ESTIMATE OF THE ANNUAL COST OF CORROSION FOR NAVY SHIPS

FY2008–10 UPDATE

REPORT DAC21T1

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Executive Summary

LMI was tasked by the Corrosion Prevention and Control Integrated Product Team (CPC IPT) in May 2011 to measure the cost of corrosion on U.S. Navy ships. This review is part of a multi-year plan to measure the effects of corrosion on DoD weapon systems. Table ES-1 lists past and current Navy corrosion studies.[1]

This report provides an update of previous studies on corrosion-related costs for Navy ships. It also is the first study to include an analysis of the effect of corrosion on availability for Navy ships.

Table ES-1. Navy Cost-of-Corrosion Studies

Study year[a]	Date baseline	Study segment	Annual cost of corrosion
2005–2006	FY2004	Navy ships	$2.4 billion
2006–2007	FY2005	Marine Corps ground vehicles	$0.6 billion
2007–2008	FY2005–06	Navy and Marine Corps aviation	$2.6 billion
2008–2009	FY2006–07	Navy ships	$1.8 billion[b]
2009–2010	FY2007–08	Marine Corps ground vehicles	$0.5 billion
2010–2011	FY2008–09	Navy and Marine Corps aviation	$2.6 billion
2011–2012	FY2008	Navy ships	$2.7 billion
	FY2009	Navy ships	$3.0 billion
	FY2010	Navy ships	$3.15 billion

[a] Study period is 1 calendar year.

[b] This represents a change from an estimate from our 2010 report ($2.5 billion). This new estimate accounts for a recent adjustment in the algorithm we use to identify Navy ship corrosion-related costs. Although this total is closer to reality, it is likely still an under-estimate because we lacked full access to organic shipyard data for surface ships.

[1] DoD funded these studies.

Using FY2010[2] as a measurement baseline, we estimated the annual corrosion-related cost for Navy ships to be $3.15 billion, or 18.7 percent of the total maintenance cost for all Navy ships, $16.6 billion.[3]

The increase in corrosion-related costs between FY2008 and FY2010 was the result of both an increase in maintenance labor costs[4] and an increase in corrosion-related costs attributable to commercial depot maintenance.

We segregated the corrosion-related costs using three schemas: 1) depot or field-level maintenance (DM or FLM) costs, as well as costs outside normal maintenance reporting (ONR); 2) corrective versus preventive maintenance costs; and 3) costs related to structure or parts.

Table ES-2 shows both the costs and percentages within each schema for FY2010.

Table ES-2. Nature of Corrosion-Related Costs for Navy Ships (FY2010)

Schema for corrosion-related costs		Cost (in millions)	Percentage of total for schema
1	DM	$1,518	48.2%
	FLM	$1,014	32.2%
	ONR	$619	19.6%
2	Corrective	$964	38.7%
	Preventive	$1,530	61.3%
3	Structure	$792	35.4%
	Parts	$1,443	64.6%

The Navy incurs the highest corrosion-related costs during depot maintenance ($1.52 billion), which represents a little less than half of the total corrosion-related costs for Navy ships. Also of note is the percentage of corrosion-related DM costs compared to the total DM costs (roughly 20 percent of $7.61 billion) and corrosion-related FLM costs compared to the total FLM costs for ships (roughly 16 percent of $6.52 billion).

The corrosion-related ONR cost ($619 million) for Navy ships is relatively high in relation to other military services. This is due to the large population of shipboard personnel who perform corrosion-related maintenance even though their skill specialty is not associated with maintenance. The amount of corrosion-related maintenance performed by non-maintenance shipboard personnel has increased significantly since the initial FY2004 study, when it was $314 million.

[2] LMI based the Navy's corrosion-related costs on FY2010 data, the most recent year for which study data was available.

[3] We calculated the total Navy ships maintenance cost by aggregating depot and field-level maintenance and select costs outside normal maintenance reporting.

[4] The FY2010 labor rates were 5.7 percent and 7.7 percent higher than the FY2008 labor rates for military and civilian maintenance technicians, respectively.

Table ES-3 shows the corrective and preventive corrosion-related costs over the years (FY2004 and FY2008–10).

Table ES-3. Navy Ships Corrective and Preventive Corrosion-Related Cost by Study Year

	Category	Corrosion-related cost (in millions)			
		FY2004	FY2008	FY2009	FY2010
DM	Corrective	$567	$348	$446	$389
	Preventive	$600	$952	$1,044	$1,103
	Total	$1,167	$1,300	$1,490	$1,492
FLM	Corrective	$440	$517	$512	$575
	Preventive	$562	$327	$333	$427
	Total	$1,002	$844	$845	$1,002
Total maintenance	Corrective	$1,007	$865	$958	$964
	Preventive	$1,162	$1,279	$1,377	$1,530
	Total	$2,169	$2,144	$2,335	$2,494

Costs incurred to prevent corrosion (e.g., painting, inspection, coating, and quality assurance) increased by more than $360 million from FY2004 to FY2010. Corrosion-related corrective costs decreased slightly during the same period.

