

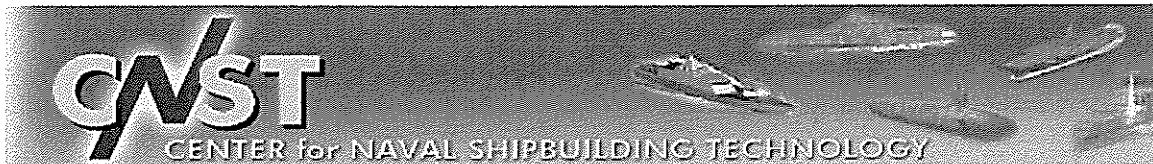
# **PROJECT FINAL REPORT MARCH 18, 2008**

Center for Naval Shipbuilding Technology (CNST)  
Task Order Agreement Number 2005-322, Task Order No. Three

## ***Nested Material Manufacturing Technology Improvement***

### **Includes Deliverable 4.1 Implementation Pilot Report**

Submitted by  
**General Dynamics – NASSCO**



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| Report Documentation Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                    |                                     |                                                           | Form Approved<br>OMB No. 0704-0188                  |                                 |
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| 1. REPORT DATE<br><b>18 MAR 2008</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    | 2. REPORT TYPE                      |                                                           | 3. DATES COVERED<br><b>00-00-2008 to 00-00-2008</b> |                                 |
| 4. TITLE AND SUBTITLE<br><b>Nested Material Manufacturing Technology Improvement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                    |                                     |                                                           | 5a. CONTRACT NUMBER                                 |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 5b. GRANT NUMBER                                    |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 5c. PROGRAM ELEMENT NUMBER                          |                                 |
| 6. AUTHOR(S)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                           | 5d. PROJECT NUMBER                                  |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 5e. TASK NUMBER                                     |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 5f. WORK UNIT NUMBER                                |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Center for Naval Shipbuilding Technology, 5300 International Boulevard, Charleston, SC, 29418</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                    |                                     |                                                           | 8. PERFORMING ORGANIZATION REPORT NUMBER            |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                           | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     |                                                           | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)              |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                    |                                     |                                                           |                                                     |                                 |
| 13. SUPPLEMENTARY NOTES                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                    |                                     |                                                           |                                                     |                                 |
| 14. ABSTRACT                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                    |                                     |                                                           |                                                     |                                 |
| 15. SUBJECT TERMS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                    |                                     |                                                           |                                                     |                                 |
| 16. SECURITY CLASSIFICATION OF:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>Same as Report (SAR)</b> | 18. NUMBER OF PAGES<br><b>23</b>                    | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |                                                           |                                                     |                                 |

## **1. Project Summary**

### **1.1 Abstract**

The objective of this project was to develop an automated planning and control system in the GD NASSCO Pipe Shop that enabled the efficient handling of pipe spool fabrication in a flexible manufacturing environment. The solution to improved efficiency in Pipe Shop operations was to implement an automated pipe spool planning process that had the ability to apply defined rules for pipe part routing and nesting, but could accept late input changes to the work plans to accommodate emerging schedule changes and shop level loading requirements. This process would include a dynamic pipe nesting component.

The project plan included a benchmarking analysis of pipe spool fabrication practices and software applications at a major international shipyard known to have successfully implemented dynamic nesting of pipe. A detailed specification and production implementation plan was then prepared, followed by application development, testing and a pilot implementation on NASSCO's T-AKE Program.

The return on investment for this project is defined by three production goals; scrap rate reduction, reduced cost of pipe nesting and work planning, and increased efficiency in pipe spool fabrication. The total cost avoidance over a five year period is projected to be \$5.5M with a calculated Present Value Return on Investment of 9.5:1.

### **1.2 Problem Statement / Project Objective**

The shipbuilding industry has unique characteristics compared to other manufacturing industries. A production contract is typically for one or a few ships of a class. Further, a single ship design is composed of tens of thousands of unique parts and assemblies. This, naturally, makes it difficult to implement modern manufacturing methodologies which have been proven in other industries that utilize standard parts and work content (assembly lines). With a typical ship production program's "one-off" nature and relatively short delivery time, Engineering and Production proceed concurrently at the first-of-class. The detailed planning process is affected by this highly dynamic environment, making it difficult to maximize the efficiency of the production flow and sequencing of interim products. This is a principle source of low material utilization, high inventory and work-in-progress in the shipbuilding industry.

As shipyards struggle to improve efficiencies in their fabrication processes, especially pipe fabrication, they naturally gravitate to more automated fabrication machines and processes; such as CNC saws, cutters, automated fitting and welding machines, CNC benders, etc. Any shipyard that has invested in this type of equipment has found, as a consequence of their automation implementation, that their traditional planning and routing procedures were insufficient to optimize the highly linked processing flow through the automated work centers and the remaining manual stations. This is due to the fact that, in shipbuilding, workstation planning cannot be optimized around the standard part approach (as in other industries), but must be performed by attribute-driven work content. Planning and routing decisions must take into account the variables of individual process times, work station capacities, emerging engineering design and schedule changes and shop level loading considerations. Traditional planning methods can not handle these variables effectively and are themselves labor intensive and not sufficiently responsive to the dynamic nature of the shipbuilding environment.

In the typical current planning process, the MRP scheduling system creates future orders for pipe spools based on required dates without consideration for shop level loading. Pipe spools are composed of cut and bent pipe parts, various valves, and fittings. These spools, which have differing work content, are

offset by standard production lead times and a planned dispatch report, by start date, is generated. Planners use this planned dispatch report to release orders for production based on actual "on-hand" material availability. Pipe spool orders are released to the shop a number of weeks in advance of required need dates in an attempt to achieve level loading of the shop to match capacity with demand. As a result, the pipe parts are not systematically nested to achieve the most efficient use of raw stock or optimum cutting and bending machine utilization.

This has resulted in excessive unused remnant pipe, excessive work in progress, excess inventory, and inflexible responses to emerging engineering and production schedule changes. The result is:

- Inefficient grouping of parts based on their routing in the shop
- High inventory
- Higher storage and material handling cost
- Loss or damage of stored spools
- Inability to optimize hull construction strategy and schedule
- High material scrap rate

This produces significant cost impacts to material and labor. It was, therefore, necessary to develop and implement another approach which mitigates the above problems.

The objective of this project was to develop an automated planning and control system for the Pipe Shop that enabled the efficient handling of pipe spool fabrication in a flexible manufacturing environment. The solution to improved efficiency in Pipe Shop operations was to implement a pipe spool planning process that had the ability to apply defined rules for pipe part routing and nesting, but could accept late input changes to the work plans to accommodate emerging schedule changes and shop level loading requirements. This process would include a dynamic pipe nesting component.

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### **1.3 Technical Approach**

Three system options were initially under consideration for development and implementation. These three options differed, primarily, by the degree to which they were linked to GD NASSCO's legacy MRP scheduling system (MACPAC) and our Product Modeling system (TRIBON).

The first task in the project was to perform an evaluation of a successfully employed dynamic pipe nesting system at a world class shipyard to determine the applicability of such a strategy at NASSCO. We found such a system at Kawasaki Heavy Industries' shipyard in Sakaide, Japan. Through collaboration on past projects, GD NASSCO had developed a working relationship with the Kawasaki Shipbuilding Corporation. Due to the ties between these two companies, a team of seven people from GD NASSCO was able to evaluate the material control software used at the Sakaide yard. The team, consisting of managers and technical resources from Production, Information Systems, Business Systems, Production Engineering, and Manufacturing Technology, spent four days at the shipyard. The target

shipyard's contract environment, scheduling constraints, production control resources and control systems were examined and a detailed definition of the yard's automated nesting process was prepared. This information was used to compare with NASSCO's operating factors and our concepts for the three system options that were under consideration at the time. From this comparison, a feasibility analysis was performed that determined what operating processes and systems needed to be altered in order to enable implementation of an automated pipe spool fabrication planning environment.

The functional requirements for the three system options and the reasoning for the final option selection are contained in the Feasibility Analysis Report (Reference 1). A detailed account of the benchmarking and evaluation activities is also included in the Feasibility Analysis Report.

The next step was to develop a detailed application specification for the proposed system, which was named the "Pipe Shop Management System" (PSMS). This specification was utilized to build the applications necessary to implement the automated, dynamic, work flow planning and pipe nesting process. The Design Specification (Reference 2) details all relevant aspects of the system including:

- Business process changes
- Definition of functional boundaries between the Product Modeling, MRP, and PSMS Systems
- Data flow requirements between TRIBON, MACPAC, and PSMS systems
- Detailed specifications for system functions
- Specifications for operator interfaces, screens, reports and tables

The initial Production Implementation Plan was developed at this time and was included in the Design Specification.

Software application design, coding and verification testing followed. Interfaces, database design and operational procedures were all extensively tested, validated and documented before the project team committed to rolling out the new system into the Pipe Shop production operations. Production pilot application of the new process commenced in September 2008. Production performance data collection and analysis of results has been performed over the last five months. The performance improvement results are reported in Section 1.4; which constitutes Deliverable 4.1 – Implementation Pilot Report.

