Surface Prep QA/QC Process Improvement

An NSRP SP-3 Panel Project

Prepared for

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December 31, 2007

Approved for public release;
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EXECUTIVE SUMMARY

This report describes the results of a project seeking to reduce the cost of shipbuilding and ship repair by re-engineering the way shipyards and owners perform QA and QC. Quality assurance for coating application and surface preparation is a labor intensive project which can involve qualitative as well as quantitative assessments. Various initiatives have looked at technology to increase the speed or improve the objectivity of individual inspection tasks. This effort takes a holistic view of QA/QC to identify the time and conflict drivers, and identify process as well as technology solutions which can reduce the associated costs.

The analysis presented herein suggests that the overall labor associated with surface preparation and coating inspection could be reduced by as much as 50%. However, it should be kept in mind that QA/QC costs are a low portion of the overall cost of work. The following broad categories should be targeted for improvement:

- Costs associated with monitoring environmental parameters during the surface preparation and coating activities dominate the overall inspection process cost. Equipment for automatically logging the necessary data is readily available. However, some owners require environmental data to be validated and downloaded frequently. Efforts should be made to extend the time which these instruments can operate unattended.
- It can take longer to access the workspace than actually perform the inspection. Where possible, inspection activities should be combined to minimize this cost impact.
- Properly implemented automated data collection and recordkeeping has the potential to impart savings and improve accuracy of inspections. However, if the review and submission procedure is still predominately a paper process much of the savings will not be recognized. Only by creating a paperless reporting and review procedure can the full benefits of datalogging equipment be recognized.

The study highlighted four coating non-conformities of primary concern that must be addressed and remedied via process control and confirmed via quality assurance:

- Invisible surface contamination (e.g. salts) has a high likelihood of occurring and a significant impact on coating service life.
- Poor coating adhesion will adversely impact service life and is very costly to repair.
- Improperly cured coating will adversely impact service life and is very costly to repair.
- Steel surface irregularities (weld splatter, rough edges, etc.) have a high likelihood of occurring.

The detailed information in this report could be used as a basis for process improvement efforts by individual shipyards. This report allows the reader to look at individual processes in the context of the entire process. It contains recommendations for improvement of the various individual processes as well as an overall perspective of the cost drivers in the family of surface preparation and coating QA/QC practices.

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BACKGROUND

There are a number of initiatives to attempt to reduce the cost of surface preparation and coating QA/QC. Perhaps most common is the development of data acquisition devices to reduce the cost associated with paperwork.[1, 2] These initiatives seek to eliminate the paperwork and cost of data review by capturing data electronically and allowing the user to automatically "flag" data which is not in compliance with the specification.

There is also an ongoing effort by the various standardization societies to improve individual inspection process, such as the improving the visual standards used in surface preparation qualification or introduction of new tools. New tools have been developed to quantify rapidly elements of the coating process. For example, routine inspection of surfaces for soluble salts via electronic gauges is a relatively recent development.

While these initiatives have made great strides at improving elements of the process, the efforts to date have not looked at the overall process. Ultimately owners have to determine the return on the quality assurance investment on the extended lifetime of their coatings and shipyards (or applicators) have to reduce their QC costs to offer the best possible work at a competitive price. Such analyses will identify what QC/QA processes are most critical, most expensive, and least effective. Improvements which are placed on the most burdensome yet crucial processes will have the most impact.

The main body of this report presents the results of an industry survey on surface preparation and coating inspection as well as the results of a process improvement demonstration. A series of appendices provide supplemental information. Appendix C includes a discussion of QA/QC processes, summarizing the procedure, discussing the significance of the data, identifying key process steps, identifying costs associated with the process, discussing potential complications with the procedure and finally discussing improvement opportunities. These sections are written in such a manner that they could be used on a stand-alone basis for the reader who is interested in a specific process. Appendix D conceptually discusses paperless processes for coating inspection. Appendix E provides some introductory information on value stream mapping and process improvement events as they might relate to coating inspection processes.

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[1] Applying Statistical Process Control to Coatings Activities in Lean Production Implementation, Final report presented to NSRP/ASE Surface Preparation & Coatings Panel (SP-3) under subcontract number: 2005-360

[2] Preservation Information Management (PIM) Working Group briefing by Wayne Mathe at MegaRust, June 2006.

CONCLUSIONS

1. The survey results indicate that industry believes surface preparation and coating inspection processes for the most part are reasonably effective and not overly costly in the scope of the overall project. Given the costs associated with coatings re-work (longer time out of service, costs associated with drydock, etc), a small increase in risk of failure could have significant cost impact to the ship owner. Thus, conservative approaches to surface preparation and coating inspection may be warranted.

2. While QA/QC costs as a percentage of the overall project remain relatively low, from the contractor's perspective, these costs and the impacts of disputes over requirement-interpretations can represent a substantial portion of their cost. Thus there remains a substantial interest on both the part of the owners and contractors to continually improve the processes and reduce their cost.

3. There appear to be some relatively simple things which can be done to reduce the cost of surface preparation and coatings inspection considerably. Specifically, more efficient processes for monitoring environmental conditions and electronic recordkeeping procedures could reduce labor required for inspections by as much as 50%. Note that this is a much smaller percentage of the overall surface preparation and coating work cost.

4. The survey results indicate the following non-conformities are the highest industry concern. These are areas which need to maintain a high level of QA/QC.

   - Invisible surface contamination (e.g. salts) has a high likelihood of occurring and is a significant impact on coating service life.
   - Poor coating adhesion will adversely impact service life and is very costly to repair.
   - Improperly cured coating will adversely impact service life and is very costly to repair.
   - Steel surface irregularities (weld splatter, rough edges, etc.) have a high likelihood of occurring and impact service life.

5. The survey results indicate that the following non-conformities are the least industry concern. These may be the candidates for relaxed QA/QC control.

   - Excessive surface profile is perceived to have relatively low impact on service life. This result may reflect that marine coatings are thick enough to cover high profiles.
   - Excessive film thickness (individual coat) is perceived to have relatively low impact on service life.
   - Missing stripe coat is perceived to be a relatively rare occurrence.
   - Flash rusting is perceived to have relatively low impact on service life.

- Excessive film thickness of the complete system is perceived to have relatively low impact on service life.

6. The following surface preparation and coating inspection processes are candidates for improvement:

    - Access to workspace can be the most time consuming component of the inspection process. As a result, limiting the number of times an inspector needs to physically access the workspace will provide savings.
    - Environmental monitoring is the most time consuming process thus offering the best opportunity for improvement. Equipment for making the necessary measurements is readily available. However, automation has not been readily accepted by the industry. Legacy practices of manually recording periodic readings remain.
    - Recordkeeping is a cost driver for all inspection processes. Present work with automated data collection and electronic storage of data should reduce this burden.
    - Surface profile measurement, dry film thickness measurement, and surface salt measurement each have instruments which can capture the measurement value electronically. Use of these instruments in conjunction with revised recordkeeping requirements has the potential to reduce the overall cost of inspection.

7. There are not many process control procedures which are widely used in the industry. A variety of new techniques are being developed, such as laser sighting for spray guns. Given the general survey results suggest that many of the standard QA processes are not likely to find non-conformities with a high degree of accuracy (i.e., > 90%), process control and training become paramount to achieving an adequate coating system. Evaluation of new process control technology will require careful study, using many of the current QA/QC measurement process, but applying them in a more intensive way for the purposes of collecting sufficient data to evaluate the process control.

8. The program also illustrates that the current QA/QC processes have a high tendency to lead to conflict. Technologies that reduce operator bias or subjectivity in the assessment of the work completed will reduce these problems.

RECOMMENDATIONS

1. Evaluate the reliability of environmental monitoring equipment. A substantial portion of the inspection effort could be eliminated if such equipment could be relied upon for several days without checking calibration or downloading data.

2. Evaluate the effectiveness of digital profile gauges. The electronic devices could potentially reduce process time, reduce recordkeeping time, and minimize transcription errors. However, the survey indicates that industry is concerned about their ability to detect non-conformities. The inconsistencies between replica tape and digital methods must be fully understood to transition to the new technology.

3. Focus on the non-conformity areas of high and low concern to more clearly identify these industry consensuses. This may provide the best opportunity to refocus current QA/QC efforts.

4. Investigate the real cost of disputes and ways of rapidly mitigating their impact. The survey indicates that one in 20 inspection checkpoints result in a dispute At a minimum, the dispute leads to "stand-around" for the dispute participants and the idle work crew. As the significance grows, disputes increase the cost of the project substantially by creating (possibly) unneeded rework, impacts on related trades, lack of clear objectives for other work of a similar nature, etc.

5. A clear cost driver is the need to make multiple inspections throughout the surface preparation and coating evolution. Ideally, coatings could be inspected once after they are completely installed. Industry should assemble a team to identify how this ideal might be recognized.

QA/QC SURVEY

A web-based survey of industry practitioners was performed to determine the opinion of industry professionals regarding what inspection processes are most expensive, most ambiguous, and least effective. The survey also sought to determine what non-conformities are most likely to occur, have the greatest impact on coating life, and are most expensive to repair. Ultimately, the most critical non-conformities should drive the inspection effort.

Survey participants were asked to rank a variety of possible non-conformities and inspection processes in each of the above dimensions. Fifty-eight respondents replied to the survey. The respondents were equally divided among engineer/designers, production/quality control personnel, and owner representatives/quality assurance personnel. More than half of the respondents reported having at least 20 years experience. A majority of respondents thought that the survey was appropriate in length and detail. One drawback of the survey was that it tried to capture the general opinion and did not ask the respondent to consider specific scenarios. For example, the effect of salt contamination on service life depends to some extent on the service environment. However, the survey constrained the respondent to one overall estimate of the effect.

Appendix A presents a summary of the survey data. Each of the six tables presents the results for a different question. The values represent the percent of respondents which selected each rating. To aid the reader, the values have been color-coded with darker colors indicating a proportionately higher percentage of respondents. Within each table, the rated processes or non-conformities are sorted with those of highest concern at the top of the individual tables.

One way to evaluate survey data is to focus on the outliers – that is the percentage of responses that are at the high and low ends of the scale. Generally, these are the issues which people feel strongly about. To create a composite analysis of the data, the percentage of responses which were at the extreme ends were counted. The net number of responses which indicate low concern (negative) or high concern (positive) was calculated as a percentage of overall responses.

Table 1 shows the net percentage of respondents ranking each of the non conformities as a low (negative) or high (positive) concern. For easier reading, the data has been color-coded to highlight the combinations of highest concern (light red) and lowest concern (light green). Key observations include:

- The non-conformities of highest overall concern are invisible surface contamination (salts), steel surface irregularities (weld splatter, rough edges, etc), improperly cured coating, and poor coating adhesion.
- Of the non-conformities of highest concern, invisible surface contaminants (salts) have both a high likelihood of occurrence and a high impact on service life.
- Two of the non-conformities of highest concern (improperly cured coating and poor coating adhesion) were deemed unlikely to occur, however they do have a high impact on service life and are costly to repair when the do occur.

- The non-conformities of moderate concern are visible surface contaminants, holidays or bare areas, insufficient film thickness, improper environmental conditions, and insufficient surface profile.
- The non-conformities of least concern are excessive surface profile, excessive film thickness, missing stripe coat and flash rust. Of those, only the stripe coat and flash rust represent inspections which could be eliminated. Surface profile and film thickness measurements might still be necessary to identify insufficient surface profile or coating thickness.

Table 1 – Summary of Nonconformity Rankings

Non-Conformities	**Overall**	**Occurance**	**Life Impact**	**Cost**
Cleanliness				
Flash Rusting	-12%	13%	-31%	-18%
Invisible surface contamination (e.g. salts)	32%	47%	38%	10%
Steel surface irregularities (weld splater rough edges etc)	16%	53%	-18%	12%
Visible surface contamination (e.g. dust)	-2%	57%	-19%	-44%
Coverage				
Holidays or bare areas (entire system)	6%	-14%	31%	0%
Holidays or bare areas (individual coat)	5%	40%	0%	-26%
Missing stripe coat	-12%	-31%	-4%	-2%
Environmental Conditions				
Improper environmental conditions	8%	13%	4%	8%
Film Integrity				
Improperly cured coating	17%	-40%	62%	30%
Poor coating adhesion	28%	-33%	65%	52%
Surface Profile				
Excessive surface profile	-15%	-11%	-42%	8%
Insufficient surface profile	-3%	-26%	6%	12%
Thickness				
Excessive film thickness (complete system)	-11%	2%	-52%	18%
Excessive film thickness (individual coat)	-13%	13%	-58%	6%
Insufficient film thickness (complete system)	1%	-6%	10%	0%
Insufficient film thickness (individual coat)	-2%	19%	-12%	-14%

Table 2 shows the net percentage of respondents ranking each of the inspection processes as a low (negative) or high (positive) concern. For easier reading, the data has been color-coded to highlight the combinations of highest concern (light red) and lowest concern (light green). Key observations include:

- For the most part, there is agreement that inspection processes are effective, appropriately priced, and not ambiguous
- Electrical holiday detection, laboratory QA of coating material and continuous environmental monitoring had the highest concentration of "cost prohibitive" ratings. Cost is

also a concern for measuring surface salts, field verification of material properties and recordkeeping processes.

