be better to have the cell operators move within the cell and leave the part set up, or fix the location where each cell operator works but move the parts between their locations? A potential downfall of this option B (part stays fixed) approach is that the part will spend more time inside the cell and there will be a critical need to clarify and define the work and other responsibilities of the cross-trained workers in the cell. However, if multiple operations are completed while the casting is set up, it will force parts to be worked further toward completion once the part enters the cell. Since the hand-held Magnetic Particle Inspection may not count as a certified inspection, the part will ultimately have to be moved to the main Inspection area so that the formal inspection can be done in the wet Magnetic Particle Inspection booth.

Either option reduces the number of castings that have to travel large distances when they are processed in the main Inspection department, which “elevates the capacity constraint” in that department, reduces the number of internal work loops and maximizes the flexibility of the work areas. Given that the process times for grinding and welding vary and are not generally equal, option B appeared to be the best suited approach.

The physical creation of a work cell can be a time-consuming and expensive endeavor if the proper personnel are not assigned to the task and sufficient resources are not committed. In order to reduce risk, maximize lessons learned, and limit initial investment required, it was recommended that the cell be completed in phases. Phase 1 of the work cell has been completed. Follow on phases that improve material movement and handling with, for example rollers, are being investigated.

**Activities Completed in Phase 1 of work cell development:**

- Demolish and clean the area where the work cell will be installed
- Decide proper welding machine capability to install in the work cell.
- Remove wall separating two existing work centers.
• Rework electrical shut-off switches, air lines, gas lines, etc. to comply with OSHA regulations and support the new cell layout.
• New construction to be done in the work cell
• Provide adequate storage and space to support all three operations (Grinding, Welding and Inspection) in the cell.
• Cut 4 ft x 6 ft welding table in half to allow 360 degrees of access.
• Re-weld legs on table.
• Install new weld tables into cell.
• Install a flexible curtain between new work areas.
• Move air lines and drain water from air lines
• Modify and install overhead air ventilation for both work areas
• Install weld machines in both work areas.
• Install grinding equipment in both work areas.
• Install swinging curtain gates in both work areas.
• Install small work status boards in both work areas to facilitate visual communication.
• Install protection for water coolant mix pipe.
• Reconfigure the cell, select and cross-train workers selected to work in the cell
• Bring in welders and grinders to arrange tools and layout the workspace per their desires and standards
• Train the welders and grinders to use the hand-held yoke for Magnetic Particle Inspection.

Activities projected for Phase 2 of work cell development:

Based on the discussions above, the second phase of the work cell implementation could be done in two different ways: (a) Either side of the cell can be specialized to do either welding or grinding, or (b) both sides could be designed to be flexible and perform both processes. The other question to address is how best to move the castings between the two work areas? The installation of a roller system would enable workers to move parts back and forth between the work areas, allowing the worker in each station to remain set up for their specific activity. The rollers themselves could be used as a queue area allowing a first-in first-out (FIFO) flow of work in the job queue. One of the following two alternative layouts are recommended for the rollers:

The rollers could be placed in a T-pattern allowing the workers to move in and out of the
work cell (Figure 2.6) or the rollers could be located around the periphery of the work cell with some form of gate system in the rollers for access (Figure 2.7). In the former design, two lanes in the front of the cell would allow material movement outside of the work area, eliminating the need for a forklift to facilitate movement between each cell area. Ideally, if a worker were cross-trained to complete the welding, grinding and inspection tasks, then the casting could remain set up and would only need to be rotated to have the next operation performed by the same worker.

**Activities projected for later phases of work cell development:**

After material movement within the cell is optimized, the next step is to integrate the movement of castings into and out of the cell area from the rest of the facility. How can castings best be moved to the Upgrade department and how will castings be moved to the Inspection department without the use of crane and forklift transfers? One option would be to place tracks in the floor to connect the two departments, as shown in Figure 2.6 and Figure 2.7. Factors to consider would be how will the part be transferred from the rollers to a cart or transfer dolly, how many carts would be needed, and do the carts need to allow for movement past each other if there is a change in the order of parts to be worked next in the booth (if moving with bridge crane to the table and multiple carts are within reach of crane this would allow that flexibility.)

**Benefits:** Combining the grinding, welding, and in-process MT inspection operations in the same area not only remove some of the work load normally routed through the Inspection shop, but it also reduces the total number of moves that the castings make, as well as “internal loops” between the Grinding, Welding and Inspection shops.

Table 1 and Table 2 below summarize analysis of four representative parts for which the work cell yields a 26%-42% reduction in total part moves and a 20%-42% reduction in the number of internal rework loops or cycles between the existing weld, grind and inspection areas.

**Table 1  Part Number Moves**

<table>
<thead>
<tr>
<th>QTY</th>
<th>PART #</th>
<th>Total Moves Before Cell</th>
<th>Total Moves After Cell</th>
<th>% Reduction of Total Part Moves</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>5X9HB360A</td>
<td>270</td>
<td>200</td>
<td>26%</td>
</tr>
<tr>
<td>8</td>
<td>5X9HB360AFAB</td>
<td>136</td>
<td>101</td>
<td>26%</td>
</tr>
<tr>
<td>10</td>
<td>6HMTAM264B</td>
<td>218</td>
<td>153</td>
<td>30%</td>
</tr>
<tr>
<td>8</td>
<td>6X15HCDS269E</td>
<td>275</td>
<td>160</td>
<td>42%</td>
</tr>
</tbody>
</table>
Table 2 Part Numbers Before and After Cell

<table>
<thead>
<tr>
<th>PART #</th>
<th>Before Cell</th>
<th>After Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Between Shop Loops</td>
<td>Inter shop Loops</td>
</tr>
<tr>
<td>5X9HB360A</td>
<td>95</td>
<td>55</td>
</tr>
<tr>
<td>5X9HB360AFAB</td>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>6HMTAM264B</td>
<td>61</td>
<td>42</td>
</tr>
<tr>
<td>6X15HCDS269E</td>
<td>77</td>
<td>48</td>
</tr>
</tbody>
</table>

Figure 2.8 below shows the more streamlined routing of the part shown originally in the Figure 2.3 “Spaghetti” Diagram when routed through the new cell.

![Figure 2-8 Improved Spaghetti Diagram](image)

Not only are casting moves and the number of internal loops or cycles reduced, but also the utilization of the shop’s heavy material handling equipment (bridge cranes and forklifts) decreases by “siphoning” some parts into the proposed cell. Figure 2.9 summarizes analysis of the shop’s utilization of material handling equipment for the four representative parts before and after cell implementation.
Considering all four representative parts, the overhead crane in the cell would account for 43%-47% of part moves for those castings, while total part moves for these samples would be reduced between 26 and 42%.