During the course of this project, GD NASSCO also documented the performance results and lessons learned from NASSCO's internally funded lot-based plate nesting project. Although not intrinsically part of the PSMS project task plan, the lessons learned from this separate project were known to be of interest and value to the U.S. Shipbuilding industry, so a report was prepared and delivered as a Cost Share activity. This report (Reference 3) documents the performance improvements realized from implementation of lot-based nesting for plate parts.

### **1.3.1 PSMS Operations Summary**

The system, as implemented, is built on a Windows/PC platform with its own Oracle database. Computational functions were built in Oracle and written in C#. The User interfaces and reporting functions were built in Excel and written in VBA. System functions include a number of automated tasks as follows:

Automated System Functions:

- Extracts and processes spool design data (from TRIBON product model)
- Extracts and processes schedule and routing data (from MACPAC)

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- Organizes, and maintains spool data within its own database
- Audits the material inventory (in MACPAC) to determine material availability and to control the release of work
- Updates and prepares production demand data for shop loading of work
- Performs automated pipe nesting and creation of production processing files
- Performs material status updating to MACPAC (for raw stock usage)
- Maintains an independent remnant management and control

Figure 1 shows the home user access screen for the PSMS. All functions are contained within the four main functional areas shown, and each is explained below.

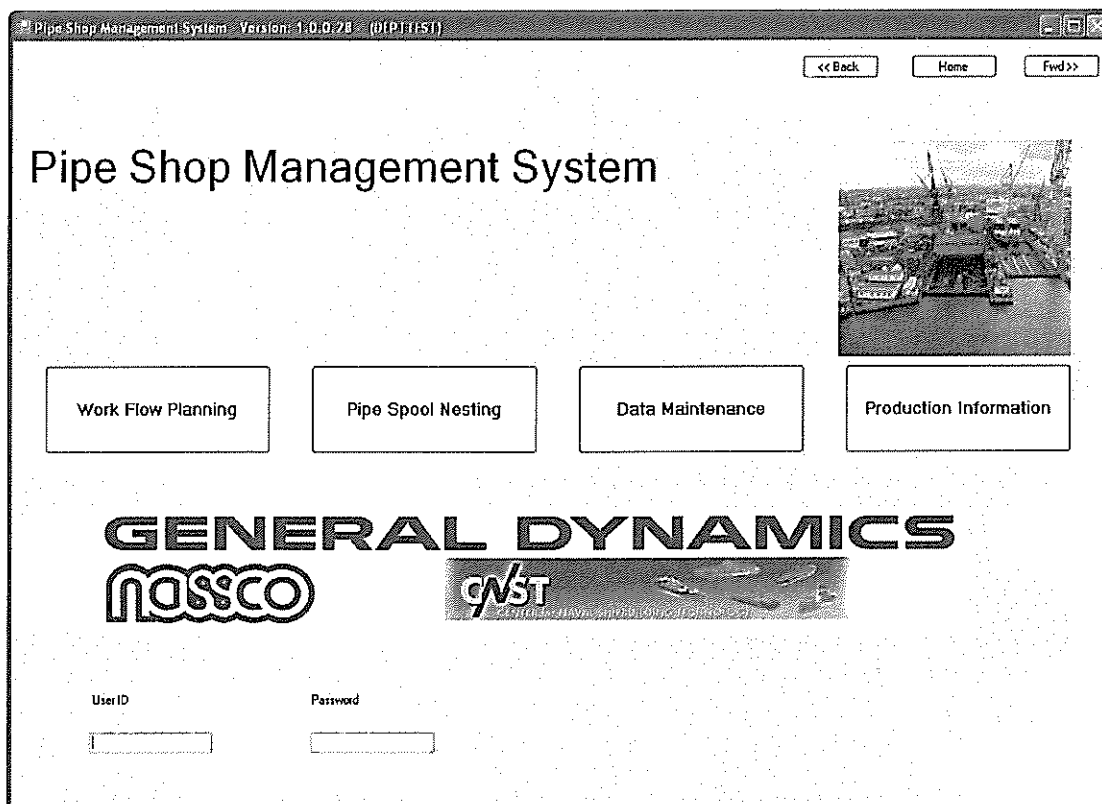


Figure 1: PSMS Home Screen

### **Work Flow Planning**

This module incorporates all the functionality to plan the work load for any future week (typically two weeks prior to the start of fabrication in the case of the pipe shop). Work can either be planned manually where the planner is able to move spool production dates around at will or automatically through programmed algorithms. The algorithms are set up to determine the number and type of spools to build in

the planned week. The number of spools is determined through an averaging process. The types of spools are determined by work-content-based families that were developed as part of this project. A portion of the family tree is shown in Figure 2.

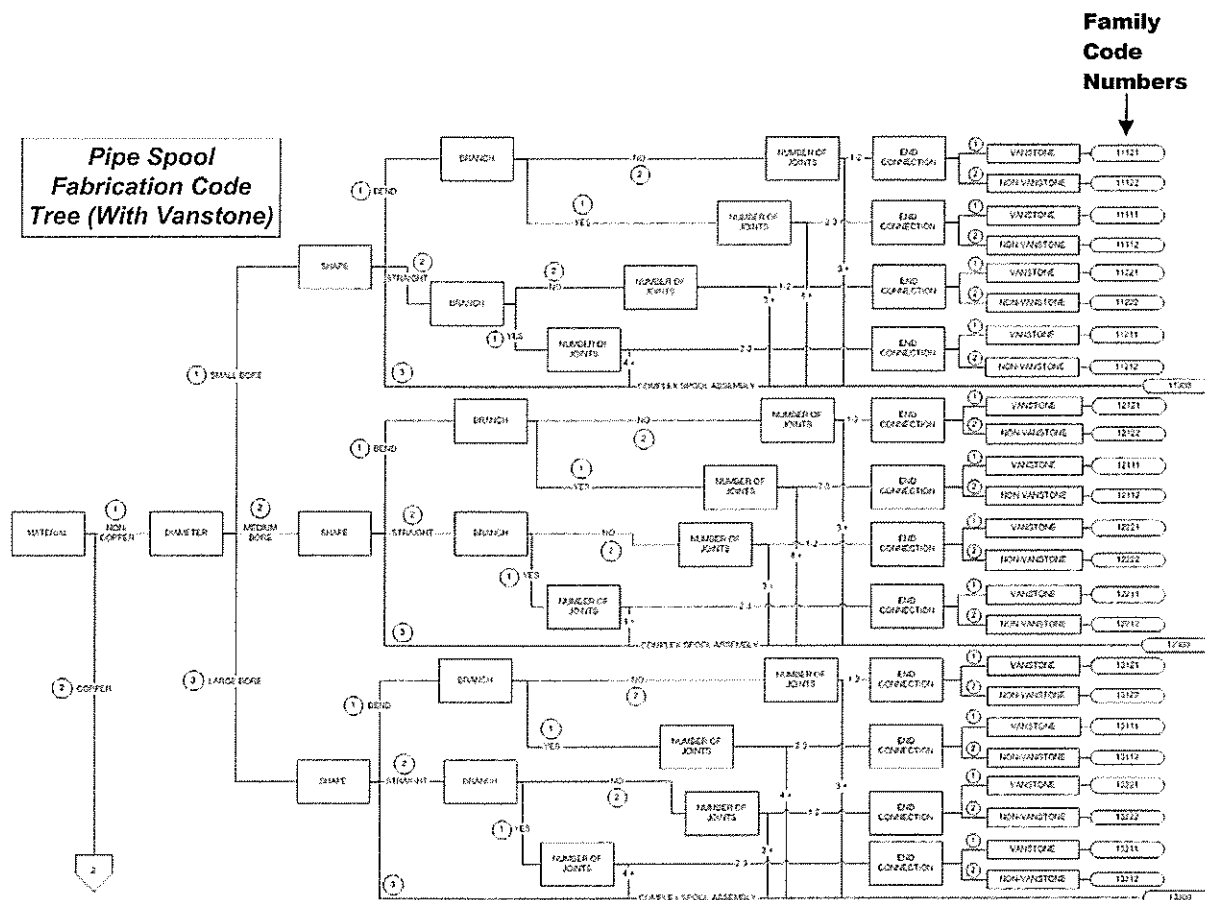


Figure 2: A Portion of the Pipe Fabrication Code Tree

Figures 3 and 4 show an example of the automatic planning process at the weekly level to determine the number and types of spools to build in the plan week. Notice that the quantities of the individual spool family types have been leveled as well as the total quantities. This evens out the work content through the shop over the eight weeks. Figures 5 and 6 show the same process occurring for the days of the plan week as well. Notice in Figure 5 that a small number of spools were moved into the plan week from the following week to achieve the level load quantity. Figures 5 and 6 also show the Excel user interface where the planner is able to make adjustments manually before saving the plan as a scenario.