Table 2 – Summary of Inspection Process Rankings

Inspection Processes	Overall	Process Cost	Dispute	Detection
Cleanliness				
Surface Salts (Conductivity Measurement)	-16%	12%	-26%	-33%
Degree of Flash Rusting	-17%	-30%	9%	-30%
Surface Salts (Chloride Measurement)	-20%	7%	-34%	-33%
UV Surface Cleanliness (oil grease etc)	-20%	-14%	-26%	-21%
Visual Surface Irregularities (weld splatter edge prep etc)	-22%	-16%	-27%	-23%
Visual Surface Cleanliness	-29%	-47%	-20%	-20%
Dust (Tape Test)	-32%	-14%	-31%	-50%
Dust (Visual)	-39%	-52%	-33%	-33%
Coverage				
Electrical Holiday Detection	-21%	38%	-52%	-50%
Visual Holiday Detection – Intermediate Coats	-24%	-27%	-41%	-2%
Visual Holiday Detection – Primer	-25%	-25%	-39%	-12%
Visual Holiday Detection – System	-25%	-27%	-43%	-5%
Environmental Conditions				
Continuous Environmental Monitoring	-23%	28%	-50%	-48%
Environmental Conditions during cure	-36%	-9%	-50%	-48%
Environmental Conditions during coating application	-39%	-22%	-45%	-50%
Environmental Conditions during Surface Prep.	-39%	-16%	-49%	-51%
Substrate Surface Temperature	-52%	-36%	-59%	-59%
Material Properties				
Field check of coating properties (e.g. viscosity)	-3%	2%	-37%	26%
Laboratory QA of Coating Material	-25%	35%	-57%	-52%
Other				
Recordkeeping (report to owner)	-24%	11%	-40%	-42%
Containment Integrity	-27%	2%	-51%	-33%
Surface Profile				
Anchor Profile (Comparator)	-22%	-21%	-34%	-10%
Anchor Profile (Dial Depth Gauge)	-26%	-14%	-45%	-17%
Anchor Profile (Testex Tape)	-39%	-9%	-49%	-59%
Thickness				
Dry Film Thickness (SSPC PA-2) – Intermediate Coats	-30%	-11%	-34%	-45%
Dry Film Thickness (SSPC PA-2) – System	-33%	-16%	-34%	-50%
Dry Film Thickness (SSPC PA-2) – Primer	-34%	-18%	-34%	-50%
Wet Film Thickness	-45%	-48%	-59%	-28%

- The vast majority of inspection processes will have an "infrequent" likelihood of dispute. The inspection processes which have the highest probability of dispute all relate to surface cleanliness. Determining the degree of flash rusting had the highest probability of dispute. Other inspection processes with reasonable likelihood of dispute were visual surface cleanliness, conductivity measurements, UV surface cleanliness (greases, etc) and inspection for surface irregularities (weld splatter, edge prep, etc).

- The vast majority of inspection processes will successfully detect nonconformities more than 75% of the time. The inspection process which has the lowest probability of detecting nonconformity is field verification of coating properties. Other inspection processes with lower than average detection were visual holiday detection, anchor profile measurements with the comparator or depth gauge, visual inspections for surface irregularities and surface cleanliness, UV inspection for surface cleanliness, and wet film thickness measurements.

For ease of comparison, the non-conformities and inspection processes in Tables 1 and 2 are grouped into categories. The category which appears to have the most opportunities for improvement is surface cleanliness. Surface cleanliness involves a number of inspection processes to detect non-conformities which are frequent and can have a significant impact on service life.

Perhaps the next category of concern is coverage. Holidays and bare areas can be frequent in individual coats and critical to service life if they occur in the entire system. As we move to coating systems with fewer coats, the issues of frequency and impact will converge. Compounding the problem would appear to be the poor detection achieved by the visual holiday inspection techniques.

A final category of interest occurs only in the non-conformity table. Clearly, we should be concerned about film integrity issues – improper cure and poor adhesion. While they do not occur frequently, they can have a high impact to service life and cost to repair. Launching ships prior to completion of the coating cure does happen. Yet we do not directly measure these properties. One might argue that the inspection processes measure issues which ultimately impact these critical non-conformities. However, if a single adequate measure of adhesion and cure was developed, perhaps a number of surrogate inspection processes could be eliminated.

Another way to analyze the survey data is to create a weighted average response. For the categories where the ratings have a numerical meaning (e.g., 1 in 5 probability of dispute) we can calculate a most probable value from the data. While the relative rankings of the individual processes are not much different than presented above, there are some interesting observations. For example, while the median response to "probability of dispute" was "infrequent," the lowest weighted average for any of the processes is 5%. This means that we can probably expect a dispute for one in every twenty checkpoints. Considering that each element of work (e.g., 2,000 ft^2 tank) may have 10 checkpoints, this means that every other work element will have a dispute. Disputes can be quite costly, especially if they are elevated through levels of management. Either the number of disputes or the efficiency with which they are dealt offers a cost savings opportunity.

With respect to the likelihood of detection, the overall average response was 70%. The median for many of the processes was 90%. This indicates that the inspection process are not highly effective – fully 10% of the coated surface area is likely to be non-compliant with the present inspection techniques. Perhaps this is one reason the surface preparation and coating industry retains layers of inspection processes.

Note that the cost data in the survey ranged from “Negligible” to “Prohibitive” with and intermediate rating of “Reasonable.” This was intended to determine if there are processes or nonconformities which carry a significant cost premium. Unfortunately this data is not amenable for process time analysis. A brief follow-up survey of three shipyard representatives was conducted to capture data on the process time required for various inspection processes. Appendix B provides the raw data from this survey. The data is not intended to represent a cross-section of shipyards, but rather it was used for the process demonstration discussed in the next section.

Appendix C includes a discussion of each of the inspection processes, summarizing the procedure, discussing the significance of the data, identifying key process steps, identifying costs associated with the process, discussing potential complications with the procedure and finally discussing improvement opportunities.

Recordkeeping was identified as having a higher than reasonable cost. Inspection instruments with datalogging capabilities have the potential to reduce recordkeeping cost. However, if the review and submission procedure is still predominately a paper process much of the savings will not be recognized. Only by creating a paperless reporting and review procedure can the full benefits of datalogging equipment be recognized. Appendix D conceptually discusses paperless processes for coating inspection.

PROCESS IMPROVEMENT DEMONSTRATION

From a time/throughput standpoint the opportunities for process improvement may vary by shipyard or even personnel who perform these QA functions. The best opportunities will only be identified after a thorough review which determines production and process time at each step of a specific process. To demonstrate how a shipyard might evaluate the impact of alternative QA/QC technologies, we evaluated three QA/QC tools with digital data acquisition capabilities in an actual shipyard production environment. Following is a brief description of the testing conducted:

Surface Profile – Digital depth gauge versus Replica Tape. Data were collected on the "touch time" required to perform surface profile measurements with replica tape in accordance with Navy Standard Item 009-32. As a potential improvement, surface profile measurements were made using a digital needle gauge (Elcometer 224). Process time data was collected for this measurement technique as well.

Process time data for surface profile measurements was collected after abrasive blasting a 2,450 square foot tank on a new construction excavation barge. Process time data for surface profile measurements were also collected after abrasive blasting the underwater hull of a small Navy barge. The underwater hull area was approximately 1,500 square feet.

Dry Film Thickness – Manual records versus digital records. Data were collected on the "touch time" required to measure the dry film thickness in accordance with the guidance in Navy Standard Item 009-32. Individual measurements were manually recorded onto the forms in the Appendix of the Standard Item. As a potential improvement, dry film thickness data were taken using a pre-programmed instrument that stores the data in accordance with SSPC PA-2 (the same specification called out in SI 009-32). The report generated by the instrument software was considered the final QA/QC submittal. Both the manual and automated sets of data were collected with the same instrument (DeFelsko Positector 6000).

Process time data for both DFT measurement processes were collected after coating application on two tanks of the excavation barge. The tanks were nominally 2,876 square feet of surface. Process time data was also collected during the measurement of coating DFT on the underwater hull of a small Navy barge. The underwater hull was nominally 1,500 square feet of surface. Two sets of data were collected for comparison – one after the first coat of antifouling coating and one after the second antifouling coat.

Ambient Condition Monitoring – Manual tools (sling psychrometer) versus data-logging tools. Data were collected on the "touch time" associated with environmental condition measurements for one day. The manual process included six manual readings in 24 hours. Manual readings were made using a sling psychrometer in accordance with the requirements in Navy Standard Item 009-32. Automated measurements were made using a DeFelsko Positector DPM. Two-hundred, eight-eight (288) data readings were stored. The process analysis assumes that one manual measurement per day is sufficient to confirm proper operation of the instrument. The analysis assumed that the data will be downloaded daily.

Process time data for the environmental measurements was collected in one of the excavation barge tanks and in the paint shop during coating of watertight hatches.

Demonstration Data

Following is the data collected from the demonstration project. It is important to note that the process evaluation focused on "touch time" associated with performing the inspections and recording the results. The evaluation neglected the time associated with inspector access to the structure and administrative notifications.

Surface Profile – Digital depth gauge versus Replica Tape.

Table 3 shows the results from the evaluations of the two surface profile measurement techniques. The tables list the various tasks completed and the time required for each. The automated process was slightly more than twice as fast as the replica tape method. The average time saved was 54%. Note that the correlation between the dial depth gauge and replica tape has been the subject of some debate. In this demonstration, both measurement methodologies indicated acceptable profile; a detailed study of the correlation between the two methods was not performed.

Table 3 – Surface Profile Measurement Process Data

			Excavator S #5	Excavator S #5
Surface profile / preparation method (5 minimum; 3 tape readings = 1)	critical ¶ 3.10.5	(I) (G)	Replica Tape/ SI 009-32, App. 3	Data logger
			Testex replica tape	Elcometer 224
			manual	**automatic**
Set up ft² to determine number of readings. 2540 ft².			6 min 19 sec	6 min 19 sec
Prepare & fill out Appendix 3, 2 pages			6 min 52 sec	
Verify calibration			30 sec	30 sec
Place, burnish, measure, & stick to App. 3; 9 readings, 27 tapes			13 min 58 sec	
Average / calculation & notation to App. 3			3 min 58 sec	
Measure 9 spots, 10 readings ea.				6 min 1 sec
Upload & print from elcometer program				2 min 17 sec
		Total touch time:	31 min 37 sec	15 min 7 sec
			1897 sec	907 sec
		Used scissor lift to access:	UF 53 hull	UF 28 hull
Surface profile / preparation method (5 minimum; 3 tape readings = 1)	critical ¶ 3.10.5	(I) (G)	Replica Tape/ SI 009-32, App. 3	Data logger
			Testex replica tape	Elcometer 224
			manual	**automatic**
Set up ft² to determine number of readings. 1500 ft².			2 min 13.8 sec	2 min 13.8 sec
Prepare & fill out Appendix 3, 2 pages			3 min 9.8 sec	
Verify calibration			30 sec	30 sec
Place, burnish, measure, & stick to App. 3; 7 readings, 21 tapes			15 min 6 sec	
Average / calculation & notation to App. 3			2 min 23.1 sec	
Measure 7 spots, 10 readings ea.				7 min 45.6 sec
Upload & print from elcometer program				included above
		Total touch time:	23 min 22.7 sec	10 min 29.4 sec
			1402.7 sec	629.4 sec

Dry Film Thickness – Manual records versus digital records.

Table 4 shows the results from the evaluation of the two dry film thickness measurement techniques. The tables list the various tasks completed and the time required for each. The automated process was two to three times faster than the manual method. The average time saved was 59%

Table 4 – Dry Film Thickness Measurement Process Data

		Tank hole access:	Excavator S #7	Excavator P #7
DFT measurements per coat; no stripe coats	critical ¶ 3.10.9.1	(I) (G)	SI 009-32, Appendix 7	Software
			Positector 6000	Positector 6000
			manual	**automatic**
Set up ft² to determine number of readings. 2876 ft².			3 min 32 sec	3 min 32 sec
Prepare Appendix 7.			3 min 13 sec	
Verify calibration.			1 min 4 sec	1 min 4 sec
Take 75 gauge readings, 25 spot readings, average & document.			23 min 28 sec	
Take 75 readings with Positector 6000 programmed for PA-2.				6 min 48 sec
Upload & print, Positector 6000.				2 min 48 sec
		Total touch time:	31 min 17 sec	14 min 12 sec
			1877 sec	852 sec
		Used scissor lift to access	UF hull 28	UF hull 28
DFT measurements per coat; no stripe coats	critical ¶ 3.10.9.1	(I) (G)	SI 009-32, Appendix 7	Software
			Positector 6000	Positector 6000
2nd coat AF			**manual**	**automatic**
Set up ft² to determine number of readings. 1500 ft². Rolled over info from above.			no	no
Prepare Appendix 7.			3 min 14 sec	
Verify calibration.			1 min 4 sec	1 min 4 sec
Take 60 gauge readings, 20 spot readings, average & document.			18 min 45 sec	
Take 60 readings with Positector 6000 programmed for PA-2.				4 min 45 sec
Upload & print, Positector 6000.				4 min 41 sec
		Total touch time:	23 min 03 sec	10 min 30 sec
			1383 sec	630 sec
		Used scissor lift to access	UF hull 28	UF hull 28
DFT measurements per coat; no stripe coats	critical ¶ 3.10.9.1	(I) (G)	SI 009-32, Appendix 7	Software
			Positector 6000	Positector 6000
last coat AF			**manual**	**automatic**
Set up ft² to determine number of readings. 1500 ft². Rolled over info from above.			no	no
Prepare Appendix 7.			3 min	
Verify calibration.			1 min 4 sec	1 min 4 sec
Take 60 gauge readings, 20 spot readings, average & document.			19 min 42 sec	
Take 60 readings with Positector 6000 programmed for PA-2.				4 min 57 sec
Upload & print, Positector 6000.				1 min 27 sec
		Total touch time:	23 min 46 sec	7 min 7 sec
			1426 sec	448 sec

Ambient Condition Monitoring – Manual tools (sling psychrometer) versus data-logging tools.

Table 5 shows the results from the evaluation of the two environmental condition monitoring methods. The tables list the various tasks completed and the time required for each. The automated process was about twice as fast as the manual method. The average time saved was 53%.

Table 5 – Environmental Condition Monitoring Process Data

			Excavator P #5	Paint Shop 1
Ambient, substrate, RH%, dew point. 12 hours prior - 48 hours after - 7 days pot / fd tanks every 4 hours.	critical ¶ 3.10.1	(I)	manual sling or auto App. 1	data logger & software
			Positector DPM	Positector DPM
Touch time only'			**manual**	**automatic**
Set up Appendix 1			2 min 8 sec	2 min 7 sec
Take manual readings #5 sbd - hi / low; document Appendix 1. One time.			3 min 45 sec	3 min 45 sec
Set data logger PM				1 min 29 sec
Retrieve data logger, upload, & print; 24 hours.				5 min 21 sec
Manual readings required every 4 hours:			22 min 30 sec	
Total touch time:			24 min 38 sec	11 min 42 sec
			1478 sec	702 sec

To allow comparisons of the actual process times measured, all of the data was normalized on a square foot basis. Figure 1 graphically shows all of the data presented above. The chart suggests that automation can save nominally 5 to 10 minutes per 1,000 square feet for film thickness and surface profile measurements. The chart also indicates that for recording environmental conditions for a single day, about 13 minutes were saved using the automated data-logging features.