Visible Management Communication System

Perhaps the biggest obstacle in a job shop is the variation in the routings of the castings, as there is rarely a “set path” that any casting travels in order to complete the required work. The problem is more severe with the MCS because the previous operation, or the previous inspection, often dictates the next step in the routing. With more than 50 part moves in a day, it takes an enormous amount of mental capacity, energy and coordination to keep track of each casting’s progress over two 8 hour shifts. Tracking of the location and progress toward completion of all active castings can suffer breakdowns in communications between cognizant personnel.

A department Foreman’s decision to move a casting or re-arrange the existing production schedule at a particular work station must be communicated by word of mouth to everyone else on the shop floor involved. This can result in excessive part movement, WIP build-up in one or more areas, and blockage of parts flow between departments. To avoid this other job shops have found it essential to create a visual communication system to track parts as they move throughout the shop floor. Visual management systems tailored to the unique needs of a company are a generally accepted lean best practice. A system should be experimented with and designed to relieve the burden of the department.
Foreman’s daily workload in tracking, locating, or directing technicians casting by casting on which part should be worked next.

**Visual Feedback in Weld Upgrade and Inspection Departments:**

The Upgrade department in the past had castings of different sizes and shapes stored together in close proximity to one another at various work centers. There are 17 work centers in the Upgrade department and 9 in the Inspection department. Overcrowding is often an issue in both departments since parts wait because their next destination has not been communicated to shop floor personnel, or it has become a lower priority part.

Between the line of booths in Welding and the line of booths in Grinding is a rectangular zone in which the majority of the parts are staged. Access to them is with the overhead bridge cranes. If two or more parts are adjacent to each other, how does an operator know which casting is to be worked on next? And, once an operation is complete, where should the casting be located to in order to be ready at the next work center? How does everyone in the shop know where that part is going next? Currently, all communication is through direct contact between the department Foreman and his workers. The foreman makes lists of which parts are to be worked on next and verbally communicates this to the workers. If the Foreman is in a meeting or busy with something else, the worker must either leave his work station to contact the Foreman, or wait for the Foreman to return. These limitations point to the need to create a more effective visual communication process based on work standards relating to part movements, or alternatively, to install a computerized scheduling system.

**Recommendations:** To effectively communicate the flow of castings throughout the shop, 4 ft x 6 ft magnetic boards have been installed at key locations (Figure 2.12). In addition, a smaller magnetic board has been placed outside each work center. Magnets are assigned to each in process part. Each magnet carries a Part Number, Serial Number, Customer and Description and is used to coordinate and monitor the movement of its casting with those of other castings that are active throughout the shop. The entire process is shown in Figure 2.13 and is described below.
Master Schedule: The Master Schedule will dictate which parts are to be worked as sorted by due date. In the future, use of a Finite Capacity Scheduler would help to modify this EDD (Earliest Due Date) sequence if “drop-in” orders or “Hot List” orders need to be inserted into the schedule based on new business conditions. Once the appropriate castings are scheduled to be released into the shop and travelers are created for each order, magnet labels are created and inserted into each traveler. The process for creating the magnetic tag for each order is documented in Figure 2.13.

Release of Work to the Shop Floor: Work is not to be released into the shop until there is adequate room in the queues. As shown in Figure 2.14 (shown as large triangles), it has been proposed that WIP be allowed to be retained in only three queues: (1) In the Upgrade department in the zone that separates the Grinding and Welding booths, (2) In front of the scheduling board located between the Upgrade and Inspection departments.
near the opening between the two departments and (3) In the Inspection department. Due to its location, Queue #2 will also feed castings into and out of the pilot cell.

Queue Area 1: Castings coming from the Inspection department, castings coming out of the hold area in the yard, castings being released into the shop and castings coming from any of the 17 work stations in the Weld Upgrade area should all be tracked using this board. As castings are removed from this area and space becomes available in this queue, new work should be released. Castings from this area will be routed to Queue Area 2 for inspection operations or into the pilot work cell.

Queue Area 2: This area controls the flow between the Upgrade and the Inspection departments. Initially, it is suggested that this queue area be allowed to carry approximately 8-16 hours of Inspection work at any time to serve as the buffer between the two departments. This buffer size will need to be experimented with. The castings queued up in this buffer area could require any combination of inspection work on the VT, MT and PT workstations of the Inspection department. This buffer will include castings needing dimensional analysis, magnetic particle inspection and dye penetrant inspection. As castings are removed from this area and space becomes available in this queue, new work would be pulled from Queue Area 1.

Queue Area 3: This area is specific to operations being performed in the Inspection department. The scheduling board should have areas that would carry the magnets for each of the 4 major types of inspection work done in the department;
Dimensional/Visual, Magnetic Particle, Dye Penetrant and Sketch. An alternative layout of the castings being staged for work in this area has been proposed to help with work queue management. Figure 2.15 shows (as shaded blocks) this potential staging layout of the Inspection area.

**Shipping Area:** A board placed in the Shipping area would be used to track daily and weekly shipments of castings. Delivery performance should be tracked to show the overall performance of the shop. Every week the board should be cleaned and magnets returned to the Quality Assurance department for future re-use. It is recommended that delivery performance be recorded in a log so that cumulative performance to promised delivery date can be assessed on a regular basis by management. Alternatively, Profit Key data could be updated after the shipping invoice is printed to retain actual delivery dates and a record of performance for monitoring trends.

The goal of the scheduling boards and magnetic job tags is to visually communicate the movement of parts throughout the shop and provide visual feedback as to the part’s progress at any given time. They also serve as a short-term “stop gap” measure until the scheduler system is brought online. The Master Schedule will control the scheduling boards and the boards will tell the operators which parts they should work in order to meet required delivery dates. The department managers will re-sequence parts based on experience, priority changes, or current work flow requirements in the shop.

Another use for the boards is to communicate queue control logic and introduce discipline in how space is used to store parts and in material handling associated with moving parts in a queue. The parts in the designated queue areas should be matched to the magnets on the scheduling boards. Those parts in the queue area for which magnets do not show on the boards should alert management that further training for the employees, or more process discipline, is needed. If the boards are not easy to use an alternative approach for coordination and production control should be explored that meets the goals discussed.
In the short term, it is important to teach employees how to determine sequencing and scheduling priorities, and how that will influence the “pulling” of new castings into space left open after castings were pulled out of those queues by downstream operations. It is anticipated there will be a need to expand or contract the area and shape of each queue, since the castings have significantly different shapes and weights. This will have to be addressed in the future layout of the facility, including the installation of material handling approaches that would allow for the castings to be more easily moved as order priorities change, castings are shipped, and new castings arrive.