We also segregated corrosion-related costs according to ship category. Table ES-4 presents a summary of these costs. We accounted for a total of 237 ships across all ship categories and all three fiscal years. The corrosion-related costs for surface warfare ships and carriers increased between FY2008 and FY2010, while the per-ship average for amphibious ships and submarines remained fairly stable.

Table ES-4. Corrosion-Related Maintenance Cost by Ship Category (in millions)

Ship category	FY2008 cost		FY2009 cost		FY2010 cost	
	Total	Avg. per ship	Total cost	Avg. per ship	Total cost	Avg. per ship
Amphibious	$375	$13	$469	$16	$393	$13
Carrier	$355	$32	$352	$32	$418	$38
Submarine	$754	$11	$726	$11	$739	$11
Surface warfare	$694	$6	$830	$7	$981	$8
Total	$2,178	$9	$2,376	$10	$2,532	$11

Table ES-5 and Table ES-6 show the top five corrosion-related costs by work breakdown structure for ships and submarines, respectively. The work breakdown structure (WBS) allows us to determine the major systems and subsystems incurring maintenance. The two highest corrosion-related WBS cost categories for surface ships and submarines are the same: 1) trunks and enclosures and 2) painting. The corrosion-related costs for submarines are more concentrated by WBS than the corrosion-related costs for surface ships.

Table ES-5. Navy Surface Ships Corrosion-Related Cost Ranking by ESWBS for FY2010

Rank	ESWBS	ESWBS description	Corrosion-related cost (in millions)	Maintenance cost (in millions)	Percentage of cost attributable to corrosion
1	123	Trunks and enclosures	$91	$206	44%
2	631	Painting	$53	$68	78%
3	311	Ship service power generation	$51	$338	15%
4	549	Compressed air systems	$38	$203	18%
5	593	Environmental control sewage and trash	$36	$155	24%

Note: Percentages are not exact due to rounding. ESWBS = expanded ships work breakdown structure. This is the work breakdown structure schema used for Navy surface ships.

Table ES-6. Navy Submarines Corrosion-Related Cost Ranking by SWLIN for FY2010

Rank	SWLIN	SWLIN description	Corrosion-related cost (in millions)	Maintenance cost (in millions)	Percentage of cost attributable to corrosion
1	631	Painting	$67	$176	38%
2	123	Trunks and enclosures	$49	$78	62%
3	100	Hull structure	$39	$77	50%
4	531	Desalination plant	$32	$94	34%
5	865	Production services and support	$25	$103	25%

Note: Percentages are not exact due to rounding. SWLIN = ships work line item number. This is the work breakdown structure schema used for Navy submarines.

Navy ships are nearly always able to put out to sea when required. What non-availability that does occur happens during the performance of depot maintenance at a Navy (organic) or commercially operated shipyard.

We determined that corrosion-related work accounts for an average of 25 percent of the total DM dry-dock work performed during dry-dock periods. Although not a precise correlation, if the average DM period is 155 days, we can infer that corrosion-related work contributes to about 38 days of the non-availability for each Navy ship in depot maintenance during a dry-dock period.

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Chapter 1
Background and Analysis Method

Congress, concerned with the high cost of corrosion, enacted legislation in December 2002 that assigned the Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) the overall responsibility for preventing and mitigating the effects of corrosion on military equipment and infrastructure.[1] To perform its mission of preventing and mitigating the effects of corrosion on military equipment and infrastructure, fulfilling congressional requirements, and responding to Government Accountability Office (GAO) recommendations, the USD(AT&L) established the Corrosion Prevention and Control Integrated Product Team (CPC IPT), a cross-functional team of personnel from all the military services as well as representatives from private industry.

In response to a GAO recommendation to "develop standardized methodologies for collecting and analyzing corrosion cost, readiness, and safety data,"[2] the CPC IPT created standard methods to measure both the cost[3] and availability[4] effect of corrosion on DoD's military equipment and infrastructure. In April 2006, the CPC IPT published the results of its first corrosion cost study,[5] which used the standard corrosion-related cost estimation method. We present the results of past and current cost-of-corrosion studies in Table 1-1.

More recently, LMI was tasked by the CPC IPT with estimating the effect of corrosion on cost for Navy ships and both cost and availability of Army ground vehicles. We used data from FY2008 through FY2010 to conduct these studies.

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[1] *The Bob Stump National Defense Authorization Act for Fiscal Year 2003*, Public Law 107-314, 2 December 2002, p. 201; Public Law 107-314 was enhanced by Public Law 110-181, *The National Defense Authorization Act for Fiscal Year 2008*, Section 371, 28 January 2008.