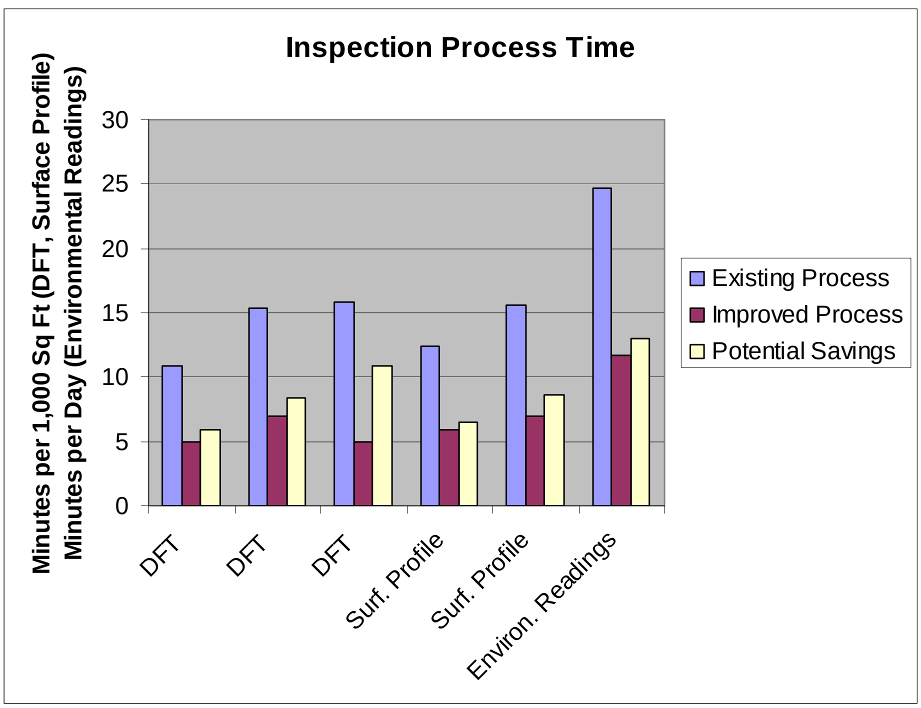

Figure 1. Inspection Process Time Improvements

Process Improvement Potential

The following hypothetical analysis was performed in order to put the individual time savings in the perspective of an overall operation. For this hypothetical analysis, we've assumed a 2,000 square foot tank where preservation takes place over a seven (7) day timeframe using a 2-coat system (with a stripe coat).

Table 6 provides a summary of the time required for the inspection process. For the purposes of this discussion, the process data from the sampling of responses shown in Appendix B was used. Either mean or median values for each process were used for the analysis. For access time, it is assumed that some operations are performed concurrently. For example, five of the 21 environmental condition checks do not require access since they would be conducted in conjunction with other inspections. Access time (25 minutes) was spilt among inspections which would be performed concurrently in the case of surface preparation, primer coat and topcoat inspection.

The analysis suggests that 17 hours and 9 minutes will be required for the inspection activities. The analysis suggests that more than half of the inspection time will be associated with environmental condition monitoring. From an activity perspective, the analysis suggests that half of the time will be associated with accessing the workspace. These are two important conclusions. Clearly the best opportunities for cost reduction are to reduce the time required to move between the workspace and office and to reduce the time associated with environmental readings. Environmental readings are the most frequently required data.

Table 6 – Conceptual Analysis of Inspection Time Requirements

Conceptual 2,000 square foot Tank - Current Process

	Access	Measure	Recordkeeping	Total	
Time per environmental condition checkpoint	25	6	5		
7 days of environmental condition monitoring (assume 3 measurements per day)	400	119	105	*624*	*61%*
Degrease per SSPC SP-1	25	10	5	*40*	*4%*
21 Textex tape measurements (e.g., "Method C")	8	22	15	*45*	*4%*
10 Conductivity measurements per 009-32	8	30	10	*48*	*5%*
7 tape readings for dust	8	21	5	*34*	*3%*
Primer - 60 dry film thickness readings (20 "spots")	13	21	10	*44*	*4%*
Time to visually inspect primer for holidays	13	28	5	*46*	*4%*
Time to visually inspect stripe coat	25	28	5	*58*	*6%*
Topcoat - 60 dry film thickness readings (20 "spots")	13	21	10	*44*	*4%*
Time to visually inspect topcoat for holidays	13	28	5	*46*	*4%*
Total	*525*	*329*	*175*	*1,029*	
	51%	*32%*	*17%*	*17 hrs 9 min*	

To determine what impact the process improvements evaluated above will have on this base case, we will adjust the "measure" and "recordkeeping" times by the percentages determined in the process demonstration. It will also be assumed that environmental condition datalogger is downloaded once per day (when a confirming measurement is also made). Table 7 shows the resulting analysis. The analysis suggests that the overall inspection time can be reduced by about

50% (nearly 9 hours). The greatest majority of this time savings is associated with the environmental monitoring (nearly 90% of the overall savings).

Table 7 – Improved Inspection Process Time

Conceptual 2,000 square foot Tank - Improved Process

	Access	Measure	Recordkeeping	Total	
Time per environmental condition checkpoint	25	3	2		
7 days of environmental condition monitoring (assume 1 measurement per day)	50	56	49	*155*	*15%*
Degrease per SSPC SP-1	25	10	5	*40*	*4%*
21 Profile measurements (e.g., "Method B")	8	10	7	*25*	*2%*
10 Conductivity measurements per 009-32	8	30	10	*48*	*5%*
7 tape readings for dust	8	21	5	*34*	*3%*
Primer - 60 dry film thickness readings (20 "spots")	13	9	4	*25*	*2%*
Time to visually inspect primer for holidays	13	28	5	*46*	*4%*
Time to visually inspect stripe coat	25	28	5	*58*	*6%*
Topcoat - 60 dry film thickness readings (20 "spots")	13	9	4	*25*	*2%*
Time to visually inspect topcoat for holidays	13	28	5	*46*	*4%*
Total	*175*	*229*	*99*	*504*	
	17%	*22%*	*10%*	*8 hrs 24 min*	

The above analysis is conceptual. To estimate actual achievable savings in a shipyard, the entire value stream for inspection processes at the shipyard of interest should be mapped. Appendix E discusses value stream mapping and process improvement events.

APPENDIX A – DETAILED INSPECTION PROCESS SURVEY DATA

For each of the following surface preparation inspection processes, rate the relative cost of inspection, including labor, equipment and indirect costs.	Negligible	2	3	Reasonable	5	6	Prohibitive
Electrical Holiday Detection	2%	0%	2%	31%	24%	21%	19%
Laboratory QA of Coating Material	4%	0%	2%	33%	22%	24%	15%
Continuous Environmental Monitoring	2%	2%	11%	35%	17%	20%	13%
Surface Salts (Conductivity Measurement)	2%	5%	0%	58%	16%	9%	9%
Recordkeeping (report to owner)	0%	2%	4%	64%	16%	7%	7%
Surface Salts (Chloride Measurement)	5%	2%	2%	57%	20%	7%	7%
Containment Integrity	5%	5%	12%	53%	14%	5%	7%
Field check of coating properties (e.g. viscosity)	9%	5%	9%	53%	7%	9%	7%
Anchor Profile (Testex Tape)	18%	2%	4%	56%	9%	2%	9%
Environmental Conditions during cure	16%	7%	11%	47%	7%	4%	9%
Dry Film Thickness (SSPC PA-2) – Intermediate Coats	16%	2%	9%	59%	7%	7%	0%
UV Surface Cleanliness (oil grease etc)	11%	7%	7%	59%	11%	2%	2%
Anchor Profile (Dial Depth Gauge)	17%	5%	12%	45%	14%	2%	5%
Dust (Tape Test)	19%	5%	10%	50%	7%	5%	5%
Environmental Conditions Monitoring	13%	9%	2%	64%	4%	2%	4%
Visual Surface Irregularities (weld splatter edge prep etc)	9%	14%	0%	64%	7%	0%	7%
Dry Film Thickness (SSPC PA-2) – System	16%	5%	7%	61%	7%	2%	2%
Dry Film Thickness (SSPC PA-2) – Primer	18%	2%	9%	61%	7%	2%	0%
Anchor Profile (Comparator)	19%	10%	7%	50%	7%	2%	5%
Environmental Conditions during coating application	18%	11%	4%	58%	2%	0%	7%
Visual Holiday Detection – Primer	25%	11%	14%	39%	0%	7%	5%
Visual Holiday Detection – System	20%	14%	14%	43%	2%	2%	5%
Visual Holiday Detection – Intermediate Coats	27%	11%	9%	41%	0%	5%	7%
Degree of Flash Rusting	20%	14%	9%	50%	2%	0%	5%
Substrate Surface Temperature	36%	5%	7%	48%	0%	0%	5%
Visual Surface Cleanliness	36%	11%	7%	47%	0%	0%	0%
Wet Film Thickness	34%	16%	9%	36%	2%	0%	2%
Dust (Visual)	45%	11%	11%	27%	0%	2%	2%

For each of the following surface preparation inspection processes, rate the likelihood of a dispute between inspectors conducting the same test on the same surface.	Never	Infrequent	1 in 100	1 in 20	1 in 5	Half	Always
Degree of Flash Rusting	2%	16%	9%	27%	18%	20%	7%
Visual Surface Cleanliness	0%	31%	16%	16%	27%	11%	0%
UV Surface Cleanliness (oil grease etc)	5%	26%	21%	21%	23%	2%	2%
Surface Salts (Conductivity Measurement)	9%	33%	7%	21%	14%	14%	2%
Visual Surface Irregularities (weld splatter edge prep etc)	2%	39%	2%	30%	14%	11%	2%
Dust (Tape Test)	7%	38%	19%	12%	10%	10%	5%
Dust (Visual)	7%	40%	14%	16%	9%	12%	2%
Dry Film Thickness (SSPC PA-2) – System	5%	41%	7%	20%	16%	11%	0%
Dry Film Thickness (SSPC PA-2) – Primer	5%	41%	7%	25%	11%	11%	0%
Dry Film Thickness (SSPC PA-2) – Intermediate Coats	5%	41%	9%	20%	14%	11%	0%
Surface Salts (Chloride Measurement)	11%	32%	7%	25%	16%	9%	0%
Anchor Profile (Comparator)	7%	39%	7%	15%	20%	10%	2%
Field check of coating properties (e.g. viscosity)	12%	35%	21%	16%	7%	7%	2%
Visual Holiday Detection – Primer	9%	39%	16%	14%	14%	9%	0%
Recordkeeping (report to owner)	9%	38%	18%	16%	13%	7%	0%
Visual Holiday Detection – Intermediate Coats	7%	43%	11%	16%	14%	9%	0%
Visual Holiday Detection – System	7%	43%	14%	14%	16%	7%	0%
Anchor Profile (Dial Depth Gauge)	7%	45%	7%	17%	17%	7%	0%
Environmental Conditions during coating application	14%	34%	18%	14%	18%	2%	0%
Environmental Conditions Monitoring	9%	42%	13%	16%	18%	2%	0%
Anchor Profile (Testex Tape)	13%	47%	7%	13%	9%	9%	2%
Environmental Conditions during cure	9%	43%	11%	18%	16%	2%	0%
Continuous Environmental Monitoring	9%	50%	11%	9%	13%	9%	0%
Containment Integrity	7%	49%	9%	26%	5%	5%	0%
Electrical Holiday Detection	10%	52%	12%	12%	5%	7%	2%
Laboratory QA of Coating Material	17%	43%	9%	13%	13%	4%	0%
Substrate Surface Temperature	7%	57%	11%	9%	11%	2%	2%
Wet Film Thickness	7%	61%	14%	7%	2%	5%	5%

For each of the following surface preparation inspection processes, rate the effectiveness of the inspection at detecting a non-conformity, assuming it exists.	Rarely Detects	Detects 25%	Detects 50%	Detects 75%	Detects 90%	Always Detects
Field check of coating properties (e.g. viscosity)	26%	21%	19%	12%	12%	10%
Visual Holiday Detection – Intermediate Coats	9%	16%	30%	16%	23%	5%
Visual Holiday Detection – System	9%	19%	21%	19%	26%	7%
Anchor Profile (Comparator)	7%	12%	34%	17%	17%	12%
Visual Holiday Detection – Primer	9%	12%	23%	23%	28%	5%
Anchor Profile (Dial Depth Gauge)	7%	17%	17%	17%	24%	17%
Visual Surface Cleanliness	2%	16%	22%	22%	24%	13%
UV Surface Cleanliness (oil grease etc)	7%	10%	21%	24%	21%	17%
Visual Surface Irregularities (weld splatter edge prep etc)	9%	14%	11%	20%	36%	9%
Wet Film Thickness	9%	9%	19%	16%	33%	14%
Degree of Flash Rusting	2%	11%	20%	23%	30%	14%
Dust (Visual)	7%	5%	30%	14%	30%	14%
Containment Integrity	7%	9%	14%	21%	42%	7%
Surface Salts (Chloride Measurement)	5%	14%	12%	19%	28%	23%
Surface Salts (Conductivity Measurement)	5%	17%	7%	17%	31%	24%
Recordkeeping (report to owner)	13%	2%	13%	13%	40%	18%
Dry Film Thickness (SSPC PA-2) – Intermediate Coats	7%	5%	9%	23%	43%	14%
Environmental Conditions during cure	7%	7%	18%	7%	36%	25%
Continuous Environmental Monitoring	11%	4%	11%	11%	41%	22%
Dry Film Thickness (SSPC PA-2) – Primer	7%	5%	9%	18%	48%	14%
Electrical Holiday Detection	7%	5%	7%	19%	45%	17%
Environmental Conditions during coating application	7%	7%	11%	11%	41%	23%
Dry Film Thickness (SSPC PA-2) – System	5%	0%	9%	32%	41%	14%
Dust (Tape Test)	5%	2%	14%	21%	29%	29%
Environmental Conditions Monitoring (surface prep)	11%	7%	7%	7%	27%	42%
Laboratory QA of Coating Material	7%	4%	17%	9%	33%	30%
Substrate Surface Temperature	7%	5%	14%	5%	43%	27%
Anchor Profile (Testex Tape)	2%	9%	9%	9%	34%	36%