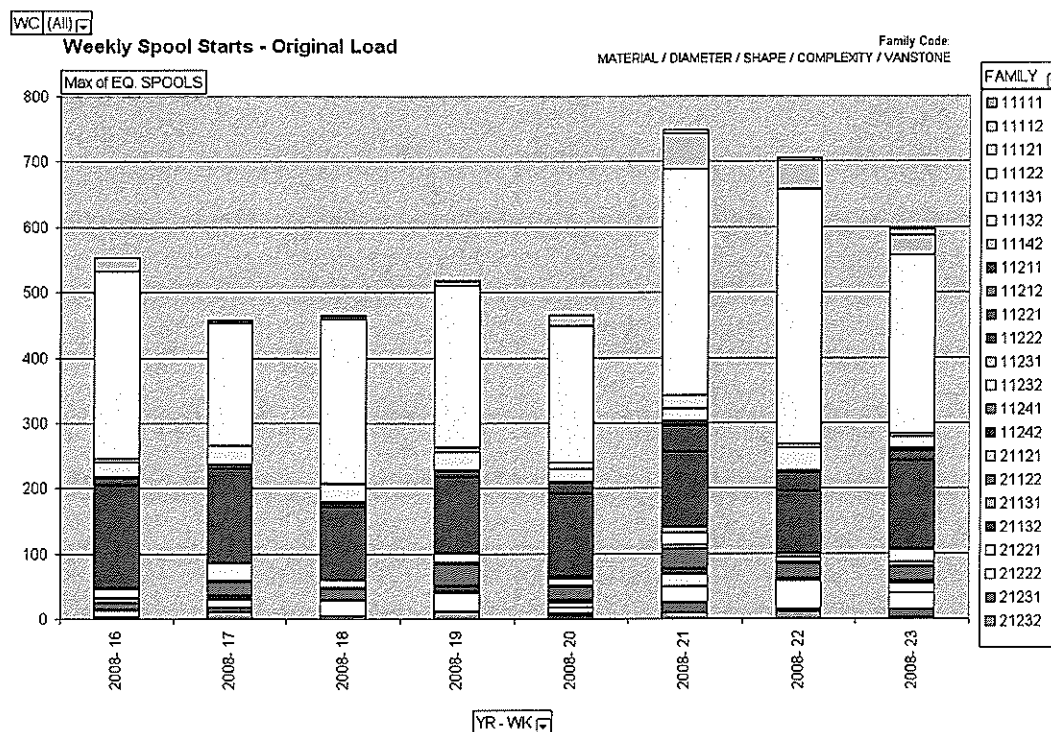


Figure 3: Display of Original Load over Eight Weeks

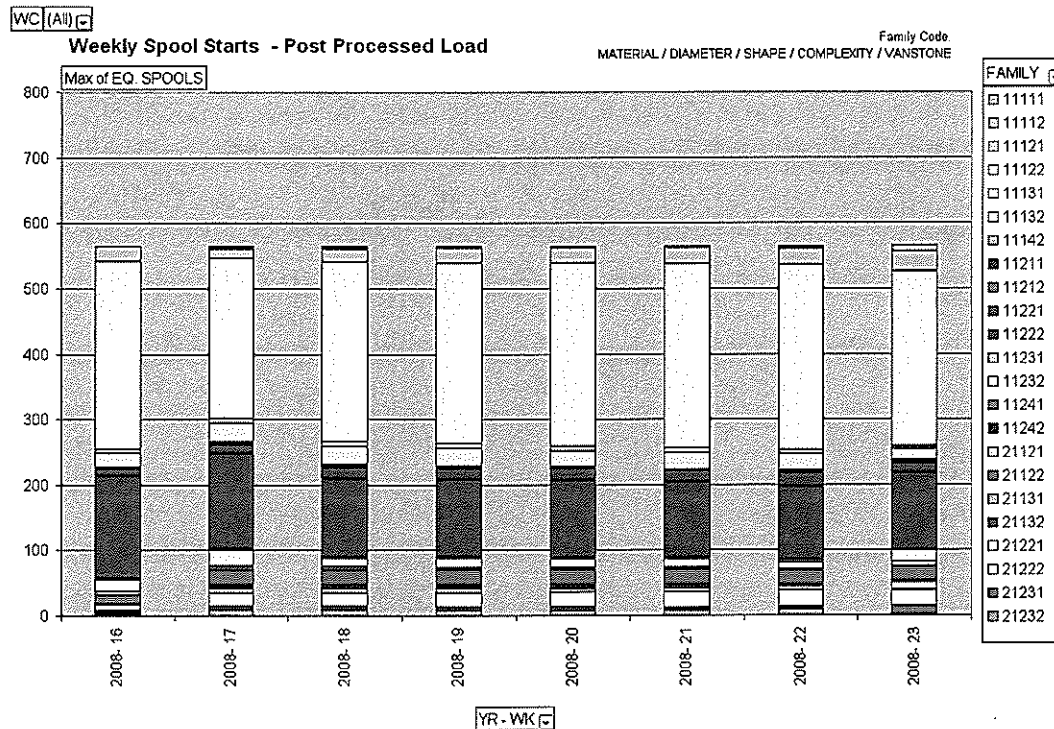


Figure 4: Display of Load after PSMS Automatic Planning

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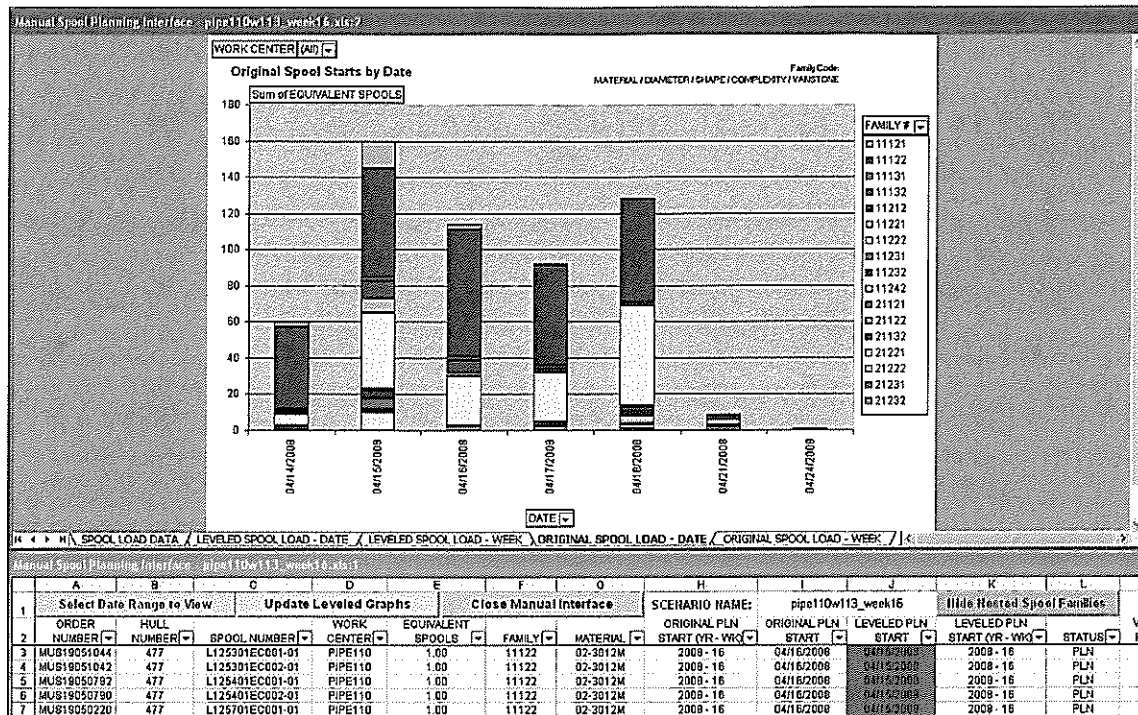


Figure 5: Work Flow Screen Shot - Original Load Shown in the Excel User Interface