**Additional Considerations for Coordination/Production Control:**
Possible improvements to the visual communication system include use of a barcode or radio frequency identification (RFID) tag system to track part movement and progress. By providing a start and end time for each transfer/move made by any part, employees could track in real-time the progress of a part. Tracking the deviation of actual time spent working on a part and estimated time spent working on a part will allow the Sales department to more accurately predict and quote lead times.

With the ProfitKey system is fully operational, a barcode system with a scanning gun could be used. ProfitKey with the bar code function has the capability to tell you instantly where the part is and/or the last time it was worked on. This can be checked at any time on ProfitKey by going into the program. The ProfitKey system does not at this time support a remote bar code scanner and these must be attached to a computer at the workstation. Maintaining and operating a computer in a high dust environment would need some consideration such as a protective enclosure with vent screens, or extended cables with location of the computer on the other side of a wall in the inspection area or other such area. Such electronic tracking of the movement of parts through the queues will progressively reduce reliance on the manual visual communication system. It would also eliminate labor time associated with employees maintaining time sheets once the part has been completed at the workstation. Training in production planning and control should be provided to personnel who will be responsible for working with and executing the schedules produced by ProfitKey.

The MCS plan is to update to the latest version of ProfitKey, put in parameters, tie serial numbers to unique lot numbers, modify the travelers (which ProfitKey prints out), improve the scheduling detail on quotes, and then conduct a dry run of several complex jobs as part of a transition process. This will be followed by possible modifications in the ProfitKey program, as needed and adding the bar code capability.

MCS management can consider contacting Mr. George Rogers (Ph: 716-897-2288) for feedback on their lessons learned in a similar transition of their ERP system, E2 (from ShopTech Corporation), to track jobs in their job shop operation (Kehr-Buffalo Wire Frame Co. Inc, [www.kbwf.net](http://www.kbwf.net))

**Benefits:** The creation of a visual management system will increase LOSE (Line Of Sight Efficiency) throughout the facility by about 50%. This will reduce the time spent looking for & tracking castings and also the amount of time personally directing
technicians on which castings to be worked next. This will allow managers to reallocate
time from the tactical to more strategic type of work including training and mentoring.
Sales employees will more quickly be able to report on the status of orders when
customers call in and employees will be able to determine where a casting is by going to
the boards vs. walking the floors.

**Visual Management in the Parking Lot**

Upon entering the MCS facility, one observes rows of castings sitting outside the Weld
Upgrade shop (Figure 2.16). Some castings have been exposed to the elements since rust
is visible on them, others have shiny machined surfaces indicting they have recently
returned from the machine shop. Other castings may be cooling down after having been
removed from the Heat Treatment furnace and others have just arrived after having been
poured at the foundry and still have casting gates attached. Some of the castings are
stacked in front of each other, preventing access and leading to wasted labor when the
casting in front has to be moved in order to access the casting behind it. Some questions
that arise when one observes this storage of castings (or any physical inventory for that
matter):

- How does someone inside the shop know what is out in the yard without physically
  walking out and taking inventory?
- Which parts have been brought in from the foundry to be released into the shop?
- Which parts are left outside to cool after being removed from the Heat Treatment
  furnace?
- Which parts are on-hold waiting for government disposition?
- Which parts are to be scrapped?

![Figure 2-16 Parking Lot](image)

**Recommendation:** It is recommended that a system be developed to organize this
storage and staging area. This could be started by writing a brief statement as to why
each casting is being stored in the area. Every few weeks repeat these steps in order to
capture a good mix of castings that come through. An Affinity Diagram can be used to
group similar reasons together. Once the needs for this area have been established, create
designated areas for each grouping per the Affinity Diagram. The areas can be as simple
as spray painted boxes on the lot establishing boundaries or as complex as an outdoor vertical shelving system. The design of this storage area should allow access to all parts from all sides. To protect machined castings or castings that have had previous work done on them, the castings could be wrapped in plastic or put inside environment-protection boxes, for example a crate wrapped in plastic. Once the areas have been established, they should be clearly marked in order to visually communicate the availability of free space, the on-hand inventory of castings by type currently in the area and how long any casting has been held in the area. This information can be tracked on a board inside the shop to prevent the “piling up” of excessive WIP of these castings in this area.

**Benefits:** By providing immediate visual feedback, this will reduce the need for material handlers, and department Foremen to expend time looking for parts. This will not only improve the organization of the area, but also support documentation as to how the shop is running at the current time. For example is there too much work being put on hold? Such a design will reduce the tendency for people to dump parts since this can result in a LIFO (Last In First Out) withdrawal process and potential for more difficult access to castings staged in the area at an earlier date. Figure 2.17 presents a possible solution for the design of the outside storage area without showing access lanes between the sections which should be included.

**Analysis of Factory Flow Alternatives**
This section provides additional analysis of MCS plant flow not addressed in the sections above and provides some answers to questions relating to the MCS facility layout.

**Wall Restriction Between Upgrade and Inspection:** As discussed in some of the sections above the MCS has a single nine foot opening through which all Upgrade work has to pass to get to the Inspection area. This raised the question of what improvements could be made for casting flow between the Upgrade and Inspection departments.
Table 3 below is the “Q” type “From-To” Chart that was generated by a Job Shop Lean tool called PFAST using the routings of representative sample castings. Table 4 is a cross reference of the work center numbering system used in Table 3 and subsequent tables. Table 3 shows the volume of traffic between every pair of work-centers in the facility. The two squares outlined in red represent the material flows between work-centers in the Inspection department and other work-centers in the rest of the shop. The sum of all flows contained in the two red squares is 56.27% of the total flows from the 250 parts captured in the sample.