For each of the following coating non-conformities, rate the relative likelihood of the non-conformity to occur on a marine coating project.	Certain	1 in 2	1 in 5	1 in 10	1 in 20	1 in 100	Unlikely
Visible surface contamination (e.g. dust)	30%	32%	20%	5%	7%	4%	2%
Steel surface irregularities (weld splater rough edges etc)	36%	25%	15%	9%	8%	8%	0%
Invisible surface contamination (e.g. salts)	38%	17%	19%	19%	0%	8%	0%
Holidays or bare areas (individual coat)	27%	23%	6%	12%	23%	4%	6%
Insufficient film thickness (individual coat)	10%	21%	25%	23%	10%	8%	4%
Excessive film thickness (individual coat)	6%	19%	29%	15%	19%	12%	0%
Flash Rusting	10%	15%	23%	23%	17%	10%	2%
Improper environmental conditions	10%	21%	21%	15%	15%	13%	4%
Excessive film thickness (complete system)	8%	13%	13%	19%	27%	19%	0%
Insufficient film thickness (complete system)	4%	12%	17%	19%	27%	17%	4%
Excessive surface profile	8%	15%	17%	15%	11%	30%	4%
Holidays or bare areas (entire system)	16%	6%	8%	10%	25%	24%	12%
Insufficient surface profile	4%	4%	19%	26%	13%	28%	6%
Missing stripe coat	4%	8%	12%	20%	14%	27%	16%
Poor coating adhesion	8%	4%	6%	12%	25%	41%	4%
Improperly cured coating	6%	2%	8%	17%	19%	42%	6%

For each of the following coating non-conformities, rate the potential impact of the non-conformity on coating service life if it is not detected and corrected.	Negligible	5% Reduction	10% Reduction	25% Reduction	50% Reduction	Catastrophic
Poor coating adhesion	4%	0%	16%	12%	25%	43%
Improperly cured coating	8%	2%	10%	10%	27%	44%
Invisible surface contamination (e.g. salts)	8%	6%	12%	23%	29%	23%
Holidays or bare areas (entire system)	6%	10%	16%	22%	24%	24%
Insufficient film thickness (complete system)	10%	15%	13%	27%	33%	2%
Insufficient surface profile	14%	14%	16%	24%	22%	12%
Improper environmental conditions	19%	12%	15%	19%	19%	15%
Holidays or bare areas (individual coat)	8%	24%	20%	18%	20%	12%
Missing stripe coat	8%	16%	25%	31%	18%	2%
Insufficient film thickness (individual coat)	19%	15%	21%	21%	17%	6%
Steel surface irregularities (weld splater rough edges etc)	10%	25%	18%	29%	18%	0%
Visible surface contamination (e.g. dust)	19%	22%	19%	19%	13%	9%
Flash Rusting	25%	25%	15%	15%	17%	2%
Excessive surface profile	48%	13%	12%	8%	13%	6%
Excessive film thickness (complete system)	35%	27%	13%	15%	6%	4%
Excessive film thickness (individual coat)	38%	23%	19%	15%	2%	2%

For each of the following coating non-conformities, rate the cost to repair the non-conformity if it is detected at the appropriate time.	Negligible	2	3	Acceptable	5	6	Prohibitive
Poor coating adhesion	6%	0%	4%	26%	6%	24%	34%
Improperly cured coating	10%	4%	0%	28%	14%	20%	24%
Excessive film thickness (complete system)	16%	4%	6%	25%	12%	14%	24%
Steel surface irregularities (weld splater rough edges etc)	8%	6%	10%	42%	8%	10%	16%
Insufficient surface profile	10%	6%	4%	43%	10%	12%	16%
Invisible surface contamination (e.g. salts)	8%	4%	6%	45%	16%	4%	18%
Excessive surface profile	24%	4%	0%	24%	10%	10%	27%
Improper environmental conditions	16%	4%	8%	34%	10%	10%	18%
Excessive film thickness (individual coat)	12%	6%	8%	33%	18%	6%	18%
Holidays or bare areas (entire system)	10%	10%	2%	46%	12%	4%	16%
Insufficient film thickness (complete system)	14%	4%	6%	47%	12%	8%	10%
Missing stripe coat	12%	6%	8%	46%	12%	2%	14%
Insufficient film thickness (individual coat)	16%	10%	6%	47%	10%	6%	6%
Flash Rusting	14%	10%	4%	49%	18%	0%	6%
Holidays or bare areas (individual coat)	18%	14%	10%	42%	10%	2%	4%
Visible surface contamination (e.g. dust)	42%	9%	9%	27%	5%	0%	7%

APPENDIX B – DETAILED PROCESS TIME SURVEY DATA

2,000 Square Foot Tank		Resp 1	Resp 2	Resp 3	Average	Range +/-	Range %	Units	Data per Unit Area or per Reading: Average	Low	High
How much time is required to access a 2,000 square foot tank from inspectors office?	Minimum	20	10	15	15.00	5.00	33%				
	Typical	30	25	20	25.00	5.00	20%				
	Maximum	45	60	30	45.00	15.00	33%				
Once in the 2,000 square foot tank, what is the typical time it would take to accomplish each of the following inspections? Include touch-time in the tank but NOT recordkeeping time, access time, etc.	Degrease per SSPC SP-1	90	8	10	36.00	41.00	114%	2	18.00	4.00	45.00
	21 Textex tape measurements (e.g., "Method C")	30	15	20	21.67	7.50	35%	21	1.03	0.71	1.43
	70 readings with a digital profilometer (e.g., "Method B")	40	15	15	23.33	12.50	54%	70	0.33	0.21	0.57
	10 Conductivity measurements per 009-32	45	15	30	30.00	15.00	50%	10	3.00	1.50	4.50
	7 tape readings for dust	35	7	21	21.00	14.00	67%	7	3.00	1.00	5.00
	60 dry film thickness readings (20 "spots")	30	25	8	21.00	11.00	52%	60	0.35	0.13	0.50
	Time for each environmental condition check	10	5	2	5.67	4.00	71%	1	5.67	2.00	10.00
	Time to visually inspect stripe coat	45	5	35	28.33	20.00	71%	2	14.17	2.50	22.50
	Time to visually inspect full coat for holidays	45	10	30	28.33	17.50	62%	2	14.17	5.00	22.50
Once the data has been collected, how long does it take to compile the records for each of the following inspections?	Record results of degrease inspection	25	5	5	11.67	10.00	86%	1	11.67	5.00	25.00
	Average and record 21 Textex tape measurements	30	5	10	15.00	12.50	83%	21	0.71	0.24	1.43
	Average and record 70 digital profilometer readings	45	5	10	20.00	20.00	100%	70	0.29	0.07	0.64
	Record 10 Conductivity measurements per 009-32	30	5	5	13.33	12.50	94%	10	1.33	0.50	3.00
	Report 7 tape readings for dust	30	5	5	13.33	12.50	94%	7	1.90	0.71	4.29
	Average and record 60 dry film thickness readings	30	5	10	15.00	12.50	83%	60	0.25	0.08	0.50
	Record environmental conditions	60	5	5	23.33	27.50	118%	1	23.33	5.00	60.00
	Reprot results of stripe coat inspection	20	5	2	9.00	9.00	100%	1	9.00	2.00	20.00
	Report results of full coat inspection	20	5	2	9.00	9.00	100%	1	9.00	2.00	20.00
Feel free to provide any comments on your responses.	(1) All of the above information is subject to change dependent upon the individual characteristics of the tank being inspected, as well as the interpretation of how things are correctly done IAW third party inspectors or NAVSEA if they are involved. All will be longer if you are teaching people as you go.										

10,000 Square Foot Underwater Hull		Resp 1	Resp 2	Resp 3	Average	Range +/-	Range %	Units	Data per Unit Area or per Reading: Average	Low	High
How much time is required to access the 10,000 square foot underwater hull from	Minimum	10	10	5	8.33	2.50	30%				
	Typical	20	30	5	18.33	12.50	68%				
	Maximum	30	60	5	31.67	27.50	87%				
Once in the drydock, what is the typical time it would take to accomplish each of the following inspections? Include touch-time in the tank but NOT recordkeeping time, access time, etc.	Degrease per SSPC SP-1	180	8	15	67.67	86.00	127%	10	6.77	0.80	18.00
	69 Textex tape measurements (e.g., "Method C")	120	10	60	63.33	55.00	87%	69	0.92	0.14	1.74
	230 readings with a digital profilometer (e.g., "Method B")	90	15	35	46.67	37.50	80%	230	0.20	0.07	0.39
	50 Conductivity measurements per 009-32	240	25	120	128.33	107.50	84%	50	2.57	0.50	4.80
	23 tape readings for dust	90	7	120	72.33	56.50	78%	23	3.14	0.30	5.22
	180 dry film thickness readings (60 "spots")	120	30	35	61.67	45.00	73%	180	0.34	0.17	0.67
	Time for each environmental condition check	10	5	3	6.00	3.50	58%	1	6.00	3.00	10.00
	Time to visually inspect stripe coat	60	10	15	28.33	25.00	88%	10	2.83	1.00	6.00
	Time to visually inspect full coat for holidays	90	10	15	38.33	40.00	104%	10	3.83	1.00	9.00
Once the data has been collected, how long does it take to compile the records for each of the following inspections?	Record results of degrease inspection	60		2	31.00	29.00	94%	1	31.00	2.00	60.00
	Average and record 69 Textex tape measurements	60		60	60.00	-	0%	69	0.87	0.87	0.87
	Average and record 230 digital profilometer readings	60		60	60.00	-	0%	230	0.26	0.26	0.26
	Record 50 Conductivity measurements per 009-32	90		35	62.50	27.50	44%	50	1.25	0.70	1.80
	Report 23 tape readings for dust	60		35	47.50	12.50	26%	23	2.07	1.52	2.61
	Average and record 180 dry film thickness readings	90		60	75.00	15.00	20%	180	0.42	0.33	0.50
	Record environmental conditions	90		15	52.50	37.50	71%	1	52.50	15.00	90.00
	Reprot results of stripe coat inspection	45		15	30.00	15.00	50%	1	30.00	15.00	45.00
	Report results of full coat inspection	45		15	30.00	15.00	50%	1	30.00	15.00	45.00
Feel free to provide any comments on your responses.	(2) The information is invalid as question 2 #1 does not give square footage or configuation. (3) Inspections may or may not be completed at the same time. I have provided one off times for each. Additionally, the UWH may be broken into many zones so the set of inspections listed here may need to be accomplished many times (up to 6 different paint evolutions). The reporting times vary, it takes a long time to record the info correctly. If the appendicies is used on the deck plates and there is no need to transpose the data to another sheet, it will cut5 time however in order to prepare for final package turn in these reports will be reviewed by 3 inspectors (another 180 minutes).										

APPENDIX C – QA/QC PROCESS EVALUATION

This appendix discusses the key surface preparation and coating QA/QC process steps. Within each discussion, possible improvement opportunities are identified. Each section is somewhat independent; the reader may only wish to review those sections which concern them most.

Surface Preparation

Surface preparation is the most important factor in obtaining good coating performance. The intent of surface preparation is to provide a dry, clean, roughened surface for coatings to properly adhere. Key attributes of surface preparation include various measures of cleanliness and a measure of the roughness of the prepared surface.

Surface contaminants may significantly shorten service life if they are sufficient to compromise coating adhesion, promote corrosion of the cleaned surfaces or draw water into the coating through osmosis. Based on the survey results, surface cleanliness issues were among the QA/QC processes of highest concern. Surface preparation cleanliness attributes include degreasing prior to surface preparation, assessment for surface salts, dust, surface irregularities, flash rusting, and overall extent of cleanliness. Each of these attributes is described in a separate section below

Cleanliness - Degrease Prior to Surface Preparation

Substrates are degreased prior to blast cleaning to remove oil or grease-like organic or non-organic materials, dust, dirt and debris that could otherwise become imbedded in the substrate during the blasting operation. Substrate contamination may also reduce the usefulness of recyclable blast media, where used. Inspection should be carried out to ensure that the substrate is indeed free of such materials before beginning the blast cleaning process.

<u>Process Considerations</u>. Navy Standard Items FY08, 009-32 section 3.10.2.1 requires the contractor to "Accomplish a visual inspection a maximum of four hours prior to starting coating removal to insure accomplishment of SSPC SP-1." A degreasing inspection may require from 10 to 50 minutes to perform on a few thousand square feet.

Subjective factors involved in any visual inspection procedure can result in differences of interpretation. The thoroughness of the inspection may also vary among inspectors. Nevertheless, when carried out by experienced inspectors, the visual inspection will reduce the risk of surface contamination.

<u>Opportunities for Improvement</u>. There is an opportunity to develop an objective measurement tool that accurately quantifies contaminates such as oil or grease-like organic or non-organic materials, dust, dirt and debris on the substrate. Some of these materials will fluoresce under a black light (in fact some inspection procedures call for the use of a black light). Incorporation of visual imaging devices (cameras) with black light illumination may facilitate a more subjective inspection procedure.

Cleanliness – Soluble Surface Salts

The presence of soluble salts on a surface is detrimental to applied protective coatings. As such, many owners have stringent requirements for maximum allowable soluble salt concentrations. Invisible surface contaminants were the non-conformity of highest concern in the project survey. Surface salts were ranked as highly likely to occur and having a high impact on service life.

Research completed in the late 1980's and early 1990's all showed that underfilm soluble salts could lead to subsequent coating deterioration. Salts just above the Lower Detection Limit (LDL) of commercially available detection technologies were shown, over-time, to accelerate the blistering and rust-through of coatings under immersion conditions.[3] Based on these findings, a criterion of 3 µg/cm2 NaCl, as Cl^-, became the U.S. Navy acceptable limit for immersion service. The implementation of these levels was supported by a host of international standards.