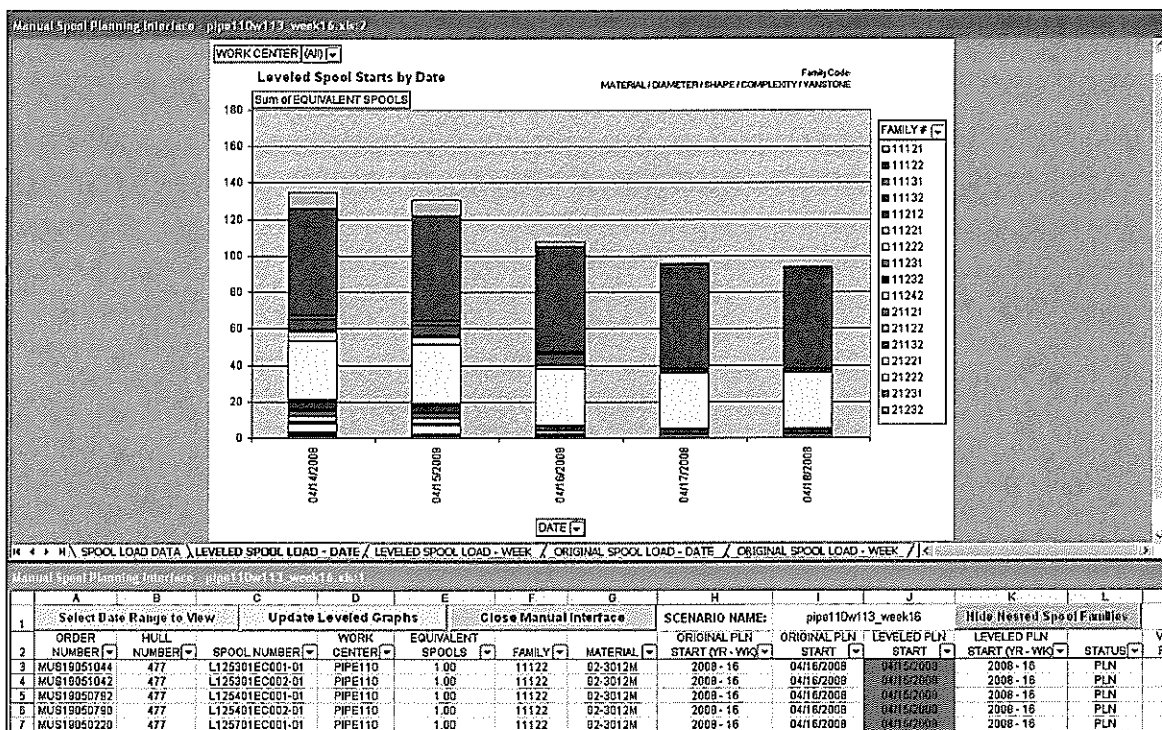


Figure 6: Work Flow Screen Shot - Plan Week Load after PSMS Automatic Planning

The planner is able to create multiple scenarios for each plan week; however, only one scenario can be selected as the final plan to be prepared for production.

### Pipe Spool Nesting

This module contains all the functionality to nest a scenario created in the Work Flow Planning Module. Figure 7 shows the results for a nested scenario.

The screenshot displays the 'Nesting' module interface. On the left, there is a photograph of stacked pipe spools. Below it, a table titled 'Raw Pipe Material/Fittings Shortages' lists various spool and part numbers, order numbers, hulls, and material codes. On the right, a form contains input fields for 'Work Center' (PIPE110), 'Plan Week' (16), 'Plan Year' (2008), and 'Scenario Name' (ppe110w113\_week16). A 'Run Nest Process' button is prominently displayed. Below the button, it shows 'Spools: 564' and 'Work Package: WPIPE110-0816-03'. The 'Nest Batch' section has radio buttons for 'Daily', 'Half Ranges', and 'Full Range', with 'Full Range' selected. A progress bar and 'Nest Elapsed Time: 00:19:42.2485076' are shown. At the bottom, there are three buttons: 'Approve Nests and create SIFs', 'View Material Shortages', and 'View Summary Stats'. Below these buttons, a summary table shows nesting statistics for different dates, including total nested, total intrapart, total recycle, total remnant, total raw stock, spools nested, and spools left.

| SPPOOL_NUMBER   | PART_NUMBER     | ORDER_NUMBER | HULL | MATL_CODE  |
|-----------------|-----------------|--------------|------|------------|
| LT00301SA003-01 | L05401GF015-031 | MUR03454797  | 479  | 02-303040M |
| LT00301SA003-02 | L00301SA003-M11 | MUR03490086  | 477  | 02-303040M |
| LT00301SA004-02 | L03201SA004-021 | MUR03494618  | 478  | 06-3639M   |
| LT00301SA004-02 | L00301SA004-021 | MUR03490080  | 477  | 06-3639M   |
| LT00301SA004-03 | L00301SA004-031 | MUR03490078  | 477  | 06-3639M   |

| NEST_DATE       | TOTAL_NESTED | TOTAL_INTRAPART | TOTAL_RECYCLE | TOTAL_REMNANT | TOTAL_RAW_STOCK | SPOOLS_NESTED | SPOOLS_LEFT |
|-----------------|--------------|-----------------|---------------|---------------|-----------------|---------------|-------------|
| 02/22/2006 12:5 | 1136685      | 10025           | 0             | 242759        | 1019394         | 564           | 12          |
| 02/22/2008 12:5 | 41341        | 75              | 0             | 31171         | 42541           | 16            | 2           |
| 02/22/2009 12:5 | 2224         | n               | n             | n             | n               | 4             | 0           |

**Figure 7: Nesting Module Screen Shot – Results and Statistics Displayed after Auto Nesting Process**

After selecting a scenario, the planner chooses how to nest the parts – daily, half ranges, or full range. The daily option limits the pool of parts to nest together to only those spools with the same start date. This option ensures that the nests created for each day of the week are only comprised of parts with start dates of that day. The daily option limits that amount of work in process (WIP) created, however, it typically increases scrap because the pool of parts available to fill out a raw stock is limited to only those spools with start dates of that day. The full range option allows spools anywhere within the week to be nested together, as long as the new start is earlier or equal to the planned start. The advantage and disadvantage to this option is the converse of the daily. Scrap is typically lower; however, WIP will increase since some parts may be built earlier to fill out a raw stock. The Half Range option is in between

with Monday through Wednesday comprising a pool of parts to be nested together, and Thursday through Friday making up the balance. During the nesting process, the inventory is checked to determine availability. If the all components of the spool are available, the pipe part continues with the next step of the process. If a component is unavailable, the spool is not nested. A report is available at the end of the nesting process to indicate the spools not nested and the unavailable material.

Nesting is controlled by programming logic that, in some cases, forces certain results, and in others, favors certain outcomes. The logic requires that pipe parts be of the same material as the raw stock before being nested. It also requires that parts that go to the bending machine are nested only with other parts that are bent, and parts that are not bent are nested with other straight parts. Other logic then fills out the nest by favoring the spools with the earliest start date which minimizes spools starting late, by favoring the placement of the largest part on the shortest piece of raw material or remnant which minimizes scrap, and by choosing to use remnant when available rather than a full size raw stock pipe which minimizes stored remnant inventory.

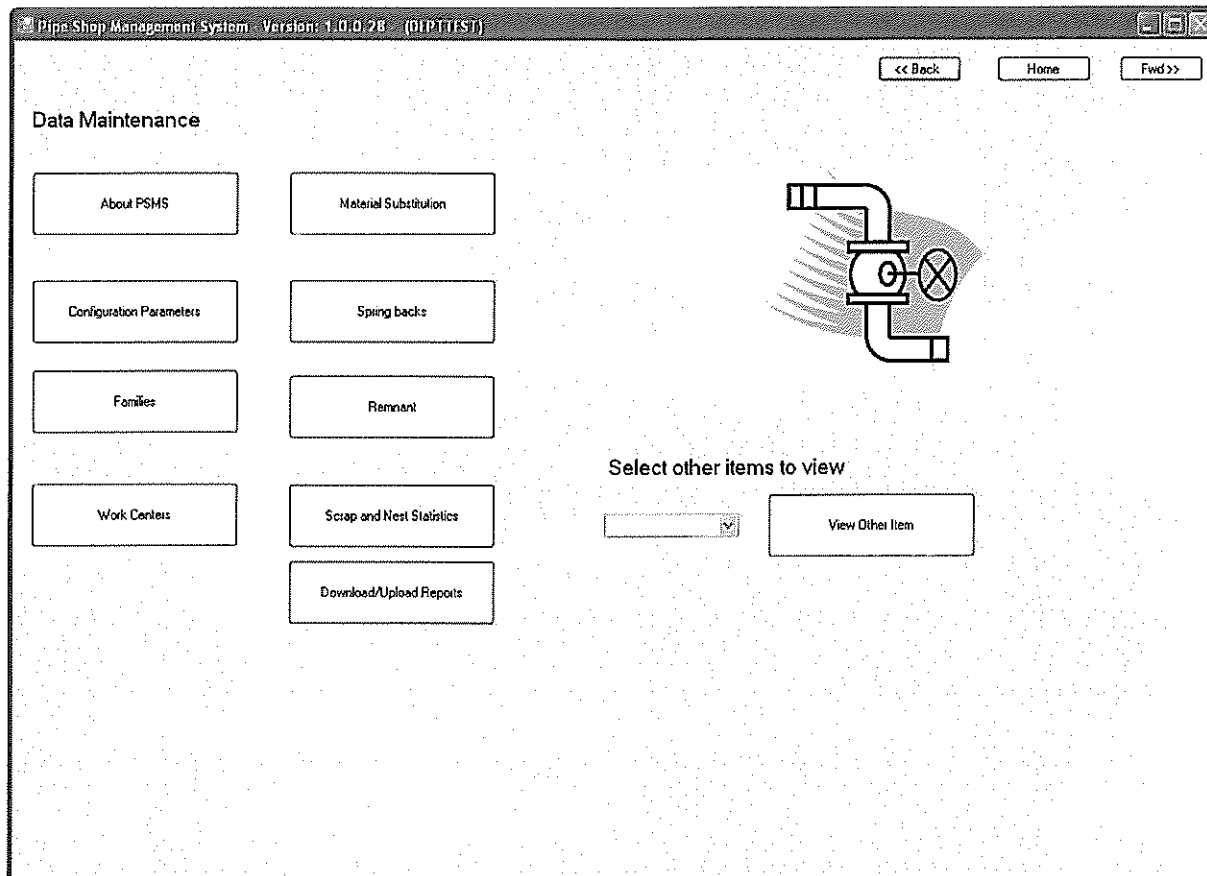
In addition to providing a list of material shortages at the end of the nesting process, the PSMS displays statistics on number of spools nested, the nesting efficiency (how well the raw stock was filled up), and the scrap rate (how much left over material was generated). The planner is able to use this information to make a decision to nest the spools as planned, wait for unavailable material to become available, or perform the nesting of a different scenario, possibly leading to a better result. If the planner decides to use the nests generated by the PSMS, the "Approve Nests and Create SIFs" button is clicked. This action results in:

1. Removing all other scenarios with the same plan week and work center from the PSMS. This prevents scenario configuration control errors.
2. Marks all spools in the scenario as nested. Preventing them from being included in later planning and nesting processes.
3. Creates the System Interface Files (SIFs) that update the spools status and obligates the material in MACPAC overnight.
4. Prepares the production information for printing.