[2] GAO, *Opportunities to Reduce Corrosion Costs and Increase Readiness*, GAO-03-753, July 2003, p. 39.

[3] DoD CPC IPT, *Proposed Method and Structure for Determining the Cost of Corrosion for the Department of Defense*, August 2004.

[4] DoD CPC IPT, *The Impact of Corrosion on the Availability of DoD Weapon Systems and Infrastructure*, October 2009.

[5] LMI, *The Annual Cost of Corrosion for Army Ground Vehicles and Navy Ships,* Report SKT50T1, Eric F. Herzberg et al., August 2004.

Table 1-1. Cost of Corrosion Studies to Date and Future Efforts

Study year[a]	Data baseline	Study segment	Annual cost of corrosion
2005–2006	FY2004	Army ground vehicles	$2.0 billion
		Navy ships	$2.4 billion
2006–2007	FY2005	DoD facilities and infrastructure	$1.8 billion
		Army aviation and missiles	$1.6 billion
		Marine Corps ground vehicles	$0.6 billion
2007–2008	FY2005–06	Navy and Marine Corps aviation	$2.6 billion
		Coast Guard aviation and vessels	$0.3 billion
2008–2009	FY2006–07	Air Force	$5.7 billion
		Army ground vehicles	$2.4 billion
		Navy ships	$1.8 billion[b]
	FY2006	DoD–other equipment	$5.1 billion
2009–2010	FY2007–08	Marine Corps ground vehicles	$0.5 billion
		DoD facilities and infrastructure	$1.9 billion
		Army aviation and missiles	$1.4 billion
2010–2011	FY2008–09	Navy and Marine Corps aviation	$2.6 billion
		Air Force	$4.5 billion
2011–2012	FY2008–10	Army ground vehicles	Pending
	FY2008	Navy ships–2008	$2.7 billion
	FY2009	Navy ships–2009	$3.0 billion
	FY2010	Navy ships–2010	$3.1 billion

[a] Study period is 1 calendar year.

[b] This represents a change from an estimate from our 2010 report ($2.5 billion). This new estimate accounts for a recent adjustment in the algorithm we use to identify Navy ship corrosion-related costs. Although this total is closer to reality, it is likely still an under-estimate because we lacked full access to organic shipyard data for surface ships.

The current estimated annual cost of corrosion for DoD is $21.5 billion. We derived this total by aggregating the most recent result of each study segment (less the 2007–2008 totals from the Coast Guard aviation and vessels study).[6] The studies for Navy ships and Army ground vehicles were follow-on efforts of previously studied segments.

This report also includes an analysis of the effect of corrosion on availability for Navy ships; this is an initial effort to quantify the effect corrosion has on the availability of weapon systems.[7] Future cost and availability studies will produce updates to help the services identify trends over time.

[6] We disregarded the Coast Guard aviation and vessels total of $0.3 billion, because the Coast Guard is part of the Department of Homeland Security.

[7] Although not directly tasked by the CPC IPT to measure the effect of corrosion on availability of Navy ships, we derived a method to do so and present this along with the cost information in this report.

We present the study results from study year 2011–2012 in two separate reports by service to ensure ease of use for each service. This report presents how we estimated the effect—in terms of both cost and availability—that corrosion has on Navy ships. We combined the cost and availability estimates within the report we are preparing for the Army, as well.

Study Objectives

As part of our tasking, we had three specific objectives for this study:

1. Measure the most recent annual sustainment cost of corrosion for Navy ships assets.
2. Identify corrosion-related cost-reduction opportunities for Navy ship assets.
3. Analyze trends and draw conclusions using both the initial and most recently concluded cost-of-corrosion studies for Navy ships.

As noted, we also analyzed, and provide in this report, corrosion's effect on reported non-availability for Navy ships.

Background

The Navy maintenance organization is framed by the types of weapon systems. The Naval Sea Systems Command (NAVSEA) is the technical authority for maintenance and upgrades to nearly all non-aviation-related equipment, such as hulls, machinery, electrical systems, and ordnance subsystems. Funding for maintenance is mostly administered by the Atlantic and Pacific Fleet commanders, whereas NAVSEA funds most investment upgrades and new construction.

Within NAVSEA, the Logistics, Maintenance, and Industrial Operations (SEA 04) directorate provides technical oversight of ship maintenance operations, provides technical authority for four naval shipyards, and maintains central databases of certain field-level and depot ship maintenance activities. The Naval Systems Engineering (SEA 05) directorate, which is the technical and engineering services organization, includes the Ship Integrity and Performance Engineering Division (SEA 05P), which includes the Corrosion Control Branch, the focal point for corrosion-related ship issues.