All these flows go through the single nine foot wide opening in the wall that separates the two departments. Clearly, that opening is a “pinch point.” If the wall can not be removed then other options should be considered to a second opening of some type (possibly where a prior opening had been bricked up) to connect the two departments.

\[
\frac{\text{Weld Upgrade} \leftrightarrow \text{Inspection}}{\text{Total Traffic in Entire Facility}} = \frac{1477}{2625} = 56.27\%
\]

Table 3 Upgrade to Inspection Flow Analysis
Table 4 Work center Location Codes For Table 3 and Subsequent Tables

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<thead>
<tr>
<th>Work Center No</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Normalization (heat treat) &amp; PWHT</td>
</tr>
<tr>
<td>2</td>
<td>Smaller Heat Treat</td>
</tr>
<tr>
<td>3</td>
<td>Jet Arc</td>
</tr>
<tr>
<td>4</td>
<td>Wheelabrator</td>
</tr>
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</tr>
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<td>Grnd</td>
</tr>
<tr>
<td>7</td>
<td>Dimensional Inspection</td>
</tr>
<tr>
<td>8</td>
<td>Magnetic Particle Inspection</td>
</tr>
<tr>
<td>9</td>
<td>Dye Penetrant Inspection</td>
</tr>
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<td>10</td>
<td>Sketch</td>
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<td>Weld</td>
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<tr>
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</tr>
<tr>
<td>13</td>
<td>Local Stress Relief</td>
</tr>
<tr>
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<td>Quench</td>
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<td>16</td>
<td>Receiving Area</td>
</tr>
<tr>
<td>17</td>
<td>Shipping Area</td>
</tr>
<tr>
<td>18</td>
<td>Weld with Jib</td>
</tr>
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<td>19</td>
<td>Radiographic Test/X-Ray 2 mil</td>
</tr>
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<td>Layout Table</td>
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<tr>
<td>21</td>
<td>Radiographic Test/X-Ray 1 mil</td>
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<tr>
<td>22</td>
<td>Subcontract (usually Brenner Machine )</td>
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Considerations in location of the existing and additional new Magnetic Particle Inspection systems:

Table 5 shows the original “From-To” of Table 3 modified to show the new shop traffic flows when Magnetic Particle Inspection (MPI) (W/C #8) is moved out of the Inspection department (possibly placed adjacent to the new MPI booth that will be located where the Layout Table is situated in the Upgrade department). Now there is roughly 20% (56.27% - 37.18%) less traffic passing through the nine foot wide “pinch point” in the wall that separates Weld Upgrade and Inspection (assuming that a second opening is not created at the other end of the Inspection department). So, on the surface, it would appear that the decision to locate both MT booths in Upgrade is beneficial. But, if the two MPI booths are split between Upgrade and Inspection, then the reduction in inter-department traffic would be halved i.e. 0.5*(56.27-37.18) (assuming equal utilization of each MT booth.)
Consideration also has to be given to the potential “cons” of a decision to locate the new MPI booth in the Upgrade department:

- Is space available in Upgrade to accommodate both booths next to each other?
- Is it economical to re-locate the existing MPI booth in the Upgrade department?
- Will the noise, dust, etc. in the Upgrade department compromise the performance of the MPI equipment and operators?
- Will it be necessary to also relocate VT equipment and personnel from the Inspection department into Upgrade?
- How will this impact material handling due to additional usage of bridge crane and forklifts for the new MPI booths in Upgrade?

**Considerations in location of the shipping and receiving areas.** Should the shipping and receiving departments be combined:

Using the same sample of castings as above, Table 6 below shows that 19.16% of the total traffic involving all pairs of work-centers in the facility occurs with the Shipping and/or Receiving departments. However, when Shipping and Receiving are considered in isolation, they have almost equal interaction (11.62% and 7.54%, respectively) with the rest of the facility. Therefore, from a “material flow” perspective, there is no
justification for grouping these two traditionally distinct functions together. However, for reasons such as labor force utilization, cost of expanding the facility, duplication of assets, etc. there may be merit in merging these two departments.

### Table 6: Shipping and Receiving Flow

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<th>Weld Upgrade Shop</th>
<th>Weld Upgrade Shop</th>
<th>Weld Upgrade Shop</th>
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<th>Inspection</th>
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\[
\frac{\text{Shipping + Receiving}}{\text{Total Traffic in Entire Facility}} = \frac{503}{2625} = 19.16\% \\
\frac{\text{Shipping}}{\text{Total Traffic in Entire Facility}} = \frac{305}{2625} = 11.62\% \\
\frac{\text{Receiving}}{\text{Total Traffic in Entire Facility}} = \frac{198}{2625} = 7.54\%
\]

**Should the Shipping or Receiving departments be co-located with the Inspection department:** With reference to Table 7 below, within the Inspection department, the shipping and receiving departments together account for 63.47% of the total casting flow. However, shipping has 25% more interaction with the rest of the Inspection department than does receiving. In view of this it makes sense to keep shipping adjacent to inspection. Discussions to build an extension from the current shipping garage door
make sense in order to separate and better organize the flow of parts through inspection and shipping areas. Further analysis is recommended to find out:

- What is common/different in the work content, processes, skill requirements, equipment, quality standards, etc. for the two departments and
- How do they interact with the Inspection department?

Table 7 Flow within Inspection, Shipping and Receiving

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\[
\frac{(\text{Shipping} + \text{Receiving})}{\text{Rest of Inspection}} \cdot \frac{\text{Total Traffic within Inspection}}{\text{Total Traffic within Inspection}} = \frac{351}{533} = 63.47\% 
\]

\[
\frac{\text{Receiving}}{\text{Rest of Inspection}} \cdot \frac{\text{Total Traffic within Inspection}}{\text{Total Traffic within Inspection}} = \frac{107}{533} = 19.16\% 
\]

\[
\frac{\text{Shipping}}{\text{Rest of Inspection}} \cdot \frac{\text{Total Traffic within Inspection}}{\text{Total Traffic within Inspection}} = \frac{244}{533} = 44.12\% 
\]
Is there a benefit to installing more Grind⇒Inspect⇒Weld⇒Inspect “partial” manufacturing cells:

The answer is yes based on the reduction in transportation and cycles (loops) between the Upgrade and Inspection departments for ferrous parts that can use the hand held MT inspection. For non-ferrous parts a similar analysis of the upgrade and inspection process is needed to determine if efficiency can be gained by combining some of the inspection elements into a partial cell. Alternatively, the location of non-ferrous upgrade work could be changed such that they were in closer proximity to the appropriate inspection station.