Shop cards used in kitting the material and tracking the progress of the spool through the shop, spool sheets used to build the spool, and metal tags to identify the spool, are printed overnight. In the morning these products are gather together and assembled into work packages defined by the PSMS to be distributed to the shop floor on the start date of production.

## Data Maintenance

While this module contains a number of configuration control and reporting features, there are two functions which are of primary importance to the planners. Figure 8 displays the Data Maintenance Module user access screen.



**Figure 8:** Data Maintenance Screen Shot – Configuration Control, Data and Statistics Functions

In order to monitor change in the PSMS, the planners download a report detailing changes and errors affecting PSMS data. This report is downloaded prior to the planning process and used to indicate future issues, highlight issues with currently planned spools, or to make the decision to delay the planning process until specific problems can be resolved. The "Download/Upload Reports" access screen is shown in Figure 9. An example of the "Spool Order Download Changes" report is shown in Figure 10.

Pipe Shop Management System - Version: 1.0.0.28 - (DEPTTEST)

Uploads
Downloads

**Work Package**

WPPPIPE110-0741-01

☐ Orders Released

**Download Date**

02/15/2008 10:12:14

☐ Spool Order Changes

Figure 9: Download/Upload Reports access screen

Created by ISD on: 02/15/2008 @ 12:03 PM  
 Report#: PSMS700P1-01 SPOOL ORDER  
 DOWNLOAD CHANGES

**National Steel and Shipbuilding Company**  
**Spool Order Download Changes**

| ORDER NUMBER | HULL | SPOOL NUMBER    | QUANTITY | STATUS | WORK CENTER | PLN START  | CHANGE CODE | CHANGE DESCRIPTION                    |
|--------------|------|-----------------|----------|--------|-------------|------------|-------------|---------------------------------------|
| MUS19053894  | 478  | LX05703FM077-03 | 1        | PLN    | PIPE114     | 03/03/2008 | 103         | No Material Pegged to Order           |
| MUS19047795  | 477  | L241004WD040-01 | 1        | PLN    | PIPE114     | 03/04/2008 | 103         | No Material Pegged to Order           |
| MUS19065792  | 478  | LF01601FT072-01 | 1        | PLN    | PIPE114     | 03/04/2008 | 103         | No Material Pegged to Order           |
| MUS19053924  | 478  | LX05702TV530-02 | 1        | PLN    | PIPE114     | 03/04/2008 | 101         | Not Nested - PSMS information updated |
| MUS19063920  | 478  | LX05702TV716-02 | 1        | PLN    | PIPE114     | 03/04/2008 | 101         | Not Nested - PSMS information updated |
| MUS19073073  | 478  | LZ11003RA002-05 | 1        | PLN    | PIPE114     | 03/04/2008 | 103         | No Material Pegged to Order           |

Figure 10: Example Spool Order Download Changes report indicating issues with specific spools

The second feature in Data Maintenance that is of significance to the planners is remnant control. Figure 11 displays an example of the data contained in, and accessible to, the planners for managing pipe remnant material.

Pipe Shop Management System Version: 1.0.0.1 (DEPTPROD)

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### Remnant

| MATL_CODE | REMNANT ID | LENGTH | REMNANT_ID                       | NEST ID   |
|-----------|------------|--------|----------------------------------|-----------|
| 08-1510M  | 08-1510MR1 | 1598   | 42C12F912D641C68E04400306E132202 | 42C12F912 |
| 08-1510M  | 08-1510MR3 | 3022   | 46727205398E0670E04400306E132202 | 467272053 |
| 08-1512M  | 08-1512MR1 | 1420   | 45FAB0DE79896EBDE04400306E132202 | 45FAB0DE7 |
| 08-1512M  | 08-1512MR4 | 4150   | 4672720539C40570E04400306E132202 | 467272053 |
| 08-1512M  | 08-1512MR5 | 5575   | 45FAB0DE79846EBDE04400306E132202 | 45FAB0DE7 |
| 08-1514M  | 08-1514MR1 | 1853   | 45E7F6BA2C5536A6E04400306E132202 | 45E7F6BA2 |
| 08-1514M  | 08-1514MR2 | 2247   | 4688E86DD8EE5B69E04400306E132202 | 4688E86DD |
| 08-4509M  | 08-4509MR4 | 4863   | 4672720538190670E04400306E132202 | 467272053 |
| 09-3204M  | 09-3204MR0 | 150    | 4192733947942905E04400306E132202 | 419273394 |
| 09-3204M  | 09-3204MR0 | 169    | 43C45A45A7411DD5E04400306E132202 | 43C45A45A |
| 09-3204M  | 09-3204MR0 | 170    | 45FAB0DE7C106EBDE04400306E132202 | 45FAB0DE7 |
| 09-3204M  | 09-3204MR4 | 4831   | 42C12F912A561C68E04400306E132202 | 42C12F912 |
| 09-3204M  | 09-3204MR4 | 4850   | 40783CF89FE53BD0E04400306E132202 | 40783CF89 |

View Available Remnant

Delete Selected Rows

Add Remnant

Show Row Table Display

☒ All Remnant  
☐ Consumed Remnant  
☐ Available Remnant

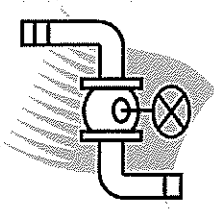


Figure 11: Remnant Control Screen Shot – displays remnant inventory in PSMS database

This module contains the inventory and availability status of all the remnant material in the pipe shop. Planners are able to view the material available to the PSMS for nesting, and more importantly, material available for uses outside of the nesting process. If a piece of remnant material is required for a need outside of nesting, the planner can delete the piece from availability to the nesting process of the PSMS.

## Production Information

The production of pipe spools is controlled using lists generated by the Production Information Module of the PSMS.

Pipe Shop Management System Version: 1.0.0.28 (DEPTTEST)

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### Production Information



Work Center  
PIPE110

Work Package Name  
WPPPIPE110-0816-03 ☐ Show Diagnostic Reports

Reports

- ☐ Spool Sequence List
- ☐ Assembly Plan
- ☐ Spool Sheet Labels
- ☐ Straight Plan w/Saddles Formatted
- ☐ Straight Plan wo/Saddles Formatted
- ☐ Bend Plan wo/Saddles Formatted
- ☐ Bend Plan w/Saddles Formatted
- ☐ Nest Statistics
- ☐ All Reports

View Work Package

Figure 12: Production Information User Access Screen

As depicted in Figure 12, the planner is able to display and print the necessary lists in Microsoft Excel by selecting the list, a work package name, and work center. The lists required to control production on the shop floor include:

1. Spool Sequence List – An example sequence list is shown in Figure 13. This list is used by the planners to order the spool shop cards and spool sheets of a work package in a fashion that corresponds with their order of appearance on the cut/bend lists (described later). The alpha-numeric information shown in the sequence number column indicates whether this spool is part of a bend list (B) or cut straight part list (C), and the line item number of the first instance that the spool number appears on the list (a spool can have several pipe parts occurring throughout the cut and bend lists.). In addition, spool sheet revisions and paint codes are shown on the report. If the revision or paint code is changed for a particular spool by Engineering, it shows up on the sequence list as a blank cell. This prompts the planners to take the necessary action to update

MACPAC with the current information. This addition to the sequence list has saved hundreds of man-hours, since only the exceptions have to be handled. In the previous system, without this list, every spool was checked to ensure the exceptions were caught.