In the marine industry, most specifications require surface chlorides to be below 5 µg/cm². NORSOK requires surface chloride levels below 2 µg/cm² for all off-shore service conditions.[4] ISO standards[5] recommend limits of 3 µg/cm² on surfaces prior to coating. Australian standards state, "For adequate surface life in an outdoor environment, low film build protective coatings of less than 100µm thickness require a level of chloride deposits not greater than 50mg/cm² (5µm/cm²)."[6] Data suggests that the probability of failure can increase by a factor of 2-7 for immersion service when the surface chloride level increases from 0 to 5 µg/cm².[7]

Process Considerations. In order to test for surface cleanliness, surface salts must be extracted and analyzed. Extraction of surface salts in shipbuilding is generally performed using a patch method (e.g., Bresle Test Kit). Subtle procedural differences are required when measuring conductivity versus surface chlorides. The survey results indicate that chloride and conductivity measurement costs were rated higher than "reasonable," but are otherwise reasonably effective techniques.

ISO 8502-6, describes the Bresle method for extraction of soluble contaminants. Subsequent to extraction, the retrieved fluid may be analyzed for total conductivity or specific ion content (e.g., chlorides). Most procedures require taking five measurements every 1,000 square feet. Each soluble salt measurement consists of several discrete steps, including:

- Adhere patch to surface
- Fill syringe with deionized water
- Inject half of the water into the patch

[3] Ellor, J. and Farschon, C., "Allowable Soluble Salt Contamination Levels for Industrial Painting," Paper presented at SSPC 1997.
[4] NORSOK Standard M-501, Surface Preparation and Protective Coating
[5] ISO 8502-9:1998 Preparation of steel substrates before application of paints and related products -- Tests for the assessment of surface cleanliness -- Part 9: Field method for the conductometric determination of water-soluble salts
[6] Australian/New Zealand Standard AS/NZS 3894.6: 1996 "Site testing of protective coatings Method 6: Determination of residual contaminants"
[7] Elzly Technology Corporation report "Development of Quantitative Relationship between Non- Standard Coating Application and Risk of Coating Failure," 2006.

- Reposition needle and evacuate air
- Remove needle from patch and expel air
- Reinsert needle and inject remaining water
- Agitate patch with finger
- Extract water using syringe
- Transfer water to conductivity meter or other container for analysis
- Record reading
- Remove patch from surface
- Clean surface
- Clean syringe and meter

Opportunities for Improvement. The accuracy of a conductivity meter is reported to be within 2 – 3%. Additional error will arise from the physical extraction procedure, quality of the water used, and effectiveness of the water recovery procedure. Soluble contaminant extraction efficiency largely depends on the leak tightness of the adhesive patch, including the adhesive bond between the patch body and the steel surface. If performed effectively, as much as 95% of the soluble contaminants can be removed by performing the extraction process once.

Another source of discrepancy is the selection of measurement locations. Depending on the consistency of the blasted surface, the selection of locations for soluble contaminant measurements can contribute to differences in observations. It is desirable to agree on a distribution of reading locations (based on the orientation and accessibility of surfaces) before comparing independent sets of measurements. The ability to make an effective measurement may dictate the locations tested. Smooth, flat, horizontal surfaces are easiest to test. Unfortunately, surfaces which are more difficult or impossible to evaluate (e.g., rough surfaces, corners and crevices) are also more likely to retain soluble salts. Thus, the overall test method and quality assurance requirement could benefit from an improved extraction technique, especially one which incorporated a better seal to the surface and one more amenable to not flat areas.

Soluble salt measurements are among the more time consuming QA/QC measurements in surface preparation and coating. There are at least two strategies to deal with the cost of the soluble salt measurements. First, an automated conductivity meter has been developed and is described in Japanese Industrial Standard JIS Z 0313. A similar instrument has been developed around US Navy standards for use in the United States. Sales literature for this instrument suggests that the instrument could offer process time and consumable savings which more than offset the initial cost. At the time of this project, the instrument was not yet commercially available to U.S. shipyards.

Second, chloride problems might be better taken care of by process control rather than by inspection. Requiring water washing process controls (e.g., runoff water conductivity monitoring) could eliminate need for surface inspection. In such a scenario, the traditional salt test might still be required to validate the process, but it could be eliminated when the process is proven.

Cleanliness – Dust

Dust on blast-cleaned surfaces may reduce adhesion of coatings. Accumulation of dust more naturally occurs on horizontal surfaces, the interior of pipes, and in structural cavities. Inspection should be carried out to ensure that such areas are free from dust before painting. Dust may significantly shorten service life if it is sufficient to compromise coating adhesion. Should coatings survive immediate breakdown, data suggests small amounts of blasting grit dust may have relatively low impact on service life.[8] Dust has less impact than soluble salts of the same surface concentration.

Process Considerations. ISO 8502-3, *Assessment of dust on steel surfaces prepared for painting (pressure-sensitive tape method)* provides an objective method for determining the level of dust on a blasted surface. The method requires pressure sensitive adhesive tape to be pressed onto the surface that is prepared for painting. The tape is then removed and placed on a display board of a color which contrasts to that of the dust, and is examined visually. The quantity of the dust adhering to the tape and the dust particle size are then estimated.

Survey data suggests that the overall process of taking and reporting a set of 7 tape tests (as would be required by the Navy for 2,000 square feet of painted surface) would take approximately 35 minutes. This does not include the time required to access the surface being inspected.

Opportunities for Improvement. As an alternative to the tape test, dust may simply be observed visually. Survey results suggest that visual observation could result in substantially lower cost than the tape test. However, the survey data suggests that the visual test has approximately 10% lower probability of detection than the tape test. Visual observations could be supported in areas of dispute with the tape test.

Survey data suggests a 12% probability of dispute when using the tape test. To make the test less subjective, it may be possible to develop an objective measurement tool based on visual imaging devices which accurately quantify dust particulate on the substrate (or on the tape).

Cleanliness – Surface Irregularities

In the survey, surface irregularities were rated as very likely to occur. However the impact of the surface irregularities and the cost to repair them were less of a concern. In part, the perceived low impact on service life is due to the fact that splatter and edges only impart local failure; they do not impact the entire structure. However, if a surface is recoated when 0.3% failure occurs, a number of small spots can be sufficient for recoating. Inspecting for surface irregularities was considered to be effective – reasonable cost, low likelihood of dispute, and a good chance of detection.

Process Considerations. Inspection for surface irregularities is largely a visual inspection. As such, accessibility to the surfaces and lighting within the space can affect the process efficiency. Standard descriptions for varying degrees of weld cleanliness are available to facilitate inspections and reporting.

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[8] Soltz, G.C., The Effects of Substrate Contaminants on the Life of Epoxy Coatings Submerged in Sea Water, NSRP Report 0329, June 1991.

Opportunities for Improvement. Instruments which could easily scan a surface for relative smoothness might be developed to expedite these inspections. For example, mechanical devices or lasers might be used to identify surface irregularities. However, no such instrument is currently available.

Cleanliness – Flash Rusting

The history of flash rust characterization has included various standards.[9,10,11,12,13,14,15] Most of the standards for flash rusting rely on qualitative or at best semi-quantitative determinations of the level of flash rusting. Visual (photographic comparators) and physical (wiping and tape tests) criteria are employed to differentiate among levels of flash rusting.

Process Considerations. Current industry standards predominately use written descriptions of visual observations and relatively simple physical tests to determine whether flash rust is acceptable for coating application. Different interpretations arise because the visual standards represent discrete levels of flash rusting while the field conditions will likely be some intermediate level. To quantify this concern, a "round-robin" evaluation of the flash rust descriptions in SSPC SP-12, *Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating* was performed as part of an NSRP project.[16] The round robin test results suggested that industry personnel could clearly establish a break point between the Moderate and Heavy grades of flash rusting as defined by the three-tier SSPC SP-12 standard. Personnel were less able to agree on distinctions between Light and Moderate.

Survey data suggested that determining the degree of flash rusting was the inspection process with the highest probability of dispute. The survey suggests that industry participants expect 2 to 4 times as many disputes when inspecting for flash rust versus other inspections.

Opportunities for Improvement. At least four initiatives are presently underway to develop more quantitative test procedures to reduce disputes.[17,18,19,20] These techniques include electrochemical

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[9] ISO 8501-4, Preparation of steel substrates before application of paints and related products -- Visual assessment of surface cleanliness -- Part 4: Initial surface conditions, preparation grades and flash rust grades in connection with high-pressure water jetting

[10] SSPC-SP 12/NACE 5: Surface Preparation and Cleaning of Steel and Other Hard Materials by High- and Ultrahigh-Pressure Water Jetting Prior to Recoating

[11] SSPC-VIS 4/NACE VIS 7: Guide and Reference Photographs for Steel Surfaces Prepared by Waterjetting

[12] International Paints Hydroblasting Standards (http://www.international-pc.com/pc/technical/tech_papers/hydrophot.asp)

[13] Degrees of Flash Rusting - Guidelines for Visual Assessment of Flash Rusting. Jotun Marine Coatings, Sandefjord, 1996

[14] STG (Schiffbautechnische Gessellschaft) Guide No. 2222, Definition of Preparation Grades for High-Pressure Waterjetting, 1995

[15] Photo Reference of Steel Surfaces Cleaned by Water Jetting., Hempel Marine

[16] *Review of Acceptable Flash Rusting for Ship Coatings*, NSRP SP-3 Panel Project, November, 2007.

[17] M. Islam, W. McGaulley, J. Tagert, J. Ellor, and M. Evans, "Experimentation to Develop a Quantitative Method for Characterizing the Level of Flash Rusting Formed on Carbon Steel after Ultra High Pressure Waterjetting," presented at PACE 2006, January, 2006.

[18] "Digital Image Processing for Rust Assessment," presentation by Muehlhan Equipment Services at the NSRP Ship Production Panel Meeting, Tampa FL, January 2006.

measurements, colorimetric measurements, digital image analysis, and measurement of the corrosion product weight.

As a group, these quantitative test techniques require analysis of a specific "spot" rather than the entire surface and they will be more complicated than the present procedures. Furthermore, they are several years from becoming industry standards. However, if such quantitative tests can be developed they will have several benefits to the industry. Quality tests which provide quantitative evidence in an electronic format have been shown to be more cost-effective for the industry.

Surface Profile

The proper and effective preparation of a surface prior to coating is essential. Making sure that the correct roughness – or profile – has been generated is essential. If the profile is too low, the adhesion of the coating to the surface will be reduced. If the profile is too high, there is the danger that the profile peaks will remain uncoated – allowing rust spots to occur. The survey results indicate that excessive surface profile is nearly twice as likely to occur as insufficient surface profile. However, insufficient surface profile is likely to reduce service life by twice as much. Both have a "reasonable" cost to repair.

Process Considerations. ASTM 4417, *Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel* describes three methods for measuring surface profile – a profile comparator (method A), a dial surface profile gage (method B) and replica tape (method C). Replica tape is the most common method. Table 8 summarizes key process elements for each of the test methods.

Opportunities for Improvement. Method C is the common surface profile measurement technique. Replica tape comes in various grades, each suitable for a different range of surface profile. One of the major problems faced in the field is using the correct grade of tape. Another source of discrepancy is the selection of spots for readings. Depending on the consistency of the blasted surface, the selection of varied locations for surface profile measurements can contribute to differences in calculated averages by different inspectors.

Despite being acknowledged as the least expensive method, the visual comparator method was determined to have a higher probability of dispute and lower likelihood of non-conformity detection than the other two methods. This is probably why it is not often used. Of the two objective methods, the dial depth gauge was ranked as slightly less expensive but considerably less likely to detect a non-conformance. It is not readily apparent why the digital depth gauge would be less likely to detect a non-conformance. This perception may arise from the fact that the digital gauge does not always agree precisely with replica tape. The reasons for this have been investigated by others[21, 22] and relate to the impact of surface wavieness, needle geometry, needle dura-

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[19] C.S. Tricou, "Quantifying the Impact of Flash Rust on Coating Performance," Final Report submitted to Naval Sea Systems Command under contract #N00039-97-D-0042/0377, January 2005.

[20] Philippe Le Calve, DCN, Lorient, France; Phillipe Meunier, SNCF, Paris, France; Jean Marc Lacam, DGA, Paris France, "Quantification of the Products of Corrosion after UHP Waterjetting", JPCL, November 2002.

[21] Keane, et. al., *Surface Profile for Anti-Corrosive Paints*, SSPC publication 74-1, Pittsburgh, PA, 1974.

[22] Fultz, Benjamin S., *Surface Texture (Profile) Measurement*, NSRP Panel Project Report (Also distributed as SSPC Publication 82-04).

bility, and the averaging methodology. While one study suggested a correlation exists between the dial profilometer and the replica tape, the other study suggested that there is no correlation.

A number of relatively inexpensive dial depth gages with data storage and transfer capabilities are available. Many of these tools have modes where the averages of measurements are automatically calculated. Rather than averaging the data, it would be better to collect the same number of individual required measurements and plot the data in a common statistical process control graph. No data points should fall outside of pre-defined control limits.

Table 8 – Summary of Surface Profile Test Procedures

	Calibration	Process Summary
Method A – Profile Comparator	No Calibration	The blasted surface is visually compared to standards prepared with various surface profile depths. A sufficient number of locations are observed to characterize the surface. The range of results from all locations is reported as the surface profile.
Method B – Dial Surface Profile Gage	Prior to use, hold the gage by its base and press firmly against a flat piece of glass. Adjust the gage to zero.	The depth of profile is measured using a fine pointed probe at a number of locations to characterize the surface. The mean of ten measurements is reported as the location profile. The mean of all location measurements is reported as the profile of the surface.
Method C – Replica Tape	No Calibration	A composite plastic tape is impressed into the blast cleaned surface forming a reverse image of the profile, and the maximum peak to valley distance is measures with a micrometer. The mean of three measurements is reported as the location profile. The mean of all location measurements is reported as the profile of the surface.