Maintenance Structure

Navy maintenance can generally be categorized as either depot maintenance or field-level maintenance:

- *Depot maintenance (DM)*, the most complex repair work performed by civilian artisans, is performed in a government-owned and –operated (i.e., organic) Navy facility or at a commercial contractor facility.
- *Field-level maintenance (FLM)*, is performed by the ships crews as well as other organizations equipped to carry out limited, albeit more complex, repairs (called intermediate maintenance).

For the purpose of the cost-of-corrosion studies, we created a third category of maintenance costs that we refer to as *outside normal reporting* (ONR). These are maintenance costs that typically are not reported in maintenance production or financial systems. The four we detail in this report—the maintenance labor hours of non-maintenance specialty personnel, research, development, test, and evaluation (RDT&E), new facilities, and purchase card expenses—contain corrosion-related expenditures.

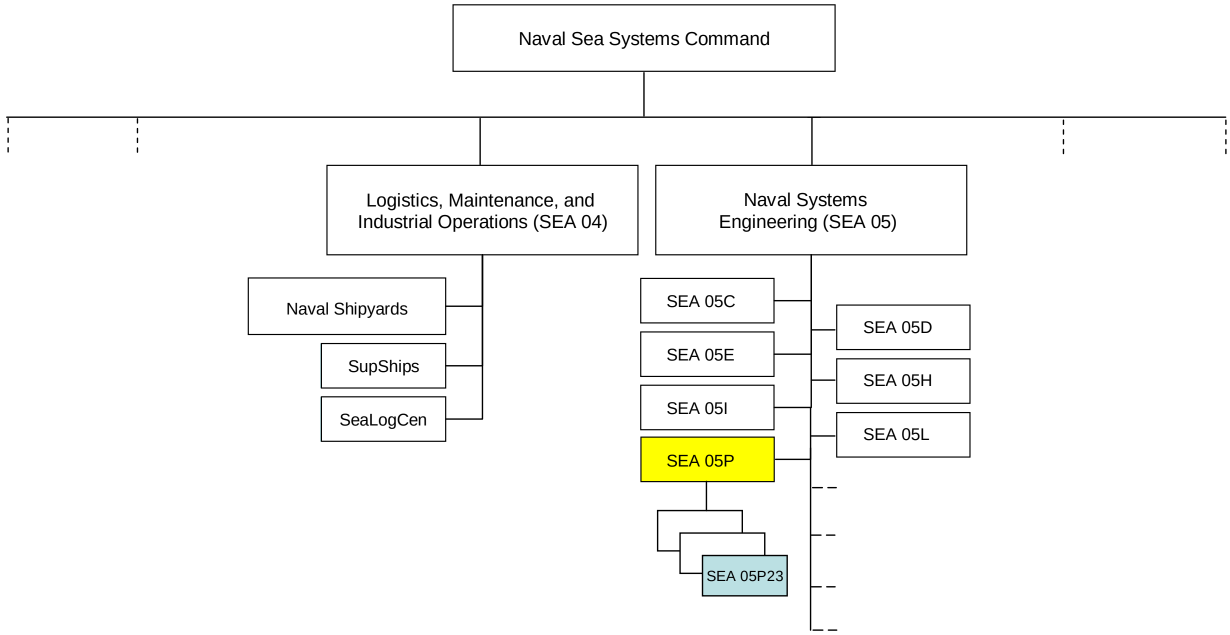
Navy ship maintenance is consolidated into regional naval support activities (NSAs) and regional maintenance centers (RMCs). In some cases, the NSAs and RMCs are consolidated with shipyards under the control of the Regional Maintenance Centers Management Office (SEA 04Y). In general, the NSAs and RMCs include former intermediate maintenance facilities, a supervisor of shipbuilding, conversion and repair offices that administer maintenance contracts, and fleet technical support centers that assist shipboard crews with maintenance issues.

The Pearl Harbor and Puget Sound naval shipyards and intermediate maintenance facilities support maintenance in Hawaii and the Pacific Northwest, respectively. The Southeast and Southwest RMCs support maintenance in the Mayport, FL, and San Diego, CA, areas. The Norfolk Ship Support Activity, which includes Norfolk Naval Shipyard, supports maintenance in the mid-Atlantic region. Portsmouth Naval Shipyard in Kittery, ME, supports submarine depot maintenance in the northeast and intermediate submarine maintenance with detachments at New London, CT, and Point Loma, CA.

Corrosion-Related Naval Organization

The National Defense Authorization Act for 2009, Section 905, "Corrosion Control and Prevention Executives (CCPE) for the Military Departments," requires that each military department designate a CCPE. It also lists specific responsibilities for those designees. In January 2009, the Navy appointed a corrosion executive. That position is currently held within the office of the Assistant Secretary of the Navy for Research, Development, and Acquisition (see Figure 1-1).