Periodic review of non-value added time with the intent of further reducing it throughout the manufacturing process is recommended. The best justification may have been provided by the case studies discussed in the article emailed to the MCS management team: Wetzel, S. & Gibbs, S. (April 2009). 8 Answers To Your Lean Questions. Modern Casting, Pages 19-21. Unfortunately, judging by the Product-Process Matrix that was generated by the Job Shop Lean toolset (Table 8 below), clear-cut part families are not obvious; still, approximate groups of parts that use similar combinations of work-centers have been highlighted using different colors. The primary reason for this is that, despite the existence of many booths in both departments, in the current routings provided Grinding is a single work center (W/C #6) and Welding is a single work center (W/C #11). But, we know that almost all the castings go through a Grind⇒Inspect⇒Weld⇒Inspect sequence multiple times which, therefore, is a logical basis for creating several “partial cells” (aka modules). Also, the Group Technology (GT) literature contains enough evidence that castings can be segregated into families based on for example size, shape complexity, material, etc. It is recommended that MCS management support a detailed Group Technology analysis to refine the current routings for the same sample (or maybe a larger sample) of castings that were used to generate this report.
Table 8 Product, Process Matrix

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### Understanding future effects of today's decisions

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Table 8 indicates that clear-cut groups of work-centers and non-overlapping part families do not exist. However, both Table 8 and Figure 2.18 suggest that the following work-centers – Dimensional Inspection (W/C # 7), Grinding (W/C #6), Sketch (W/C #10) and Welding (W/C #11) – are heavily utilized by a significant portion of the entire product mix that MCS handles. Therefore, in the short term, while more detailed group technology analyses are conducted to segregate the castings into families, MCS management should pursue all other feasible strategies – Theory Of Constraints, Setup Reduction, Time Studies, Work Methods Improvement, Mobile VT and hand held MT (inspectors go to where the big heavy castings are located instead of having the castings moved to the Inspection department), “right-sizing” of material handling to reduce reliance on the use of bridge cranes in the Upgrade and Inspection departments – to maximize the velocity of cash flow. Alternatively, as Avi Goldratt would say, Maximize Throughput, Minimize WIP and Minimize Operating Expenses!

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<td>Local Stress Relief</td>
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Figure 2-18 Work Center Usage

2.2 PHYSICS BASED SOLIDIFICATION AND CAD SOFTWARE TOOLS

While conducting Best Manufacturing Practice Enterprise assessments in support of shipbuilding operations, Willcor engineers surveyed operations that used cast components and the foundries that produced those components. As part of this work, the Willcor team determined that the use of software tools in pattern and mold design a critical element in the achievement of superior quality. The Philadelphia Naval Foundry’s implementation of these tools significantly improved their 1st time cast component quality. The team also observed that foundries that did not use these tools had more issues with 1st time quality. The Willcor Best Manufacturing Practices Enterprise team determined that the use of software tools for pattern and mold design was an industry best practice.
An outline was established that included parameters and conditions necessary for the successful implementation of software tools to aid pattern and mold design at small foundries. This included:
- Identify personnel with credentials and background suitable to learning and using sophisticated engineering software tools
- Train personnel in the use of 3-D CAD software tools which can integrate with physics based solidification suites
- Put the 3-D CAD software into regular use in the molding processes
- Develop the ability to use the 3-D CAD software as the basis to develop Computer Numerically Controlled routines for the manufacture of patterns
- Train MCS personnel in the use of a commercially available physics based solidification software suite
- Validate the physics based solidification software in the cast shop though the use of test pouring
- Make process changes
  - Bidding and sales operations request digital renderings of cast components
  - Integrate software tools into the core operations of the cast shop and the marketing operation

The procurement of software tools to aid pattern and mold design is expensive. The use of these tools requires additional expenditure of technical man-hours. Consequently, a cost analysis is required and should consider the following investment and benefit areas:

**Investment:**
- Hiring and training appropriate personnel
- Procurement and maintenance of 3-D software
- Procurement and maintenance of physics based solidification software
- Engineering/technician time required to produce pattern and mold designs for a cast component

**Benefits:**
- Reduced cost of patterns with 3-D CADs drawing driving the use of CNC routines
- Improved 1st time quality of castings which reduces upgrade work content/cost and cycle time
- Improved schedule compliance and resulting improved customer satisfaction

The MCS decided not to conduct this task as originally proposed due to staff loading concerns and also the question of the return on investment given the small production runs of each potential mold modeled. The task was partially completed and successful in that an engineer was hired who BMP had trained in CAD tools. This placed MCS in a position to use solidification modeling tools on their more challenging castings with an outside provider on an as needed basis.

### 2.2.1 ASSESSMENT OF MCS FOR THE INTRODUCTION OF SOFTWARE TOOLS

The Willcor team worked with MCS management to develop a plan to implement Physics based software and 3-D CAD software tools. Following the decision not to fully
implement “in house” the physics based software tool an engineer was hired by MCS who BMP had trained in CAD tools. This and the following steps allowed the use of this capability on their challenging castings. Key cast shop personnel were integrated into a team to execute the key activities outlined below.

2.2.1.1 Implementation

In order to familiarize the new-hire engineer with casting operations, a process map for the cast shop was developed. MCS and Willcor engineers walked the cast shop floor and visited the various work centers. At each work center, the mechanic was interviewed and process steps were identified. The entire process was entered into the IGRAPHIX software suite. This dual use document was employed as a training aid and to provide an overview of operations for the targeting of process improvements.

The new MCS engineer had previous experience with 3-D software and basic knowledge of the 3-D CAD SOLIDWORKS software package. He initiated the use of this tool and attended SOLIDWORKS training at the Columbia, MD facility.

With the new engineer in the lead, MCS started to employ 3-D CAD software to create digital renditions of patterns. To ensure the utility of the 3D output product, the Willcor team visited a local pattern maker that was working from a drawing produced using the SOLIDWORKS software package. The pattern maker had positive feedback.

MCS had a third party perform a solidification study of a digital rendering of a pattern drawing produced by their personnel. The casting was viewed as one of their more challenging. The MCS subsequently noted that this casting effort was successful. The MCS has continued this practice of using third party solidification evaluations of problematic cast components on a case-by-case basis.

During the execution of this project element, MCS cast shop management expressed a desire to move its planning and scheduling operations to Manufacturing Resource Planning (MRP) software. They identified the ProfitKey software suite, utilized by the upgrade facility, as the target system. To support this effort, the Willcor Team worked with the appropriate cast shop personnel to create a process map that will assist in the development and transition to the MRP system.

Most large modern manufacturing operations, such as shipyards and their first tier suppliers, regularly create and use digital drawings of components. Providing component drawings as digital renditions would significantly reduce the cost of creating pattern drawings. Both the cast shop and the Willcor SME requested digital renditions of cast components to facilitate the use of CAD software. A positive response to these requests has not yet been received, but it is recommended that this be followed up on in the future, as it would appear to be in the best interest of all parties.

2.2.2 CONTINUING IMPROVEMENTS

Going forward, it is recommended that the MCS continue on the current path of outsourcing solidification modeling as needed on more challenging castings while
continuing to request customers (shipyards and their 1st tier suppliers) to obtain 3D product representations. As of this time the MCS has used the third party solidification modeling on two castings which they considered successful. As experience is gained using the outsourced modeling capability, data will become available which can be used to make a case as to whether there is an adequate return on investment to bring the capability “in house.” The up front software and personnel training costs to develop an organic capability is available, however there is not yet enough data on hand to determine the amount of Upgrade work content that could be avoided by bringing the capability fully in house and expanding it’s use to a wider range of the product line.