2. Spool Sheet Labels – An example of the spool sheet labels is shown in Figure 14. These labels are affixed to the spool sheets and include order number, work center information, start date, and the cut/bend list line item numbers of the parts on the spool. The labels are used to order the spool sheets in accordance to the cut/bend lists should they get out of order on the shop floor.
3. Cut and Bend Lists – These lists are used by the saw and bend machine operators to sequence production. The lists, with their associated shop cards and spool sheets are distributed to the appropriate work centers. As depicted in Figure 15, these lists provide the machine operators with all of the relevant information they need to perform their work efficiently, including:
  - type and length of raw pipe material used for the nest
  - spool order number, hull number, part number
  - family number
  - start dates
  - required length of part
  - pipe end prep codes used for routing of parts
  - amount of pipe left over after processing the nest
  - line items of the other pipe parts in the spool

Each un-shaded line is the first part on a nest, while the following shaded line items are the additional parts on the nest. The lists are sorted by nest start date in ascending order so the operator is able to perform the work in start date order. As each nest is processed, the operator initials the list to indicate its completion. This action adds transparency to the fabrication process. The shop management is able to instantly see where each operator is in their production requirements.

### **1.3.2 Updating of PSMS Software**

It was anticipated that changes to the PSMS software would be made as the system evolved to include new functionality and as further refinements to the planning and nesting algorithms were developed. While many of the changes are handled through the configuration control parameters in the Data Maintenance Module, some changes are required to be done within the programming itself. To facilitate updating of the code, the system architecture was set up to have the version of the software checked each time a user logs into the system. If a newer version exists, the new version is automatically downloaded at that time. This was a departure from the previous process which required: contacting the users, indicating a new version would be downloaded, contacting the Information Systems department to schedule a time to download the new version, and then performing a local installation on each of the users' computers. This simple change cut days of delay out of the updating process and will become the model for future software development within the company.

## National Steel and Shipbuilding Company Spool Sequence List

| BLOCK | HULL | SPOOL NUMBER    | ORDER NUMBER | PART WC | BEND | SPOOL WC | FAMILY | SEQUENCE | DRAWING REV | PAINT CODE |
|-------|------|-----------------|--------------|---------|------|----------|--------|----------|-------------|------------|
| 364   | 477  | LS36401CW155-M1 | MUR03207146  | PIPE110 | N    | PIPE110  | 21222  | C283     |             |            |
| 220   | 478  | LA22001CW076-02 | MUR03251562  | PIPE110 | N    | PIPE110  | 21232  | C224     | A           | NP         |
| 067   | 478  | LF06701PW055-01 | MUR03278698  | PIPE110 | N    | PIPE110  | 21232  | C123     |             |            |
| 067   | 478  | LF06701PW051-05 | MUR03278700  | PIPE110 | N    | PIPE110  | 21222  | C223     | A           | NP         |
| 067   | 478  | LF06701PW051-04 | MUR03278702  | PIPE110 | N    | PIPE110  | 21222  | C127     | A           | NP         |
| 002   | 478  | LT00203GF201-07 | MUR03298207  | PIPE110 | N    | PIPE110  | 11222  | C94      | -           | NP         |
| 054   | 478  | LL05403FM164-01 | MUR03298714  | PIPE110 | N    | PIPE110  | 11222  | C307     | A           | NP         |
| 022   | 478  | LY02202SW057-08 | MUR03300260  | PIPE110 | N    | PIPE110  | 11232  | C212     | B           | NP         |
| 022   | 478  | LY02202SW057-07 | MUR03300261  | PIPE110 | N    | PIPE110  | 11222  | C214     | B           | NP         |
| 022   | 478  | LY02202SW057-06 | MUR03300262  | PIPE110 | N    | PIPE110  | 11222  | C213     | B           | NP         |
| 220   | 478  | LA22001CW078-02 | MUR03409532  | PIPE110 | N    | PIPE110  | 21232  | C128     |             |            |
| 112   | 478  | LZ11202TV566-01 | MUR03487430  | PIPE110 | N    | PIPE110  | 11222  | C324     | B           | KW         |
| 112   | 478  | LZ11201SPP13-01 | MUR03487441  | PIPE110 | N    | PIPE113  | 11222  | C296     | A           | KW         |
| 112   | 478  | LZ11201EC992-01 | MUR03487465  | PIPE110 | N    | PIPE110  | 11222  | C322     | -           | KW         |

Figure 13: Spool Sequence List – Cross references order numbers with production sequence designations

|                                                                                    |                                                                               |                                                                               |
|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| 478_LX05702WD027-01_110/110<br>WK: 16_SD: 04/16_MUS19073236<br>110= B255 C178 C274 | 478_LL84101WC045-02_110/113<br>WK: 16_SD: 04/16_MUS19074328<br>110= B275 C278 | 478_LL84101WC045-01_110/113<br>WK: 16_SD: 04/16_MUS19074329<br>110= C275      |
| 478_LL84101WC044-02_110/113<br>WK: 16_SD: 04/16_MUS19074332<br>110= C276           | 478_LL70101WC154-02_110/110<br>WK: 16_SD: 04/16_MUS19074473<br>110= B259      | 478_LC21601SPP02-03_110/110<br>WK: 16_SD: 04/18_MUS19074720<br>110= B382 C167 |
| 478_LC21402TV661-03_110/110<br>WK: 16_SD: 04/17_MUS19074762<br>110= B306           | 478_LC21401WF302-03_110/110<br>WK: 16_SD: 04/17_MUS19074774<br>110= B234      | 478_LC16601SPP04-03_110/110<br>WK: 16_SD: 04/14_MUS19074802<br>110= B58       |

Figure 14: Spool Sheet Labels  
(16)

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# National Steel and Shipbuilding Company Bend List

| WORK CENTER: | PIPE 10        | PLAN WEEK:   | 16           | PLAN YEAR:        | 8           | SCENARIO:        | PIPE 10W13 week16 |                   |             |                  |              |                   |             |                  |              |                   |             |
|--------------|----------------|--------------|--------------|-------------------|-------------|------------------|-------------------|-------------------|-------------|------------------|--------------|-------------------|-------------|------------------|--------------|-------------------|-------------|
| NEST NUMBER  | RAW STOCK MATL | STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER      | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER |
| B0802220007  | 02-3013M       | 0096         | MUS19058188  | PIPE110           | 477         | 6096             | MUS19058188       | PIPE110           | 477         | 6096             | MUS19058188  | PIPE110           | 477         | 6096             | MUS19058188  | PIPE110           | 477         |
| B0802220008  | 02-3013M       | 0096         | MUS19058663  | PIPE110           | 478         | 6096             | MUS19058663       | PIPE110           | 478         | 6096             | MUS19058663  | PIPE110           | 478         | 6096             | MUS19058663  | PIPE110           | 478         |
| B0802220009  | 02-3015M       | 5000         | MUS19054592  | PIPE110           | 477         | 5000             | MUS19054592       | PIPE110           | 477         | 5000             | MUS19054592  | PIPE110           | 477         | 5000             | MUS19054592  | PIPE110           | 477         |
| B0802220010  | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242       | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |
| B0802220011  | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242       | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |
| B0802220012  | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242       | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |

| NEST NUMBER | RAW STOCK MATL | STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER | RAW STOCK LENGTH | ORDER NUMBER | ORDER WORK CENTER | HULL NUMBER |
|-------------|----------------|--------------|--------------|-------------------|-------------|------------------|--------------|-------------------|-------------|------------------|--------------|-------------------|-------------|------------------|--------------|-------------------|-------------|
| B0802220007 | 02-3013M       | 0096         | MUS19058188  | PIPE110           | 477         | 6096             | MUS19058188  | PIPE110           | 477         | 6096             | MUS19058188  | PIPE110           | 477         | 6096             | MUS19058188  | PIPE110           | 477         |
| B0802220008 | 02-3013M       | 0096         | MUS19058663  | PIPE110           | 478         | 6096             | MUS19058663  | PIPE110           | 478         | 6096             | MUS19058663  | PIPE110           | 478         | 6096             | MUS19058663  | PIPE110           | 478         |
| B0802220009 | 02-3015M       | 5000         | MUS19054592  | PIPE110           | 477         | 5000             | MUS19054592  | PIPE110           | 477         | 5000             | MUS19054592  | PIPE110           | 477         | 5000             | MUS19054592  | PIPE110           | 477         |
| B0802220010 | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |
| B0802220011 | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |
| B0802220012 | 02-3018M       | 6096         | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         | 6096             | MUS19054242  | PIPE113           | 478         |

| PART NUMBER     | REQUIRED LENGTH | END CODES | GENERATED REMNANT LENGTH | GENERATED REMNANT ID | NEST START | NEXT PART          | LINE ITEM |
|-----------------|-----------------|-----------|--------------------------|----------------------|------------|--------------------|-----------|
| L44101OW344-M11 | 2165            | SQ/SQ     | 557                      | SCRAP                | 04/14/2008 | 110= B21           | 21        |
| L05201OW225-041 | 3349            | NC/SQ     |                          |                      |            | 110= B22           | 22        |
| L00301OW235-022 | 1055            | SQ/SQ     | 514                      | SCRAP                | 04/14/2008 | 110= B23 B142      | 23        |
| L05201OW225-022 | 1084            | SQ/SQ     |                          |                      |            | 110= B19 B24       | 24        |
| L00301OW236-011 | 1333            | NC/NC     |                          |                      |            | 110= B25           | 25        |
| L21201OW319-021 | 2035            | SQ/SQ     |                          |                      |            | 110= B26           | 26        |
| L20802WD066-M22 | 989             | SQ/SQ     | 3125                     | 02-3015MR3           | 04/14/2008 | 110= B27 C146 C147 | 27        |
| L12505HV003-031 | 2011            | NC/SQ     |                          |                      |            | 110= B28           | 28        |
| L00301GF302-M41 | 1111            | SQ/NC     | 1211                     | 02-301840MR1         | 04/14/2008 | 110= B29           | 29        |
| L05601DT024-021 | 5500            | SQ/SQ     | 596                      | SCRAP                | 04/14/2008 | 110= B30           | 30        |
| L21901SP005-021 | 2407            | SQ/NC     | 888                      | SCRAP                | 04/14/2008 | 110= B31           | 31        |
| L05601DT002-033 | 2776            | SQ/SQ     |                          |                      |            | 110= B32 B34 B36   | 32        |