Figure 1-1. Navy Corrosion Prevention and Control Organization



The Corrosion Control Branch (SEA 05P23, highlighted in) of the Navy's Ship Integrity and Performance Engineering Division (SEA 05P) is a technical authority for corrosion-related ship issues within NAVSEA. NAVSEA 05P23 has several corrosion-related responsibilities including:[8]

- Developing unique technology solutions that solve surface treatment problems.
- Communicating preservation assessment techniques to facilitate best practices.
- Conducting innovative training that addresses surface treatment requirements.
- Hosting the authoritative website for coatings and corrosion.
- Developing software services that provide database and web solutions.
- Providing environmental and quality assessment techniques including ISO, Lean Manufacturing, and Six Sigma.

[8] See Naval Surface Treatment Center website home page, http://www.nstcenter.biz/

Determination of Ship Lists

To capture the cost-of-corrosion prevention and repair for Navy ships, we selected ships that were identified as "battle force ships" in FY2008, FY2009, or FY2010. The battle force ships count is used by OSD, Congress, industry, and the media as a standard measure of the Navy's fleet size.

We excluded ships operated by the Military Sealift Command (MSC), as significant differences exist between MSC-operated ships and commissioned Navy battle force ships. MSC operates support and strategic sealift ships with crews of civilian mariners and a small contingent of military personnel. Maintenance on MSC ships is performed nearly exclusively by commercial firms under contracts negotiated and administered by MSC, and apart from the infrastructure that maintains Navy battle force ships.

Excluding the MSC ships, we identified 237 battle force ships as the basis for this study. We excluded support, mine warfare, and reserve category B ships that are listed in the official Naval Vessel Register but are not categorized as battle force ships. We also excluded minor vessels (such as small boats, landing craft, and service craft) that are not listed in the Naval Vessel Register.

We grouped the 237 ships into four categories, as depicted in Table 1-2.

Table 1-2. Numbers of Navy Ships by Category

Ship category	Number of ships
Aircraft carrier	11
Amphibious	33
Surface warfare[a]	123
Submarine[b]	70
Total	237

[a] Includes 14 mine warfare ships and 12 support ships.

[b] Includes 52 nuclear-propulsion attack submarines (SSNs) and 18 submersible, ballistic, and nuclear ship (SSBNs) and submersible, guided missile, nuclear ship (SSGN) ballistic missile or guided missile submarines.

Appendix A lists the 237 ships (by category, class, hull number, and name) for which we accumulated costs in this study.

ANALYSIS METHOD

The cost-of-corrosion analysis method we applied to Navy ship assets was the same as what is described in the original reports produced for the CPC IPT. For the sake of brevity, we only provide a brief description of our method here. Chapter 1 of *The Annual Cost of Corrosion for Army Ground Vehicles and Navy Ships* contains more information on how we measure the cost of corrosion.[9]

We adapted (and modified) the cost analysis method to the availability portion of the study. Because this is an initial effort to quantify the effect corrosion has on availability of Navy ships, we provide details on our availability estimation methodology.

To ensure consistency, we used the definition of corrosion that Congress developed: "The deterioration of a material or its properties due to a reaction of that material with its chemical environment."[10]

We have applied this definition of corrosion to each corrosion-related study we conduct for DoD.

Our estimation method segregates maintenance levels and activities by their source and nature, using the following three schemas:

1

- *Depot maintenance* (DM)—corrosion-related costs incurred while performing depot maintenance
- *Field-level maintenance* (FLM)—corrosion-related costs incurred while performing organizational or intermediate maintenance
- *Outside normal maintenance reporting* (ONR)—corrosion-related costs not identified in traditional maintenance reporting systems

2

- *Corrective maintenance*—costs incurred while addressing an existing corrosion-related problem[11]
- *Preventive maintenance*—costs incurred while addressing a potential future corrosion-related issue

3

- *Structure-related costs*—direct costs of corrosion incurred by the body frame of a system or end item
- *Parts-related costs*—direct costs of corrosion incurred by a removable part of a system or end item.

[9] LMI, *The Annual Cost of Corrosion for Army Ground Vehicles and Navy Ships*, Report SKT50T1, Eric F. Herzberg et al., April 2006.

[10] Public Law 107-314, p. 202.

[11] According to International Organization for Standardization 9000:2000, preventive costs involve steps taken to remove the causes of potential nonconformities or defects. Preventive actions address future problems. Corrective costs are incurred when removing an existing nonconformity or defect. Corrective actions address actual problems.