Environmental Conditions

Air temperature, relative humidity (moisture content in the air), and the dew point (temperature at which moisture will condense a surface) are collectively referred to as “environmental conditions.” These environmental conditions in conjunction with the surface temperature of the part being coated are the attributes of interest for surface preparation and coating.

If work is performed when the environmental conditions are not within the required ranges, there is an increased risk that the coating will not perform as intended. Improper environmental conditions between surface preparation and coating application can lead to surface rusting or surface moisture. Surface rusting may hinder adhesion and may contain invisible contaminants (salts). Coatings applied over a wet surface have a high risk of delamination unless they are specifically formulated for that purpose.

Improper environmental conditions may also prevent proper cure. In gross cases this is observable as a soft coating or amine blush. However, improper cure conditions may imperceptibly decrease the degree of polymerization, resulting in the formation of conductive pathways which may allow water to penetrate the film. Limited data exists to quantify the impact of subtly under cured films.

Process Considerations. Specifications require monitoring of environmental conditions using specialized instruments and test methods before the start of work and periodically during the work. Measurement of these environmental conditions is especially important when weather conditions change during the course of a work shift. However, environmental conditions may be consistently maintained when work is performed inside of containment systems.

Environmental condition monitoring may be performed with data loggers, digital monitors, sling psychrometers, thermometers and other methods as required. During surface preparation and coating operations (including coating cure), ambient and substrate surface temperatures, relative humidity, and dew point should be measured in close proximity to the structure being coated. These environmental readings shall be taken from 12 hours prior to, to 48 hours after, the application of a coat of paint.

For Navy work, the preferred method of measurement is using a data logger. If a data logger is used, it shall collect data at a minimum of every 5 minutes. Manual readings shall be taken once every 12 hours. If a data logger is not used, environmental readings shall be manually taken every 4 hours.

Opportunities for Improvement. It is important to recognize that the trends in environmental data are as important as the absolute values. Coating applicators, supervisors and inspectors should utilize this information to anticipate environmental changes that may produce detrimental effects and take necessary actions to avoid them.

Digital equipment which stores the relevant environmental data has the potential to significantly reduce the man-hours associated with this process. When using a data logger to measure environmental conditions the Navy and other owners may require manual confirmation of the data with manual readings every 12 hours. While it is prudent to check the accuracy of equipment, steps should be taken to make this process less labor intensive (e.g., perform the manual checks daily or weekly, or only in conjunction with other needs to access the tank). A better understanding of the equipment reliability and susceptibilities might allow this requirement to be reduced. If the equipment is not sufficiently reliable, two automatic recorders could be deployed so that backup data is readily available.

It is becoming more common to build containments around structures being painted and provide dehumidified and/or heated air into the work area. Monitoring of environmental conditions is most likely redundant to equipment controls in environmentally controlled spaces. Frequency of readings could be reduced when equipment operating logs are available and contain the necessary environmental data.

Coating Application

Materials Sampling and Testing

QA/QC checks of coating materials are not commonly performed. Field methods to determine basic properties of the liquid coating (e.g., viscosity) before application were once more common. Currently, paint manufacturing processes are much better controlled and most manufacturers perform batch testing and maintain quality data. Some owners will require certifications for the coating manufacturers or may run acceptance testing of material samples in the laboratory.

Process Considerations. Meaningful materials sample testing takes time, equipment, and expertise which is beyond that which is available in the field. Many of the tests which are run require sophisticated equipment (e.g., "fingerprinting" of coatings) and must be conducted in the laboratory. Tests which are appropriate for the field are generally less meaningful given today's sophisticated coatings. It is considered good practice to retain a sample of coating from each batch of material used as a contingency. If problems occur with the coating, testing of the liquid material may lend insight into the problem. However, retention and eventual disposal of samples can require considerable effort.

Opportunities for Improvement. Sampling and testing coatings can be an expensive, time consuming process which may add little value. Worse yet, such tests often duplicate manufacturer quality testing. Even the simple process of keeping a liquid sample from each batch of coating can be an expensive process, especially given that most coatings must be managed as hazardous materials. This required safe storage and disposal as well as maintaining the appropriate literature (Material Safety Datasheets) and properly labeling the containers. The coating manufacturer is better equipped than the shipyard to deal with material sampling issues. If the proper trust and accessibility exists, materials sampling and testing should be handled by the coating manufacturer.

Coverage

Pinholes and voids which cause discontinuity in a coating are known as holidays. "Misses" is a term that is sometimes applied to larger uncoated areas. No matter how small some of these defects may be, they will allow immediate access of water and ionic species to the substrate, resulting in corrosion and coating breakdown. Small pinhole holidays may moderately to significantly shorten the service life depending on the importance of aesthetics and/or the corrosiveness of the service environment. The resultant substrate corrosion may cause an aesthetic problem (staining) and subsequent disbondment/undercutting of the film. Coating holidays should not significantly impact coating performance in immersion service when the coating is under proper cathodic protection (assuming the cathodic protection system has sufficient capacity to protect all of the exposed surface area).

Navy Standard Item FY08, 009-32 generally requires only the performance of a visual holiday inspection. However, sometimes holidays are more precisely identified with an electrical holiday detector. Electrical holiday inspection is performed in accordance with NACE RP0188 "Discontinuity (Holiday) Testing of Protective Coatings" or ASTM D 5162-91 "Standard Practice for Discontinuity (Holiday) Testing of Non-conductive Protective Coating on Metallic Substrates."

Process Considerations. A visual holiday inspection might take 30 to 45 minutes for a few thousand feet of surface area. Visual inspections are impacted by the available lighting, color contrast between the applied coating and the surface, and ease of access. It is difficult to visually discern small holidays (e.g., less than ¼-inch diameter). Furthermore, holidays and missed areas are often in difficult to observe locations such as corners, crevices and backsides of objects. Good lighting, mirrors, and plenty of time is required for a thorough visual holiday check.

Electrical holiday testing is performed with an instrument that essentially consists of a power source and an audible alarm. The instrument has a ground lead which is attached to the structure and an electrode (wet sponge or carbon filled rubber) which is dragged across the coated surface. The coating serves as an insulator in the alarm circuit. A defect in the coating allows the electrical circuit to be completed causing the alarm to sound. This device is capable of detecting holidays that are not discernable to the naked eye. The electrical technique also makes it easier to inspect difficult-to-access areas. The primary drawback of an electrical holiday test is that it is quite time consuming. The electrical holiday test had the highest cost rating of all of the inspection techniques. The electrical technique is also not suitable when additional coats are applied over holiday-free coatings.

Opportunities for Improvement. Subjective visual holiday checks increase the risk of missing coating defects thereby decreasing the opportunity to correct them before being placed back in service. Not detecting holidays increase the risk of rework and premature coating failure.

The use of an electrical holiday detector during coating inspections is the most accurate and rapid way of determining a coating’s continuity. Its use will pinpoint holes or voids in a coating and insure that they have been properly repaired. Ideally, an electrical holiday test should be done on the first coat of primer. Holidays would be touched up in conjunction with the stripe coat. Once a holiday free coating is achieved, subsequent coats would only have a visual holiday inspection. Electrical holiday detection can be cost prohibitive on large areas. To make electrical holiday testing more cost-effective, the scope of testing could be limited to complex geometries (edges, welds, fasteners, etc.).

One of the most promising innovations in the coatings industry is optically active pigments. For various reasons, coating colors are often selected which do not substantially contrast with the surface to which they are applied. However, higher contrast improves the effectiveness of visual holiday inspections. Optically active pigments can be used to create contrast under certain situations. For example, fluorescing pigments have been used in primers to improve the visual holiday check. Other optically active pigments allow wet paint to have a substantially different color than it would when dry.

Thickness

Measurement of dry film thickness (DFT) involves systematically making representative measurements of the thickness of the cured coating. Electronic and magnetic gages are commonly used for non-destructively measuring film thickness over metallic substrates. Alternative methods such as destructive measurement and ultrasonic measurements have special applications that are not common in shipbuilding.

Film thickness is critical to ensure an adequate barrier from the transmission of ionic species to the substrate. Organic coatings limit substrate corrosion by providing a barrier from the environment. Research suggests that each coating has some critical minimum thickness below which service life may be significantly impacted. In the extreme, service life may be shortened by more than half. At extremely high thicknesses coatings may become brittle. As a result, thick coatings are more susceptible to cracking and delamination when subject to mechanical forces. In extreme cases, thick films may not fully cure, resulting in material which is skinned over with a high risk of early failure. Less extreme uncured films may take up water more easily. The degree to which such water uptake is offset by the thicker film is unknown. Moderate thicknesses likely have a low risk of premature failure.

Most procedures require reporting of DFT data as averages. However it is important to remember that the coating thickness on any given structure is actually a range – each thickness in that range is represented on some portion of the structure.

<u>Process Considerations</u>. DFT measurement is commonly performed in accordance with SSPC-PA 2, Measurement of Dry Coating Thickness with Magnetic Gages. This specification provides instructions for calibrating gages and making measurements. DFT measurement consists of several discrete steps, including:

- Calibrate gage
- Calculate required number of readings
- Take readings
- Record readings and calculate averages

SSPC PA-2 requires a specific number of "spot" readings dictated by the coated surface area. Each spot reading is the average of three individual measurements.

- 0 – 100 ft^2 – 5 spot readings required
- 101 – 200 ft^2 – 10 spot readings required
- 201 – 1,000 ft^2 – 15 spot readings required
- greater than 1,000 ft^2 – 5 additional spot readings required per 1,000 ft^2 of area

<u>Opportunities for Improvement</u>. Manufacturers reported accuracy of gages can range from 1% to 2% for digital gages. Magnetic (Type I) gages have accuracy as high as 15%. The calibration process is the greatest source of discrepancy for the most common, Type II gages. The specific issue is related to the impact of surface profile on the gage reading. A rough surface contains an interface where there is coating and substrate to varying degrees. Depending on how it is calibrated, the gage will see some intermediate point in this mixed region as the point of zero coating thickness. This obstacle can be addressed by either (1) calibrating the gage on representative flat steel and correcting for the apparent thickness of the blasted steel; or (2) calibrating the gage on blasted steel, thereby measuring the thickness "over the peaks." Either situation requires access to a representative blasted surface. The degree to which that calibration surface is representative of the area where the measurement is being made will contribute far more error than is inherent on the sophisticated digital measurement instrumentation.

Another common source of discrepancy is the selection of spots for readings. Depending on the consistency of the applied film thickness, the selection of varied locations for DFT measurements can contribute to differences in calculated averages by different inspectors.

A number of relatively inexpensive gages with data storage and transfer capabilities are available. Many of these tools have modes where the averages of three measurements are automatically calculated to arrive at a "spot" reading. Unfortunately, the individual measurements which comprise the spot reading are not always stored. Additionally, the data output from the machines are not automatically printed in a format consistent with Navy Standard Items 009-32 or other owner requirements. To maximize the benefit of automated data capture, manually re-formatting the data is a step which should be eliminated.

As mentioned above, the coating thickness on any given structure is actually a range – each thickness in that range is represented on some portion of the structure. Rather than averaging the data as required in SSPC PA-2, it would be better to collect the individual required measurements and plot the data in a common statistical process control graph. No data points should fall outside of pre-defined control limits. In this type of scenario, the number of measurements required could be reduced or increased based on the demonstrated competency of the coating applicator.

Wet Film Thicknesses (WFT) should be taken by the painter as part of the application process. These measurements are a form of process control because they provide the operator with direct feedback on the quality of the workmanship, allowing for immediate adjustments to the application process. Unfortunately, the WFT measurements cannot be documented or verified except by looking at DFTs. An instrument which allowed for logging of WFT data could substantially reduce the number of DFT measurements required.

Cured Film Integrity

The integrity of the cured film is not commonly a formal QA/QC checkpoint, but it is possible to test for the degree of cure, adhesion, and other properties of the cured film. The survey results indicated that "improperly cured coating" and "poor coating adhesion" were a very high concern based on the cost to remedy the problem and the potential impact these issues would have on the service life of the coating. However, these non-conformities also had the lowest probability of occurring as ranked in the survey.

Process Considerations. Test procedures for determining the integrity of the cured film typically include a rudimentary physical evaluation of the film with a knife or one's fingernail. Generally, the cured film is inspected for a hard, smooth appearance. More sophisticated evaluations of coating cure are possible. These tests may include removing a small sample of coating for laboratory analysis. Also, there are field tests using a solvent-rub test to evaluate the degree of chemical resistance offered by the material.

Tests for coating adhesion are not typically performed. Adhesion tests can be destructive in nature and require coating repair after they are performed. Pull-off adhesion tests require a considerable amount of time to run because the glue used to attach the test fixture to the surface typically has to dry for 24 hours. Faster curing adhesives generally have less strength than slower curing adhesives.

Opportunities for Improvement. It is interesting that the coating features which are deemed most important are not directly measured. Rather, we indirectly determine that these attributes will be acceptable given that the various process attributes were satisfactory. For example, we observed paint storage, mixing and application and assume that if they are done properly the applied film will be appropriately cured and well adhered. If we could eliminate some of the process measurements and instead focus on the ultimately desired attributes of the coating, there may be an opportunity for considerable savings. Unfortunately, tests to evaluate the quality of a coating after application are not yet available.

APPENDIX D – PAPERLESS QA

Data entry and reporting is a key part of the QA processes. Automating this process offers an opportunity to improve the surface preparation and coating QA/QC. This would require compatible instrumentation as well as a convenient and user-friendly interface for manual entry/user selection. Figure 2 shows conceptually how this might work. Automated instruments/processes are shown in green, whereas manual inputs are shown in yellow. Stop points are shown in red, external processes are shown in grey and supervisor review is shown in orange. Electronic data stores are white and electronic data flows are shown as dotted lines.