2.3 TECHNICAL PROCESS IMPROVEMENTS

A thorough assessment of cast shop operations and processes initiated this phase of the effort. The review was a combination of factory floor observations by a foundry expert and audit of written procedures in use by the MCS cast shop department which included operation sheets, procedures, process conformance, casting techniques, component finishing techniques, testing, and quality assurance processes. Mr. W. L. Mankins of Metallurgical Services, Inc. (METALANS@CS.COM) was the team’s Subject Matter Expert that conducted the assessment.

The goal of this review was to identify Best Practice operating processes and technologies applicable to the cast shop operations that are “off-the-shelf” cost effective solutions.

2.3.1 CAST SHOP FLOOR ASSESSMENT CONDUCTED JUNE 2009

2.3.1.1 Introduction

The overall objectives of any Melt Shop improvements are to produce defect-free castings the first time a pattern is made and every time thereafter. This is imperative when one considers the critical applications where Regal Cast parts are used. It is human nature to resist changes in our habits or the way that we do things, however, we must be willing to embrace new ideas or concepts to compete and meet customer needs. Improvements or changes of any type remove us from our “comfort zones” as we move in directions that do not guarantee immediate positive results.

It is recognized that changes or improvements in operations come at a cost, simply stated, “there are no free lunches,” so the changes proposed will be discussed in terms of cost and projected savings that would come from modifications in equipment or procedures recommended.

This report will investigate process steps required by the cast shop operation, from receiving a melt order to the shipment of a quality casting to the MCS upgrade facility for finishing and delivery to the customer.
2.3.1.2 Discussion

The cast shop operation has a product mix that consists of carbon/low alloy steels, stainless steels, and high nickel based alloys. All stainless steel alloys are normally melted in an Induction Melt Furnace and processed through the Argon-Oxygen-Decarburization (AOD) vessel to decarburize and desulfurize them. Additionally, nickel-base and cupro-nickel alloy castings are made by melting and deoxidizing these alloys in the Induction Melt Furnace.

2.3.1.2.1 Overview of Processes

The processing steps from receiving an to the shipment of finished castings to PRL will be discussed in the order they are performed. The comments made and recommendations proposed are based on observations made during the visit to Cast Shop operations in June 2009, known best practices, and the experiences gained through many years of metal casting.

It should be mentioned that the operation of the foundry is well conceived and runs smoothly, but there are changes that can improve the efficiency of the operation and the quality of the castings made. Processing steps will be listed, discussed, recommended provided, and benefits projected.

2.3.1.2.2 Control of Material Melt Weights

**Observations**

On June 3 casting operations that produced components made of Stainless Steel grade 410 (CA15) castings. This operation is typical of those observed during the assessment period.

Shop personnel melted 5000 lb in the induction furnace. The chemistry was adjusted and 3000 lbs was tapped to the ladle. As shown in Figure 2-19, two impellers of approximately 1100 lb each and test blocks were poured. The remainder was pigged for revert. It can be seen that the pig is approximately 24 in tall, indicating it would weigh approximately 1600 lb. It is not known if any material was poured back into the furnace from the ladle.

The induction furnace was recharged to a total weight of 5400 lb. It is not known if the additional charge added was weighed or estimated. After melting this charge, the furnace was tapped and transferred to the Argon-Oxygen Decarburization Vessel (AOD).

An additional 2600 lb. of punchings were added to the AOD and melted for a total charge in the AOD of 8000 lb. After decarburization, desulfurization, adjusting the chemistry of the heat, and heating to the tap temperature, it was tapped to the ladle.

Two valve bodies of approximately 3400 lbs each were teemed into the molds and test blocks were poured. The remainder was pigged for revert. A second pig was filled with approximately 1600 lb of revert and an additional 200 lb revert was poured into a second mold. The slag and small amount of metal in the ladle was poured into a slag dish estimated at around 200 lbs.
The revert from the second pour of this heat would be estimated at nearly 2000 lbs. It can be seen that the two pours made from this heat resulted in about 3600 lbs of revert. The total furnace charges for these two heats was estimated at 11,000 lbs plus small additions made to the AOD.

The revert produced 32.7% \( \left( \frac{3600}{11000} \times 100\% \right) \) as a percentage of charge weight.

This amount of revert produced is excessive and indicates charge and addition weighing procedures need to be implemented to reduce this amount. This clearly points to the need for weighing all materials used in the melting and casting processes.

Prudent use of revert materials has a direct effect on the cost of production of all alloys cast. Revert material has already been purchased so using it is like “free” charge metals. Each pound of revert used replaces a pound of punchings or other raw materials that must be bought which adds “new” dollars to the cost of producing the castings.

Figure 2-19 Melted 5000 lb Induction Melt Furnace tapped out with 2 1100 lb impellors, 1500 lb test block and 1600 lb pig

Best Practice Planning Processes

**Weekly Melt Plan:**
This document was generated by cast shop management for the week and is a primary planning document for cast shop operations. The plan should include the following information:

- States the alloys that will be made
- States the castings that will be made, the number of each and their weight
- How much revert and raw material will be needed for the melt program
- The required patterns
- Location of the pattern, local or distant storage
- The required molds and cores that will be needed and when
- The sequence of melting
- The number of heats produced per day

**Charge or Melt Sheets (Heat Sheets):**

- Alloy
- Special chemistry requirements
- Number of molds to be poured
- Indication if heat will use only the Induction Melt Furnace or if both Induction Melt Furnace and the argon-oxygen-decarburization vessel will be utilized.
- Special instructions
- Weight of the cast components
- Additional cast weight for Risers, Sprues, and Test Blocks
- Weight estimated for Induction Melting furnace losses,
- Weight estimates for process losses; ladle losses (if AOD used), AOD losses, Slag-off losses, Teeming ladle losses.
- Additional weight for slag pot after teeming of molds and cast bars estimated from the number of castings made or total weight cast.
- The Total Charge calculated from the above
- Melt weight required for the Induction Melt Furnace
- Additional weight to be added in AOD

**RECOMMENDATION**

Develop weekly Melt Plan and Charge /Melt or Heatsheets with the additional information recommended above designed to reflect the complete heat history including the materials and amounts used in making up all furnace and AOD charges and additions. Weighing tickets for all materials need to be included in the heat history for all heatsheets produced. This history of all heats needs to be archived to provide traceability of each casting sold for critical applications.
OBSERVATION

There did not appear to be an effective use of revert within the casting operation. Platform scales in the additions room are available and fitted to record weights (not demonstrated) or can be made to record and print weights. Crane scales are available but would need to be modified to record amounts weighed and would also need to be fitted with a heat shield for use when weighing hot ladles and contents. Figure 2-20 clearly shows that there is enough room between the crane hook and the ladle for installing a crane scale. The heat radiating from the ladle demonstrates the need for a heat shield to protect the scale electronics. Mechanical scales have been observed in other foundry operations.