Summary of Cost Estimation Method

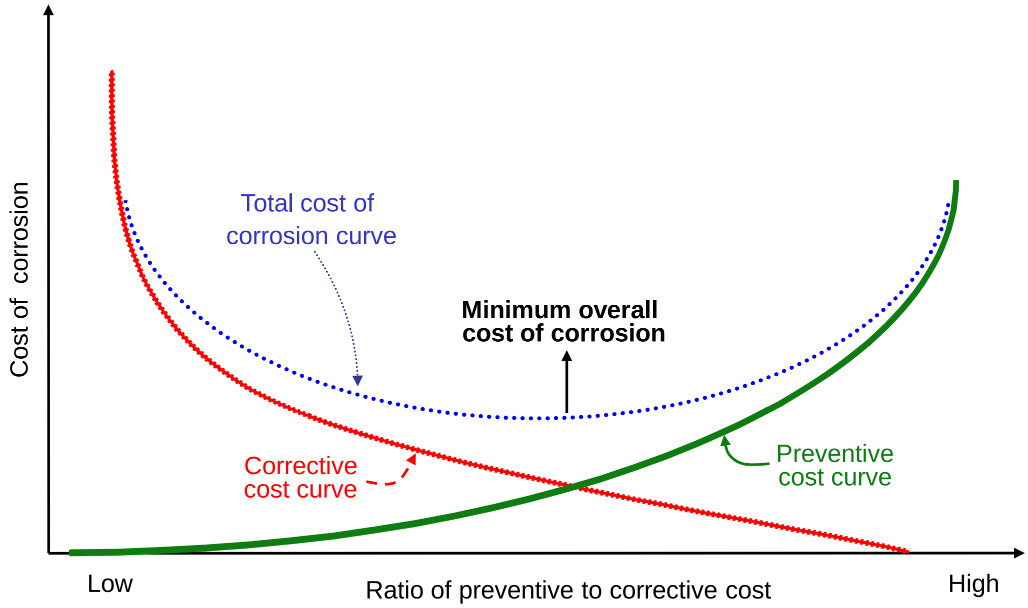
The method we use to estimate corrosion-related Navy ship costs focuses on direct costs of labor and materials and services as well as indirect costs, such as research, development, test, and evaluation (RDT&E), facilities, and purchase card expenditures (i.e., those materials and services purchased using a charge card).

To estimate the overall corrosion-related cost for Navy ships, we use a combined top-down and bottom-up approach. For the top-down portion, we use summary-level cost and budget documents to establish spending ceilings for DM and FLM for both organic and commercial activities. This establishes a maximum cost of corrosion in each maintenance area. For the bottom-up portion, we use detailed work order records to aggregate any specific occurrences of corrosion-related maintenance and activity. This establishes a minimum level of corrosion-related costs in each activity area. Where necessary, we use statistical methods to bridge any significant gaps between the top-down and bottom-up figures to derive a final estimate for the cost of corrosion in each maintenance area.

In terms of corrosion-related costs, it is useful to determine the ratio between corrective costs and preventive costs. This is typically an inverse relationship; the higher the amount of spending on preventive measures, the lower the corrosion-related corrective spending will be.

Over time, it is usually more expensive to fix a problem than it is to prevent one. But it is also possible to overspend on preventive measures. Classifying the cost elements helps decision makers find the proper balance between these categories and minimize the overall cost of corrosion. To identify the value of classifying costs into preventive and corrective categories, we establish the ratio between preventive and corrective costs and determine if an optimum ratio between the two categories would result in the lowest total cost. We illustrate this visually in Figure 1-2.

Figure 1-2. Preventive and Corrective Corrosion-Related Cost Curves



Summary of Availability Estimation Method

Navy ships are nearly always able to put out to sea when required, and Navy ship non-availability usually occurs only during the performance of depot maintenance at a Navy or commercially operated shipyard. That is why our availability study method considers the percentage of corrosion-related work performed during a depot maintenance cycle. This method also estimates the amount of time the ship is in dry dock[12] for corrosion-related maintenance.

The effect corrosion has on costs is directly related to the effect it has on availability (see Figure 1-3).

[12] Dry dock, which is a large dock from which water can be pumped out, is used for building or repairing a ship below its waterline. A ship in dry dock, therefore, has been pulled out of the water and so cannot perform its mission. This is typically the situation during a depot maintenance period.

Figure 1-3. Relationship between Availability and Spending on Corrosion-Related Maintenance