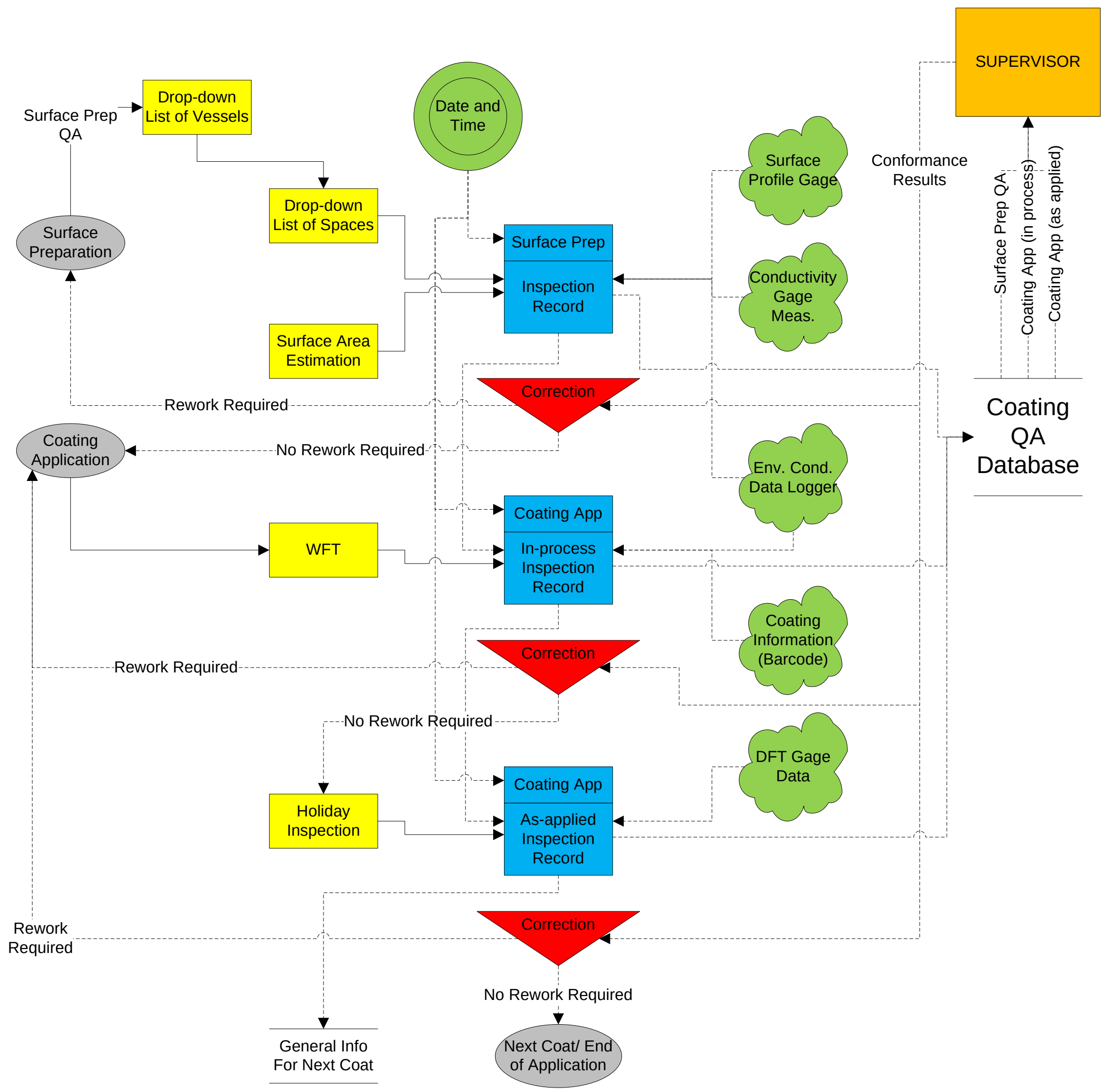


Figure 2. QA Data Entry and Flow.

Automating and computerizing the data entry process offers the potential for improved data flow, automated review and potentially quicker response time and higher probability for correction of out-of-specification areas. Figure 3 shows how such data might flow to the supervisor for easier review and action. Non-conformities are highlighted for evaluation and appropriate action by supervisor.

Ship Name & Hull: USS ABC, 123	**Date/Time:** 1/1/1900, 0847
Location: Tank AB123XYZ789	**Product Applied:** MIL-PRF-24441, Manf. XYZ
Square Feet: 100	**Coat:** Primer **DFT:** 2.0 to 4.0 mils

Spot	Reading	Location	Conformance
1	4.5	North wall, top left near ceiling	Yes, 12.5% of range
2	4.8	North wall, mid left	Yes, 20% of range
3	5.2	North wall, middle	No, 30% of range
4	4.7	North wall, bottom right near floor	Yes, 17.5% of range
5	4.0	North wall, mid right	Yes, within range
Average	4.64		No, outside range

Figure 3. Conceptual Data Record for DFT Measurements.

Systems similar to what is described above have been developed. One such system has been developed and demonstrated on several Navy ships.[23] The operational testing of this system included tracking 102 preservation work items. Over 22,000 data sets were recorded and stored, eliminating thousands of pages of paper data. Due to the success of the demonstration, the Navy is implementing a similar system fleet wide.

By using automated and computerized data entry there is the potential to improve the response time by the supervisor for correction of non-conformities. Automating these processes and including identification of out-of-spec areas would allow quicker evaluation and recommendation or acceptance of variation from specification. This could allow for corrective measures to be performed at each step of the preservation process as non-conformities are identified as compared to the current requirement of providing information from the QA Checklist Forms within 72 hours of completion of preservation of each location.

Paperless systems include a wide variety of alternatives including instrument manufacturer software, Navy developed software, and “custom” applications which can be as simple as spreadsheet programs or scanned versions of paper documents. Automation has the potential to free up valuable resources, can provide for timely notification of out of spec conditions, and reduce time spent in review of records that are difficult to read. Each of these tools brings one or more features to the user. It is important to consider if or how the entire process will benefit from a paperless component. Possibilities include:

- A great deal of energy is spent on hand writing data. There are problems with legibility, accuracy of the math, properly recording the specific readings, etc. DFT, surface profile, and environmental instruments are available that record readings to memory for download through computers. Unfortunately, when these features are used, inspection data is still transcribed onto paper forms, eliminating many of the benefits of the system.

[23] Hagan, Lynn, “PQADS and Navy Ship Preservation: An Operational Testing Report,” Presented at the 2007 Tri-Service Corrosion Conference, Denver, CO.

- Much of the QA paperwork includes redundant information. Databases allow information such as signatures, instrument identification, etc to be captured once and linked to multiple related data points.
- Sophisticated databases can check for compliance and highlight out-of-spec data. Automatic e-mail notification of non-compliances is also possible.
- Electronic data can be accessed by multiple users in remote locations via the internet or other computer networks. Such access is possible whether the data is stored in an interactive database or as electronic versions of documents.
- Paperless processes can be more accommodating to changing criteria.

APPENDIX E – VALUE STREAM MAPPING AND PROCESS IMPROVEMENT EVENTS

Throughout this report, Value Stream Maps (VSMs) and structured process improvement activities have been discussed. With the exception of the demonstration, the concepts presented are general in nature. To take advantage of the ideas presented in this report, each shipyard may wish to develop their own VSMs or conduct other structured improvement activities. This appendix is intended to provide a very basic, general guidance on these tools. For more information, a variety of texts and papers are available on these topics.

Team Selection

The first step is the selection of the team for this event. The team should include:

- Champion – person at a senior management level supporting the project/event.
- Sponsor – person with budget authority to make changes.
- Facilitator – Lean Six Sigma Black Belt (or equivalent) they help the team members achieve the goals of the event, but DO NOT execute the event.
- Team Leader – person within the work area that has the respect of others and can lead the discussions and improvement activities.
- Team Members – individuals that work in or with the area(s) being evaluated, provide value-added inputs, understand the processes being investigated and can implement/evaluate changes made.

The team members should be dedicated to the event being performed (i.e., be authorized to attend by their supervisor for the entire scheduled length of the event). Continual changes in team structure can be disruptive and counterproductive. Conversely, disruptive team members or those who do not add to the overall group dynamic may be asked to leave.[24] The Champion and Sponsor may or may not participate in the process improvement event; however, they should be asked to participate during key activities (e.g., charter development, process mapping and changes) and be present during the project out brief.

Charter

The charter is the first task that should be asked of the team. Often a draft charter has been developed and can be used as the base document. However, this should not be considered to be "set in stone". As the process improvement event evolves new opportunities and/or customer values might be identified, changing the focus of the event. The charter should be considered a living document. Components of the charter should include:

- Event Dates
- Champion, Sponsor, Facilitator, Team Leader and Team Members

[24] Disruptive and/or not adding to the group dynamic DOES NOT mean individuals who do not support the process improvement activity, contrary view and opinions can help guide the improvement activity and ultimately result in process changes that are of the most benefit. However, individuals who are not participating, continually having side conversations not related to the event, disrupting the overall consensus of the group, etc. may be asked to leave.

- Problem Statement
- Deliverables (major goals, sponsor wants)
- Project Scope
- Process Start and End
- Commandments and Monuments (things that cannot be broken or changed)
- Customer Value (what the customer values out of the process)
- Anticipated Return on Invested Capital (ROIC)

VSM/Process Mapping

The value stream is the set of processes that are conducted to perform a given work function, produce a given product or deliver a specific service. It is called a value stream as it is a series (or stream) of processes that ultimately create some value for the customer. For tank coating the value created might be a properly preserved tank on a Navy vessel.

Mapping should be performed by hand and by walking the actual process with the entire team. A tabloid size piece of blank paper (11 x 17) works well to map the processes being conducted. Once created then other data collection activities can be done such as recording process events and associated times, identifying improvement opportunities, development of physical mapping and spaghetti diagrams showing work flow, etc.

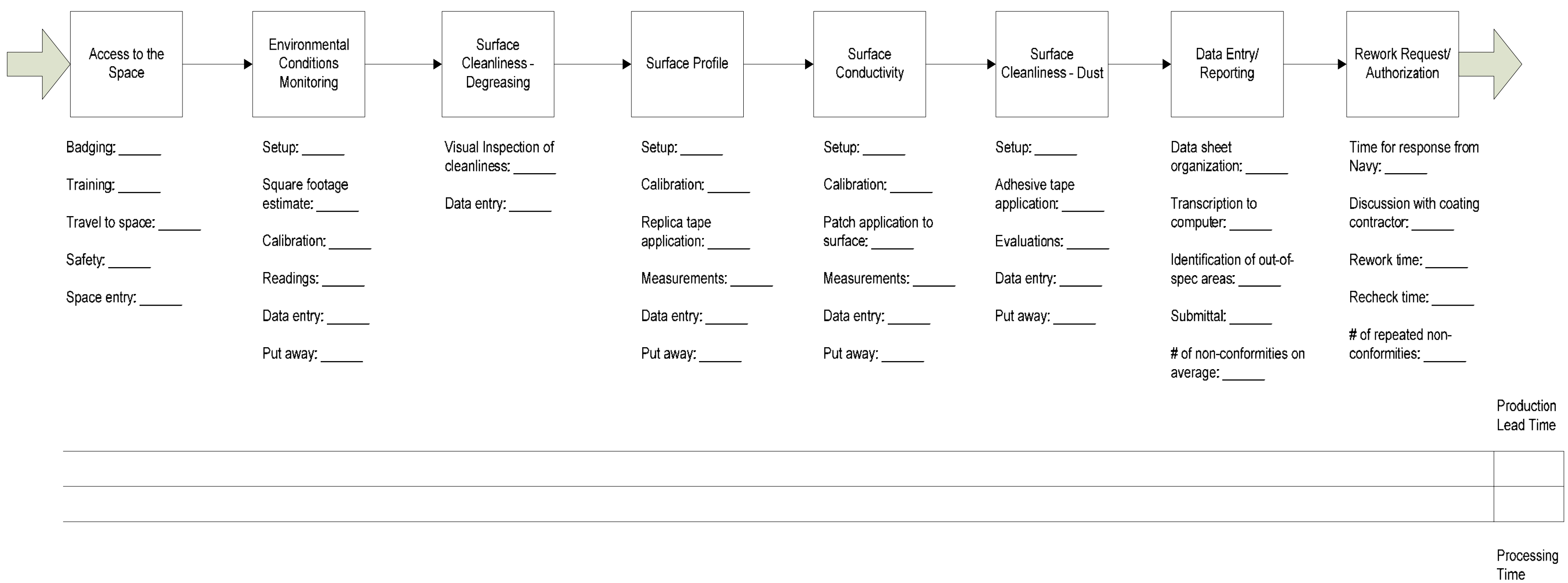
The initial mapping activity should be used to capture the current state ONLY, no changes or improvements should be made at this point.