Figure 2-21 shows a portion of the revert material stored outside the foundry. The iron oxide (rust) on many of the pieces indicates that it has been exposed to the weather for an extended period of time. The value of the material stored in this area was significant.
The large pigs shown in the foreground are excess material that remained in the ladle after pouring the castings and test blocks. The pigs, approximately 17 inches in diameter weigh around 67 lb per inch of height. AA 24 inch tall pig would weigh ~1600 pounds. If the total furnace weight is 8000 lb, then the pig weight is approximately 20% of the melted weight which is considered excessive. This pig weight is the “insurance” that the cast weight will be sufficient to adequately fill all of the molds and the test blocks. Excessively large pigs cost money and result from not weighing the amount of metal going into the Induction Melt Furnace and the AOD as additions to adjust the alloy chemistry or to deoxidize the heat.

**BEST PRACTICE**

System control of the amount of revert produced can be accomplished through the use of planning documents such as the Heat/Charge Sheet discussed above and by weighing materials during the melting process.

Revert must be re-consumed at approximately the same rate that it is generated to preclude increasing non-value added revert inventory. A second best practice in this area is the consumption and reuse of revert produced from pigging as well as the risers, sprues and runners that are cut off as scrap from the cast component. The post cast component clean up process should include several steps

- Revert from all sources, risers, sprues, runners and pigged material, must be weighed
- The revert must be marked with alloy and weight
- Organized storage of revert must facilitate the use of these materials

**RECOMMENDATION**

The MCS cast operation should develop processes to minimize and effectively utilize revert materials. To clear the revert inventory shown in Figure 2-21, each item should be
identified as to alloy. For items where the alloy is in question, that item must be alloy checked (analyzed).

The MCS cast operation should organize the revert storage operation to facilitate the easy use of this material.

2.3.1.2.3 Temperature Measurement and Monitoring:

Temperature control in all foundry operations is necessary. Temperature control starts with furnace procedures each time a heat is melted. Casting quality is directly dependent on the temperature of the metal during the entire melting and casting processes to ensure proper metal fluidity, oxidation and de-oxidation, and solidification.

**Observation**

The cast operation of the MCS uses immersion thermocouples to determine bath temperatures in the Induction Melt Furnace and the AOD vessel.

There is not a capability of measuring stream temperatures of metal being tapped from the furnace or vessel, or the temperature of molten metal being teemed into molds.

The quality of the casting produced has a strong dependence on the temperature of the molten metal poured into the mold. The amount of superheat, heat content as a function of temperature above the melting point of the alloy, influences the fluidity of the molten metal. A number of critical casting parameters are directly influenced by the fluidity including:

- Fill rate which determines the rate at which metal fills the mold, particularly in thin or intricate passages in the mold.
- Solidification time which controls metallurgical quality of the casting, coarse structure for longer solidification time and fine cast structure for material which solidifies or is nearly chill cast.
- Surface quality of the casting (amount of surface defects produced.)
- Escape rate of entrapped gases which contribute to porosity is also temperature dependent since lower temperatures do not provide as much time for gas bubbles to rise from the liquid soon to be solidified as metal.

Obviously, the metal being teemed into the first mold is hotter than that being teemed into the last mold of a sequence. Determining the pour temperature is a critical quality parameter.

High tech consumers such as the navy nuclear power, civilian nuclear power, and process industries of foundry products are either demanding full disclosure of adherence to established manufacturing process steps or they will be requiring this documentation in the near future. Foundries will be mandated to show that written procedures are being followed. It will be necessary to continuously monitor and also document the measured values which are relevant to individual product quality. Temperature measurement is so
connected to product quality that it will be a required physical parameter to record and archive for each heat produced.

**BEST PRACTICES**

Temperature monitoring at each step of the casting process is critical to ensure the quality of the product.

Measuring and recording the metal temperatures at critical times during the IM furnace operations, during transfer of metal to the AOD vessel, during the AOD processing procedures, and during tap and teeming operations are quality assurance steps. The proposed Heat History sheet should include lines or data boxes for the measured temperatures to be recorded. Compilation of this thermal data also becomes part of the shop floor process control.

State of the art, hand held, optical infrared pyrometers are available for foundry use wherein accurate readings of temperature can be collected on a continuous basis. High temperature pyrometers for measuring molten metals cost about $3000, depending on the features that are included in the design of the equipment. Low temperature pyrometers (RAYTEK MT-4 or MT-6, with Laser guide and range to ~ 1000F) can be purchased for less than $100.00.

**RECOMMENDATION**

Hand held infrared optical pyrometers are readily available and have been identified. Arrangements need to be made with one or more equipment suppliers to conduct field usage trials at the MCS cast operation. Once the preferred equipment has been selected, it is recommended this be purchased and used.

2.3.1.2.4  **Mold Drying:**

The need to heat and dry all molds before casting is a fundamental principle of casting doctrine. Mold heating in foundries producing premium castings has been practiced for many years.

**OBSERVATION**

The cast operation has two ovens on site, Figure 2-22 that are used for Cu-Ni castings and sparingly during other operations. These ovens are natural gas heated and do not support the internal air flow within the mold.

An extra lift and move using a fork lift is required to utilize these furnaces. The extra move increases the risk of interior damage to the mold.

The ovens are large enough to accommodate molds up to 60 inches square or four smaller molds. The largest molds are problematic to maneuver into and out of the ovens.
A provider of mold driers stated they have supplied equipment to a number of casting operations including Philadelphia Naval Foundry, Newport News Naval Shipyard foundry, Pascagoula Mississippi Naval Yard, St. Mary’s Foundry in Ohio.

This provider of mold heaters provided the following insights:

- As a result of mold heating, scrap reduction has been reported especially when chills and mold coatings are used.
- Thoroughly dried molds obtain maximum strength from binders prior to casting.
- Heating and drying molds eliminates variability in the temperature and retained moisture due to changes in atmospheric conditions.
- Mold heating eliminates variability in vapor due to the out-gassing of glues and cements used in mold preparation.