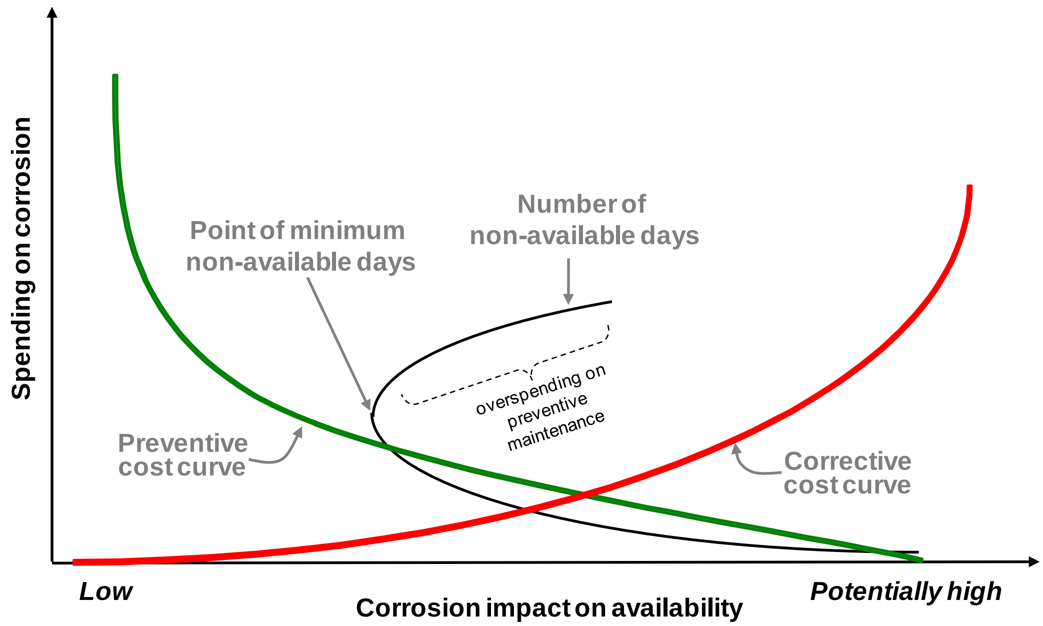


Figure 1-3 shows two relationships. The first is the relationship between preventive spending and corrective spending (which is the same as illustrated in Figure 1-2).

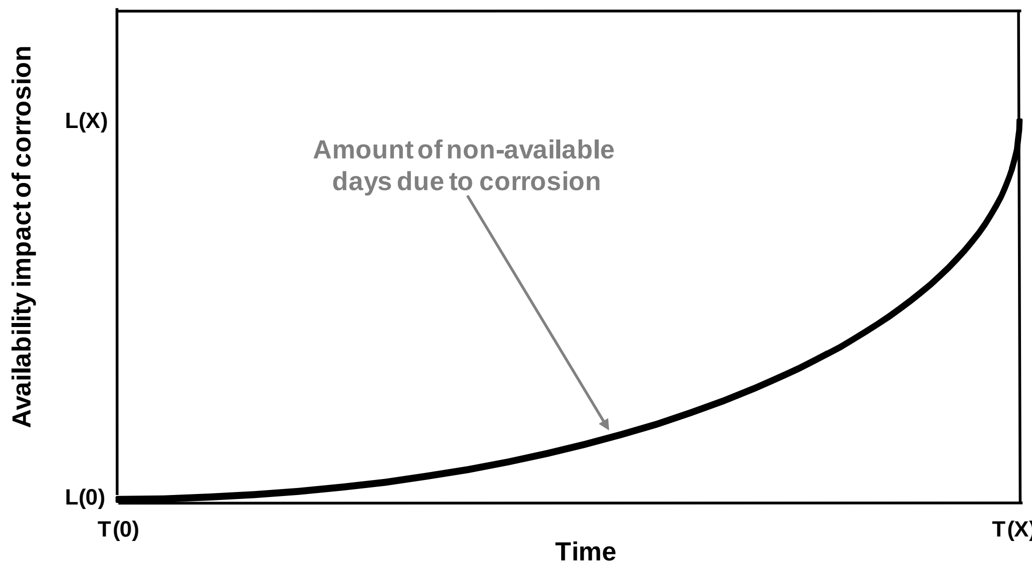
The second relationship is the amount of corrosion-related spending and its effect on availability. An extreme amount of spending on preventive measures that do not result in a reduction of corrective maintenance actions will have an overall negative effect on availability. This is similar to changing the oil in a car every month. The excessive amount of preventive maintenance has only a negligible effect on improving the reliability of the car's engine, but it reduces the car's availability while the maintenance is performed.

Of course, spending too little on preventive measures will eventually result in greater corrective corrosion-related spending. This, too, can have a negative effect on availability. This is only a potential negative impact, because organizational units could increase their efficiency when dealing with unplanned corrective requirements, or they could take exceptional measures—such as working an extensive amount of unplanned maintenance hours—to minimize the availability impact of corrective corrosion-related actions.

The point of minimum non-available days on the curve in Figure 1-3 represents a theoretically optimum preventive-to-corrective maintenance ratio.

It is also useful to examine the availability-related effects of not spending on corrosion. Figure 1-4 shows the effect on availability of not spending any maintenance funds for corrosion. The initial effect is minimal; but, over time, the negative effect on availability accelerates as corrosion starts to degrade all ships.

Figure 1-4. Availability over Time at Zero Corrosion-Related Spending



Notes: L(0) = initial level of corrosion effect on availability; L(x) = level of corrosion effect on availability at time interval *x*; T0 = start time; T(*x*)100 = time interval *x*.