Figure 15: Typical Bend List - Cut and Bend Lists set the production sequence for machine operators and provide information for tracking all spool parts (17)

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## 1.4 Results

The performance of the PSMS has exceeded initial expectations by not only planning and nesting the work as expected, but accomplishing it significantly faster and more accurately than the users had known in the previous, manual process. NASSCO has documented performance benefits enabled by the PSMS implementation in the following areas:

1) *Reduced labor and duration to perform spool release ~ \$44K/yr*

Automation of this process has proven to be a significant recurring labor savings. The span time to release (the typical) 380 orders for one spool assembly work center dropped from 8 hrs to 30 minutes. More significantly, the span time to release the historical peak quantity of work orders (~1800) for all three major Pipe Shop work centers is now only 45 minutes. Pipe Shop planners would previously take 40 hours to release this quantity of orders to the shop.

*"What used to take us a whole week now gets done in a day-and-a-half." – Planner, pipe shop*

2) *Reduced scrap and remnant ~ \$1000K/yr*

Data collected over the first ten weeks of auto nesting has shown a reduction of scrap generation of approximately 15% from the previous production history. In addition to the reduction in scrap, there has been a significant reduction in pipe remnant turnover time. This is a direct consequence of the PSMS's ability to identify remnant creation, keep track of it in its database, and to specify its use for nesting.

*"This is the first time that the remnant storage has been empty." – Operator, bending machine*

3) *Increased Efficiency ~ \$300K/yr*

The comparison of labor hours required to produce spools over different periods of time is made difficult by the highly variable nature of the work content of spools as the different ship piping systems are scheduled through the shop. Despite this, comparison of labor efficiencies over the past year to the initial data from the last three months indicates a 6% improvement in man-hours per spool. Additionally, in this same period of time, the quantity of spools that were "late-to-complete" was reduced by 56%. This is a substantial reduction in this key metric value and is an indicator of the eventual total cost reduction to the shipyard by reducing production delays and re-planning at the later stages of construction.

*"This is the first time that the late-to-completes have ever been this low." – Manager, pipe shop*

4) *Visibility of production data errors*

Since the implementation of the PSMS a number of Product model / production information disagreements have been caught prior to build by the shop floor personnel. This has been made possible by the readily available and easily readable design data displayed in the Cut and Bend lists provided to the cutting and bending machine operators. Since the data in these lists come directly from the Product Model database, they now have the ability to check the data listed on the spool sheets, which may not have been updated with the latest design data. This results in the cost avoidance of rework on these spools.

5) *Visibility of Production Status*

As discussed Section 1.3.1, the Production Information Reports provided to the Pipe Shop planners, floor supervisors and machine operators include cross references from/to all spool parts of their respective spool assemblies and the associated spool assembly order numbers. This allows the Pipe Shop to process the pipe parts of spools in parallel with an improved ability to track the status of all

pipe parts required for the assembly. The result is a reduction in span times to fabricate and assemble spools.

*"We now have a better idea of what to build when." – Saw operator, pipe shop*

## 1.5 Conclusions

The Pipe Shop Management System developed and implemented through this project is an unqualified success and is already demonstrating significant performance benefits to GD NASSCO's Pipe Shop operations. These benefits will continue and increase with further use, applications and enhancements to the system.

The success of this project demonstrates the value to U.S. shipbuilders and their customers of the research and development program managed by the Center of Naval Shipbuilding Technology.

## 2. Accomplishments:

- The system concept Feasibility Analysis Report (Deliverable 1.0) was completed and delivered in June 2006. This analysis provided a detailed summary of the pre-existing pipe shop operational control system and two distinctly different options for development of a new, highly automated planning, nesting and control system. The Analysis detailed the evaluation of each option and described the reasoning behind the selection of the option that the project team proceeded to develop and implement in the NASSCO Pipe Shop.
- The Functional Requirements Document (Deliverable 1.0) for the new Pipe Shop Management System (PSMS) was completed in June 2006. The functional requirements contained in this document define the framework for system design work.
- Data collection and cost savings analysis for lot-based plate nesting implementation at NASSCO was completed in November 2006. The technical report, Improved Steel Material Flow through A Lot Based Concept (Deliverable 5.0), was released in January (2007).
- PSMS detailed design was completed in May 2007. This task included the completion of the following system design tasks:
  - Detailed decomposition of PSMS system functions. This level of detail was the prerequisite for completing the system specification and final system design. The functional decomposition also identified, by department, who had responsibility for design and development of each individual function, application, interface, and database.
  - Data flow charts for the PSMS application. Completion of data flow requirements enabled the start of data and file interface specifications.
  - Development of user interfaces (screens designs, output table designs, reports, etc.), MRP and design model data extraction specifications, and algorithm specifications for the automated Planning and Nesting applications.
- The PSMS Software Design Report (Deliverable 3.0) was completed and issued in May 2007.
- Production implementation of the PSMS system was initiated on Sept 24, 2007. Rollout and expansion of its use in all major pipe spool fabrication work centers was successfully accomplished during the 4<sup>th</sup> quarter. The PSMS system is now the primary planning and shop floor production control tool used in the GD NASSCO Pipe Shop.

- Production performance improvements have been validated. Initial performance improvements were presented to the U.S. Shipbuilding Industry as part of a project briefing (Deliverable 4.2) given at the NSRP Joint Panel Meeting held in New Orleans on December 12, 2007.

### **3. Task Status and Completed Project Schedule:**

The following is a detailed discussion of the project Statement of Work and the final status of each task.

#### **Task 1.0) Evaluate Dynamic Pipe Nesting Processes**

*Status: Complete*

Task 1.1) Project kick-off was commenced on March 9, 2006 with a review of the project objectives and task plan for the project participants. The project plan called for the identification of a "target" shipyard that has implemented a dynamic pipe nesting and process control system. The target shipyard would then be solicited to provide the team with an opportunity to study their system and the manufacturing environment in which it is operating. That task objective was accomplished with confirmation of Kawasaki Shipbuilding Corporation's (KSC) Sakaidi shipyard as the target yard.

Task 1.2) Evaluation of Kawasaki Shipbuilding Corporation's pipe shop operations and K-MACS (Kawasaki - Material Planning and Control System) was accomplished during an evaluation trip conducted on May 8 – 12, 2006. A detailed explanation and review of the K-MACS system was obtained from KSC, including demonstrations of various functions and observation of the control aspects in their pipe shops. A description of KSC's K-MACS system is contained in the Feasibility Analysis Report.

Tasks 1.3) The definition of KSC's environment, constraints, resources and processes was made possible by the evaluation trip in May. A summary of the most important of these parameters, as they apply to our implementation plans, is contained in the Feasibility Analysis Report.

Task 1.4) Our access to KSC process and control documentation facilitated the project team's definition of KSC's dynamic nesting process. More importantly, our understanding of the function of dynamic pipe nesting as an integral part of a comprehensive material planning and control system was formulated by our evaluation of the K-MACS system. This understanding was a key factor in the project team's development of functional requirements for a NASSCO implemented system.

Task 1.5) Differences in the NASSCO and KSC production environments were identified and used in our determination of the best fit of system functions, degree of automation and integration, and in our development of functional requirements for a NASSCO implemented system.

Task 1.6) The Feasibility Analysis was completed and documented in the report delivered to CNST as Deliverable 1. The associated Milestone 1 was also met on schedule. The specific model developed by this project was selected by the project team. NASSCO's senior level Steering Committee was briefed on the evaluation process and the resulting recommendations for system implementation. The Steering Committee concurred with the project team's recommendations and authorized the design and development stages of the project; thus meeting the Milestone 1 requirement.

#### Task 2.0) Pipe Nesting Implementation Planning

*Status: Complete*

The original project plan referred to the creation of an Implementation Plan (Del 2.1). It was supposed to contain the following information (from the Project Plan): "Report details implementation requirements and specifications of the selected model and the production implementation plan." As it turned out, the project's first deliverable (Implementation Feasibility Analysis), contained the information regarding "requirements and specifications" in the Appendices of that document and the Software Design Report (Del 3.0) included a section on "implementation." The project team, PTR and CNST considered this deliverable (Del 2.1) satisfied with the completion of Deliverables 1 and 3. With the presentation of the project plan at the December 2006 NSRP Joint Panel Meeting in Savannah, all requirements for Task 2 were satisfied.