QA/QC processes have multiple sub-processes where work is actually being performed on the tank (inventory). To better illustrate how one might develop a value stream map for QA/QC processes a VSM was created for each of three major process and their respective sub-processes. These are:

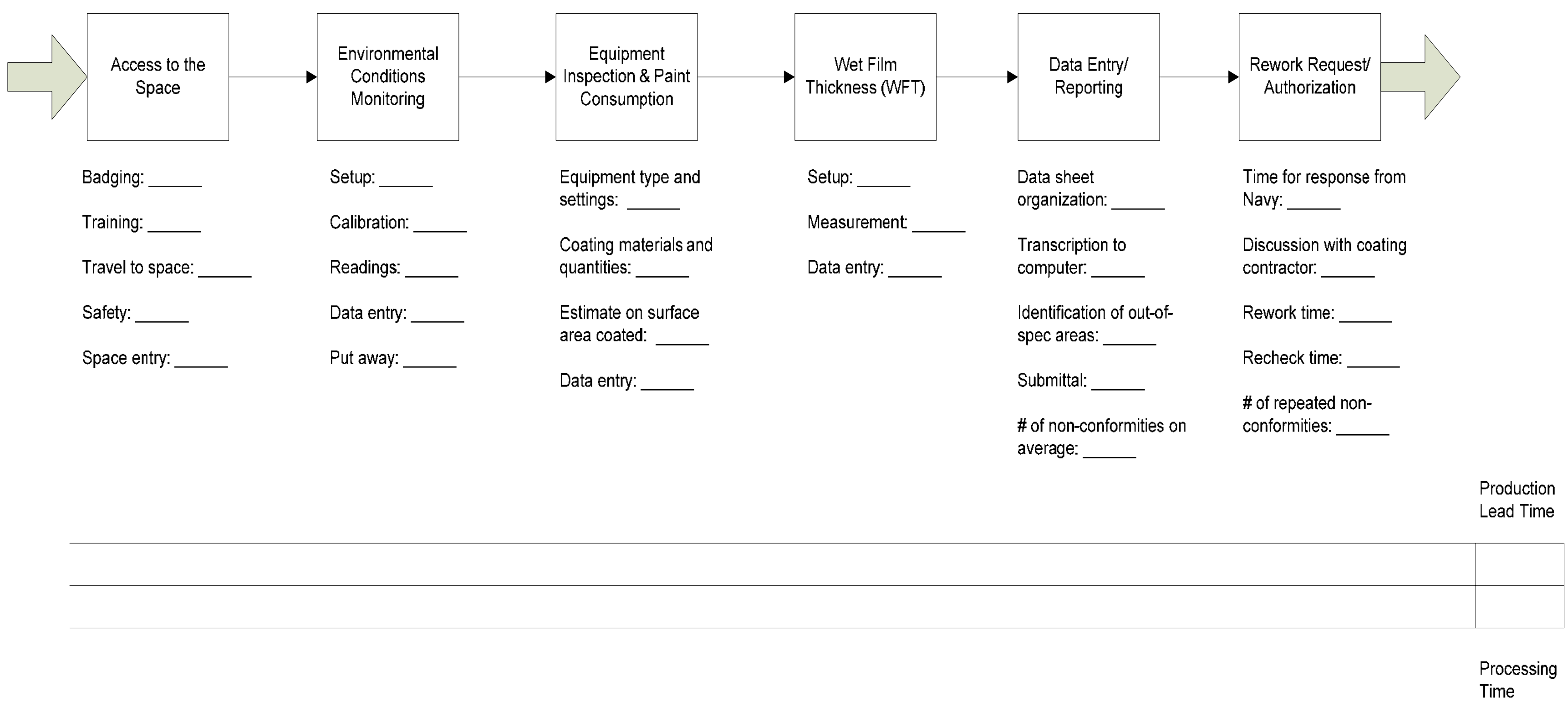
- Surface Preparation QA Checkpoint
  - Environmental Conditions Monitoring
  - Surface Cleanliness – Degrease
  - Surface Cleanliness – Dust
  - Chlorides/Conductivity
  - Surface Profile
- Coating Application (in-process)
  - Environmental Conditions Monitoring
  - Coating Information (materials, manufacturer, expiration, VOC, thinning, etc.)
  - Square Feet Painted and Quantity of Paint Used
  - WFT
- Coating Application (as-applied, dry)
  - Space/Location and Coating Information
  - DFT
  - Holiday Inspection

These are current state VSMs that can be used to evaluate the QA process for tank coating and the results used to identify waste and opportunities for improvement.

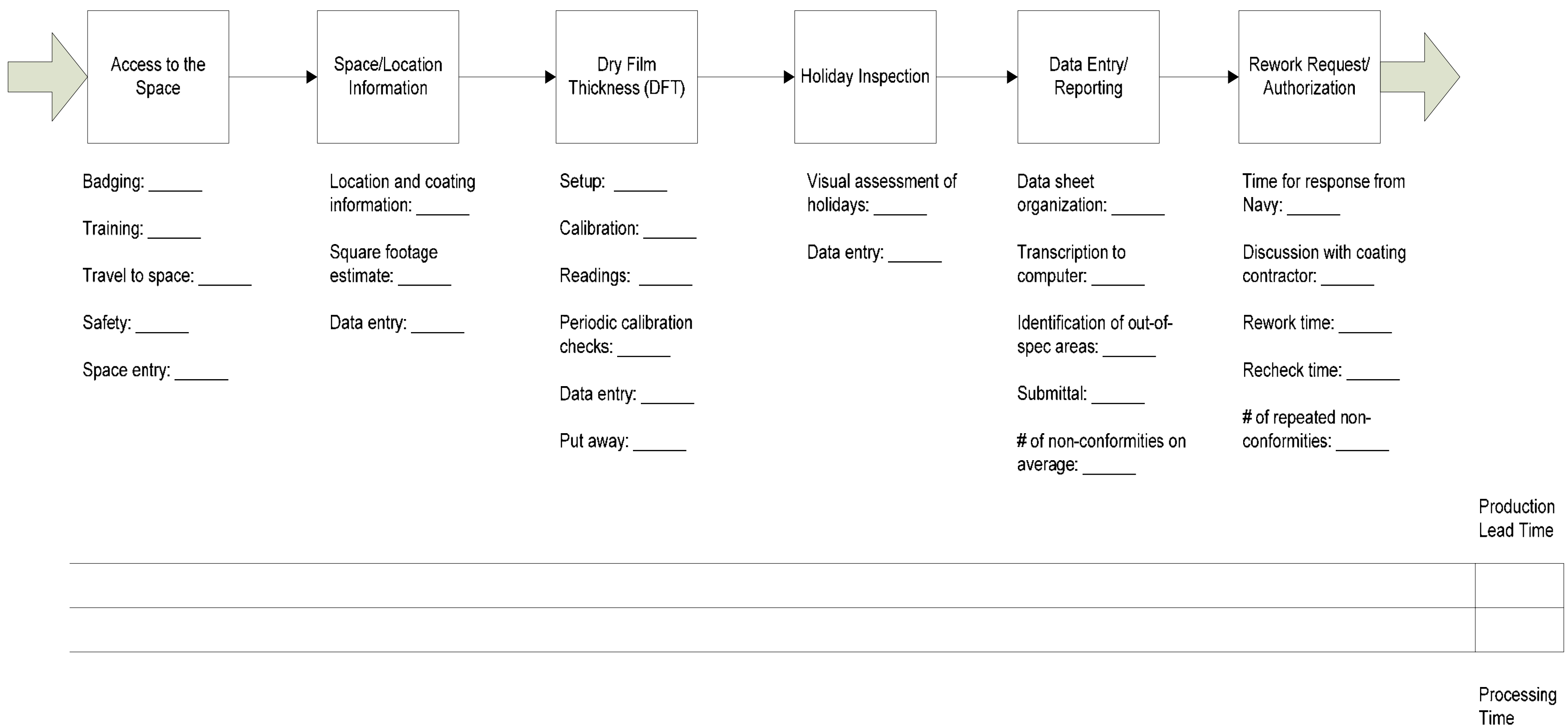
US Navy Tank Coating Value Stream
Surface Preparation QA



US Navy Tank Coating Value Stream
Coating Application QA (in process)



US Navy Tank Coating Value Stream
Coating Application QA (as applied, dry)



Spaghetti Diagrams

These are called spaghetti diagrams because typically they look like a plate of spaghetti when completed (at least for the current state). This is part of the process for developing a process improvement plan. These diagrams map out the physical layout of the work area(s) being investigated and the flow of personnel, work product (inventory), data etc. Figure 4 shows an example of what a spaghetti diagram might look like for coating inspection work.

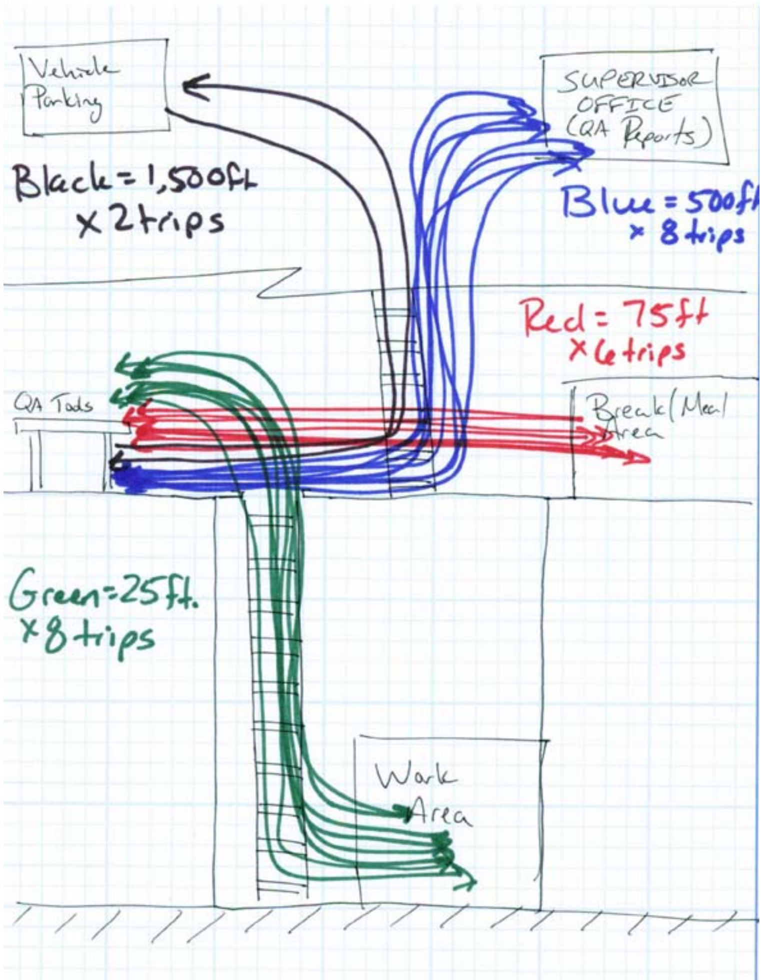


Figure 4. Tank QA Spaghetti Diagram.

This diagram shows a process that has a logical layout (for illustrative purposes only), but contains multiple trips in and out of the work area, multiple trips to and from the office and multiple trips to and from the break area. Eliminating the unnecessary trips through process consolidation, technology changes or through other methods can help lean the overall process.

Measurement of the Process

Measurement of the process includes time measurements of the steps in each process as well as measurements of errors (here rework), measurements of uptime (percent of time where the equipment is available for work during each process step) and other key metrics identified as being part of that process.

For the current state this is a baseline of the process. This demonstrates the time it takes for the entire production (lead time) as well as the time in which work is actively being performed on the work item (processing time). Any process improvements made to the process will be evaluated against this baseline. Also, by measuring error rates, uptime and other key metrics process improvements that do not necessarily improve the overall process time, but improve the process in other ways can also be measured. This is all related to what provides the customer value (which can be different things at different times or for different customers).[25]

Brainstorming

Brainstorming is where process improvement ideas will be developed and discussed with the team members. Some ground rules that should be followed include:

- *Respect all ideas and opinions* – do not dismiss any ideas immediately, in fact initially ideas should be solicited without discussion, there will be plenty of time for discussion later.
- *Voice of the customer* – this is a concept to use throughout the project, especially during the brainstorming phase; keep in mind what your customer really values and try to suggest ideas that ultimately provide additional benefit or support what the customer values (keep in mind most processes have multiple customers, internal and external to an organization).
- *Take turns speaking* – do not talk over anyone else, respect their opinions and thoughts.
- *Parking lot* – ideas that might not necessarily fit within the current topic or require additional discussion outside what it currently allotted should be put in the parking lot and the parking lot should be revisited.
- *Facilitator is neutral* – he/she is here to help the overall process, but not to impose their own thoughts or ideas; they can help when the group is stuck or going around in circles, but should always remember the team is the expert and as such they should do most of the work.
- *Create an environment that supports the open exchange of ideas* – should be a comfortable environment free of distractions, have sufficient resources available (paper, markers, etc.), cell phones should not permitted or turned off (vibrate is an option, but then you risk participants taking calls during the meeting), frequent breaks should be planned (need to stretch, take calls, return calls, allow for meals/snack, etc.), etc.

During the brainstorming session is where many of the ideas for process improvements will be suggested and vetted. From the group's consensus those having the most promise should be selected for further investigation/process modification.

[25] In the case of tank painting if the ship is in dry dock for other repairs the value may be having a quality paint job in which life cycle performance is maximized; here quality over time is the higher value to the customer. Conversely, if there is a limited window of opportunity for painting the customer may value a good paint job at a rapid pace over the best possible application with tight QA controls.

Just Do It

"Just Do Its" are changes that are obvious to the group, facilitator and/or sponsors that will improve the overall process. These are changes that typically require little capital to implement, little disruption to workflow and usually are readily accepted by personnel (e.g., replacing a DFT gage with one that calculates the average of three individual measurements with the push of a button instead of manually calculating averages).

Process Changes and Design of Experiment (DOE)

Process changes recommended by the team should be made on the actual production line/in the actual work area. Associated with these changes should be a DOE activity which includes measurement of the key metrics for which the change has been made (time savings, error reduction, improved quality, reduced cost, etc.). DOE is done to capture relevant data from the actual product line and by the actual operators who will perform the work (i.e., demonstration of the process improvement should not be based on measurements made under "lab" conditions or by manufacturer representatives or a trainer who do not perform this function routinely under the actual work conditions). Process changes should also be evaluated over time, not during a single work shift or on a single work item. If significant process changes are required there will naturally be a learning curve associated with incorporating the new process compared to the old, know process.[26] Multiple operators and shifts should be used to evaluate the process, with the results compared to the original baseline data. The ideal process should have the following characteristics:

- Value (customer's perspective)
- Value Stream – stream (series) or processes that supports the customer's value
- Flow – process that flows naturally from one event to another
- Pull – process that flows from the pull of upstream events not a downstream push (creates just-in-time delivery and eliminates waste and inventory)
- Perfection – a process that fulfills all of a customer's values, has no waste, no unnecessary inventory, this is achieved through continual improvement

Continual Monitoring and Process Improvements

The end of the process improvement event should NOT be the end of monitoring or the end evaluation of the process. Even when process changes have proven to provide benefit to the production line, their effect should be continually monitored to demonstrate long-term benefit. Furthermore, it is likely that there are additional opportunities for process improvement either from re-evaluation of the new as-is process, from changes in customer requirements (or value) and/or from changes in technology. Improvement is a continual process, not a one-time event.

Project Out-brief

An out-brief should be prepared and delivered to the Champion and Sponsor by the team. It should demonstrate the activities conducted, the improvements made, the metrics and overall benefit to the process. Be sure to include a few key thoughts/items to take away as they will likely have to brief their management on the success of the process improvement they sponsored.

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[26] Continual monitoring should be performed even if the new process has shown an initial improved performance (time, cost, etc.) compared to the baseline, as further improvements may be realized.