Hot air is used to heat all surfaces of the mold to 250F. The higher interior temperature is advantageous in pouring castings with thin sections such as impeller blades/vanes. Metal flow is more uniform and the solidification time of the casting will be more uniform and can be predicted more accurately using available software (physics based solidification). More uniform solidification parameters aid in more uniform mechanical properties in the finished casting.

The MCS Upgrade facility has identified gas as a recurring reason for scrapping castings. Sources of gas porosity include moisture within the mold and/or out gassing glues and cements used as binders for the sand. Other sources of gas are the incomplete de-oxidation of the molten charge in the AOD or re-oxidation that occurs during tapping to the ladle or teeming of the metal into the molds.

**BEST PRACTICES**

Mold heating and drying prior to the pouring operation is a critical process and its success has been demonstrated at the Naval Foundry Propeller Center located in Philadelphia, PA.
RECOMMENDATION

The need for mold heating has been positively identified and the implementation of mold heating can be initiated without a capital expenditure by using existing ovens on the Melt Shop floor. This will provide a proof of concept and permit costing studies to be conducted that will justify purchasing additional mold heating equipment.

It is recommended that the existing mold ovens on the shop floor be used to explore and verify the benefits obtained by mold heating. Molds can be loaded into the ovens with a tow motor. They can be heated for a specified time and temperature and then moved into position for casting when needed. A heating temperature of 250°F for two hours would be used and the molds would be removed from the ovens just before teeming. A cover needs to be placed over the pouring cup and risers during heating. Comparisons of identical castings made from molds that were heated before teeming and those produced using present day practice would need to be made. Melting/furnace practice must be held constant during these experiments with close control of teeming temperatures for all of the castings made in the experiment so the only variable to be measured will be mold heating. Temperatures can be measured with the proposed optical pyrometers that have been suggested for purchase. A MiniTemp (low temperature) pyrometer is capable of providing accurate measurement of the heated mold temperatures.

Additional mold heating capacity can be obtained from companies such as CASTEC. One purchased mold heating station with a manifold and flexible ducting would be capable of heating a single large mold or multiple smaller molds.

There is adequate space for a portable heating station between the existing ovens and the melting platform as is shown in FIGURE 2-23. The area identified is presently used to store raw material such as iron punching. These drums of material are palletized and can be moved by tow motor, therefore, they can be placed in any convenient location in the proximity of the melt furnaces.
The quality of the molten metal introduced into the mold is determined by the de-oxidation practice used in the furnace and the ladle. It is imperative that the supervising melt shop personnel as well as the melters know and understand de-oxidation, process of removing gases, primarily oxygen, and practices for the many alloys that are produced.

Observation

Carbon, low alloy, and stainless steels that are initially melted in the Induction Melt furnace and ladled to the AOD vessel have additional metallurgical requirements. The AOD process is intended for decarburization, desulfurization, reduction of oxidized elements back to the metallic state, and final de-oxidation of the heat. It can be utilized to melt additional charge, however, it is not a melting furnace since it has no source of externally supplied thermal energy. An exothermic, heat producing, reaction between aluminum and oxygen raises the temperature of the molten bath to more than 3000°F and melts the material added as extra charge. The addition of charge metal cools the molten bath to the desired temperature range between 2800°F and 2900°F.

All of the reactions that occur within the AOD vessel are predictable and obey the laws of physical chemistry and metallurgy. This is the reason that the operation of the AOD process can be programmed using the computer and give reproducible results from heat to heat of the same alloy and from one alloy to another.

The comprehensive hardware and software program installed on the MCS cast shop AOD computer includes the PRAXAIR Intelligent Refining System (IRS), a sophisticated program for refining steels.

PRAXAIR wrote a paper discussing operating experiences using their IRS to control the AOD vessel. The comments below are quoted from that report.

“IRS makes the system easy for the operator to use. It integrates operator responsibilities (blow program, alloy additions, data management) into a single system. Minimizes operator data entry, to reduce errors and to improve productivity. Automates many tasks to reduce operator error, enforce reproducibility, and increase reliability. It promotes operator-to-operator consistency and standardizes best operating practices. It improves process efficiency by optimizing:

- Temperature—attain temperature aims while avoiding over-temperature conditions.
- Carbon removal—maximize carbon removal rate.
- Reduction of alloy elements—minimize metallic oxidation.
- Inert gas cost—maximize nitrogen use instead of the more costly argon gas use.
- Refractory consumption—manage slag composition and tuyere protection control.
- Alloy cost–Use a least cost program that includes slag and reduction alloys in the calculation.”

This program automatically handles a product mix that includes carbon, low-alloy, stainless, and nickel-base alloys. It incorporates automatic data collection and management to allow reporting and off-line process optimization by the metallurgical staff. Aids in maintenance and provides on-line help in maintaining the system. It provides remote monitoring and problem resolution via modem or network access. Provides a platform for integration of new systems and technologies to further improve stainless steel processing. Full use is made of graphical interfaces. The IRS system even provides a simulation mode for training and demonstration.

Due to the wide variety of alloys and complexity of the operation, management should set aside some time for ongoing training. The training and simulation mode should be taken advantage of as appropriate as part of ongoing refresher training. If the physical chemistry and metallurgical features of the above program are not fully understood by all melt shop management personnel as well as the AOD operating personnel, a training session or tutorial on the system would be a high priority.

**BEST PRACTICE**

Training programs to ensure personnel can operate equipment safely and effectively are a core responsibility of management.

**RECOMMENDATION**

Personnel in the Melt Shop (Management and Operating) are critical to successful operation of the foundry and should participate in periodic training sessions. A full day effort with periodic follow-up is a good investment of company resources. This training would provide personnel with expanded knowledge and technical understanding of the AOD process and operation, but also enable management and operators to discuss operating procedures or problems that may occur.

PRAXAIR can provide an expert to teach such a tutorial and the cost is estimated to be more than offset by the knowledge gained which would support improved operations and also analysis of root cause of problems when they occur. A one day training session was provided by PRAXAIR as part of this effort. The training covered melting processes and AOD operations. Additional training sessions with PRAXAIR or using the system’s embedded training feature could be held on a Friday outside of production hours. This training would be particularly valuable for a new employee such as Mike Ecenroad (Mechanical Engineer, with little metallurgical background), and Donnie Kirkwood (AOD vessel operator, a potentially very valuable employee, who needs a good metallurgical understanding of what is happening in the process, and what certain process steps accomplish). A tutorial in the metallurgical understanding of the Induction Melt furnace would be beneficial and should be included in future training efforts.
Given the complexity of the processes associated with the wide range of metal types, internally lead (or outsourced) periodic refresher training for all personnel would be beneficial to the company.