#### Task 3.0) Pipe Nesting Application Development

*Status: Complete*

Tasks 3.1) System design and coding have been completed for the functionality and features that are currently implemented in the PSMS. Final testing of the data upload/download functions was completed in September 2007. Additional functionality and features were added during the pilot implementation period (Task 4), as required to support the recommendations of the user groups.

Task 3.2) The planned task to develop a new part identity structure in NASSCO's Product Modeling System (Tribon) was determined to be unnecessary. After review of system data and file format requirements it was determined that we could avoid restructuring part identity data.

Task 3.3) Fabrication routings for pipe spools were identified and incorporated into the logic of the "Spool Family Tree" and the nomenclature of the Capacity Planning module.

#### Task 4.0) Production Implementation

*Status: Complete*

The rollout of the production version of the PSMS began on Sept 24, 2007 with the first use of the new system for level loading and nesting of small bore pipe spool fabrication tasks scheduled for week 41 (week of Oct 8). Medium and large bore spool fabrication followed after a two week assessment of the small bore operations. The PSMS is now the permanent method for planning and controlling pipe spool fabrication in the Pipe Shop. An industry briefing of the implementation pilot results (Del 4.2) was presented at the NSRP Joint Panel meeting in New Orleans in December 2007.

#### Task 5.0) Document results of lot-based nesting and lessons learned

*Status: Complete*

Tasks 5.1 & 5.2) Collection of production cost data on the TAKE Program was completed in November 2006. Analysis and cost comparison to baselines was completed and delivered in the industry report (Del 5.0) in January 2007. An industry briefing of this report was also presented at the December 2006 NSRP Joint Panel Meeting in Savannah.

#### Schedule and Milestones:

The final project plan is shown below. Progress on individual tasks is indicated in the final project schedule (Figure 16) and project major milestones are listed in Table 1.

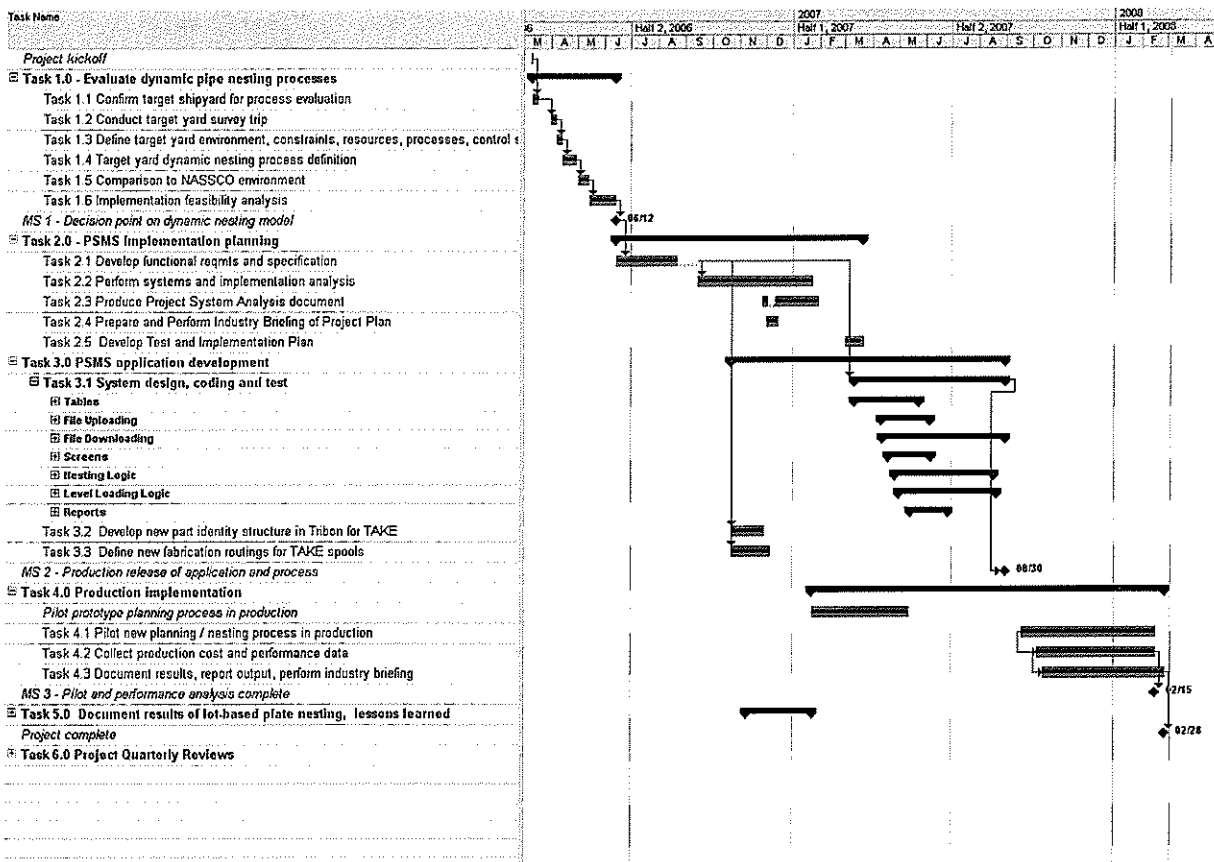


Figure 16 – Project Schedule and Milestones

### Milestones/ Completion Criteria

The first key milestone was the completion of the feasibility study at the conclusion of Task 1.6. It was at this time that we decided on the specific model that would be further developed for the dynamic pipe nesting application and process. Our original draft specification reflected a model which was mainframe-based and driven by our MRP system (MAC-PAC). This was the model that was previously successfully deployed in our automated profile fabrication center. The initial information that we had on KSC's nesting model was that it was Windows-based and not specifically controlled by a high level MRP system. This insinuated a more flexible type of nesting application, but it may have had significant limitations in our type of ship construction environment. The feasibility analysis would determine the direction that our development effort would take.

The second key milestone was the release of the developed application software for production implementation on the T-AKE Program. This event marked the point in time when production cost savings to the Program would begin to accrue.

The third key milestone was the completion of the pilot implementation and the production cost data collection during the pilot timeframe. It is at this point that we would be able to assess and communicate the actual results of the implementation of this new technology to the industry.

| Milestone Number and Description                              | Completion Criteria                                                                                                         | Metric for Go/No-Go Decision                                                                                 |
|---------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| MS 1 – Decision point on dynamic nesting model                | Feasibility study completed; team recommendation to management to proceed                                                   | Nesting model defined that meets criteria for production application                                         |
| MS 2 - Release of dynamic nesting application and process     | Software applications, interfaces and databases completed, tested and validated. Operating processes defined.               | Validation testing confirms shop data downloaded without errors. Nest & work package file data accuracy >95% |
| MS 3 – Pilot implementation and performance analysis complete | Pipe spools for TBD target blocks completed through fabrication. Pipe Shop performance and cost data collected and reduced. | N/A                                                                                                          |

Table 1- Key Project Milestones

#### 4. Technology Transfer Status:

Throughout the course of this project, industry briefings and publicly accessible deliverable reports were produced. Briefings were conducted at NSRP Joint Panel Meetings to ensure the broadest transfer of information to U.S. shipyards. Briefing events included the following:

- December 12, 2006: NSRP Joint Panel Meeting – Savannah, GA  
Industry briefing on NASSCO's Material Flow Improvement and Lot-Based Plate Nesting Project. Details of the project plan and execution were presented, as well as, a discussion of the business case for the effort and a summary of the resulting effects on production costs, efficiencies and value streams.
- December 13, 2006: NSRP Joint Panel Meeting – Savannah, GA  
Industry briefing on the PSMS Implementation Plan. The project concept and system and implementation requirements were detailed for the attending industry members.
- December 12, 2007: NSRP Joint Panel Meeting – New Orleans, LA  
Industry briefing of the implementation pilot results (Deliverable 4.2) was presented detailed for attending industry members.

#### 5. Implementation Status:

The Pipe Shop Management System developed under this CNST funded project is now fully implemented in GD NASSCO's Pipe Shop operations.

During the time period of this development work, GD NASSCO management made a decision to open a new Pipe Shop facility in our wholly owned subsidiary company - TIMSA. The pipe spool fabrication planning and production control process at TIMSA will be controlled by the Pipe Shop Management System. Initial planning for system modifications required to implement the PSMS at TIMSA and a rollout plan are in work. The target for production implementation at TIMSA is June 2008.

#### References:

- 1) Deliverable 1.0: Evaluate Dynamic Nesting Processes - Feasibility Analysis; June, 2006
- 2) Deliverable 3.0: Design Specification - Software Design Report; May 2007
- 3) Deliverable 5.0: Document Result of Lot Based Plate Nesting; January, 2007