Data Challenges

According to the Naval Sea Systems Command (NAVSEA), the text descriptions of the job orders may contain sensitive information concerning nuclear propulsion systems for ships and submarines. The job orders are categorized as Navy Nuclear Propulsion Information (NNPI) and, therefore, may not be viewed except on an NNPI-certified computer terminal. The closest NNPI-certified terminal was at a NAVSEA facility in Norfolk, VA—approximately 200 miles from LMI's headquarters in McLean, VA.

This situation resulted in several challenges:

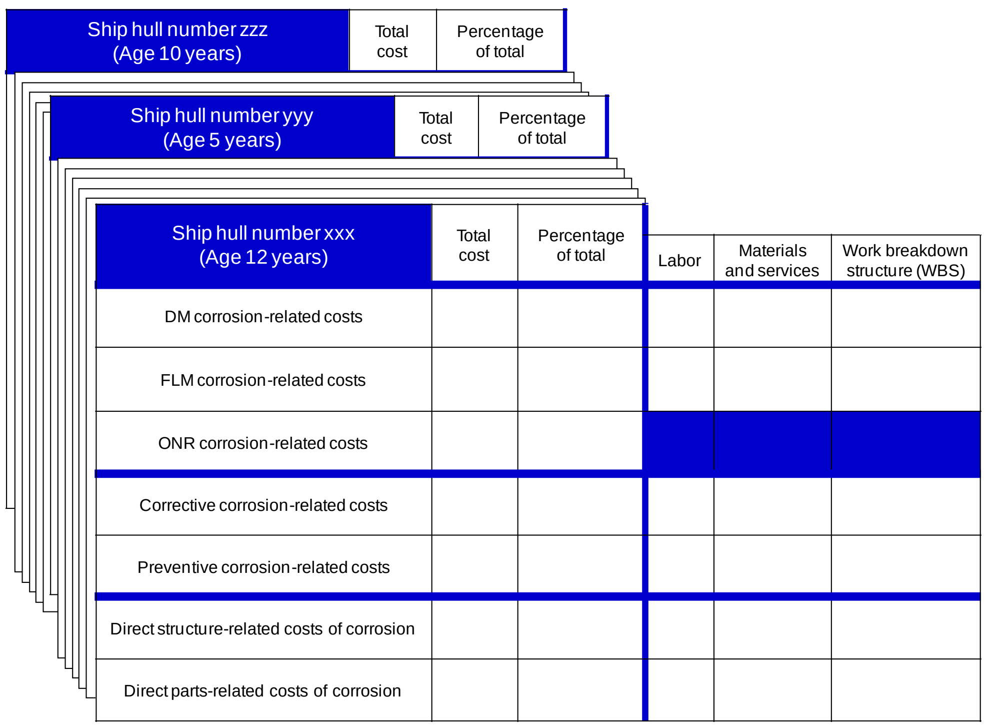
- Coordination between the NAVSEA and shipyard personnel was difficult. The shipyards had to resend their data to the NAVSEA facility multiple times to overcome formatting issues, which led to significant delays and additional study costs. Also, not all of the data was usable.
- Once we determined corrosion-related tasks from the text fields of the maintenance records, NAVSEA security personnel determined that they needed to erase these fields from all job orders before LMI could bring the data back to LMI and complete our analysis. This made it extremely difficult to understand and correct discrepancies within individual data records during our final analysis.
- Follow-on requests for data requiring the use of text fields could not be accomplished for shipyard data as the text fields had been removed. This led to a loss of capability in supplying the Navy ships community with the information they need.

NNPI-certification of the analyst team performing future Navy ships corrosion studies would alleviate these difficulties.

Data Structure and Analysis Capabilities

To accommodate the anticipated variety of decision makers and data users, we designed a corrosion cost data structure that maximizes analysis flexibility. Figure 1-5 illustrates the data structure and different methods of analysis.

Figure 1-5. Data Structure and Methods of Analysis



Using this data structure, we were able to analyze all available data within the following categories:

- Ship type and hull number
- Age of equipment
- Corrective versus preventive cost
- DL and FLM costs

- Structure-related versus parts-related costs
- Material costs
- Labor costs
- Work breakdown structure (WBS).[13]

This structure also enabled us to combine categories and create a new analysis category. For example, we can isolate the corrective corrosion cost for FLM materials.

REPORT ORGANIZATION

In this chapter, we explained our analysis approach, the Navy ships maintenance- and corrosion-related organizations, the existing maintenance structure, and the specific ships that are within the scope of the study.

We are now ready to detail how we determined corrosion's effect on costs and availability.

In Chapter 2, we detail the corrosion-related costs for Navy ships (based on FY2010 costs) and present our analysis of those costs. In Chapter 3, we provide our overall conclusions about the trends and patterns identified in corrosion-related cost data. We also include our estimate of the effect of corrosion on the length of ship non-availability. The appendixes provide supporting data and analysis.

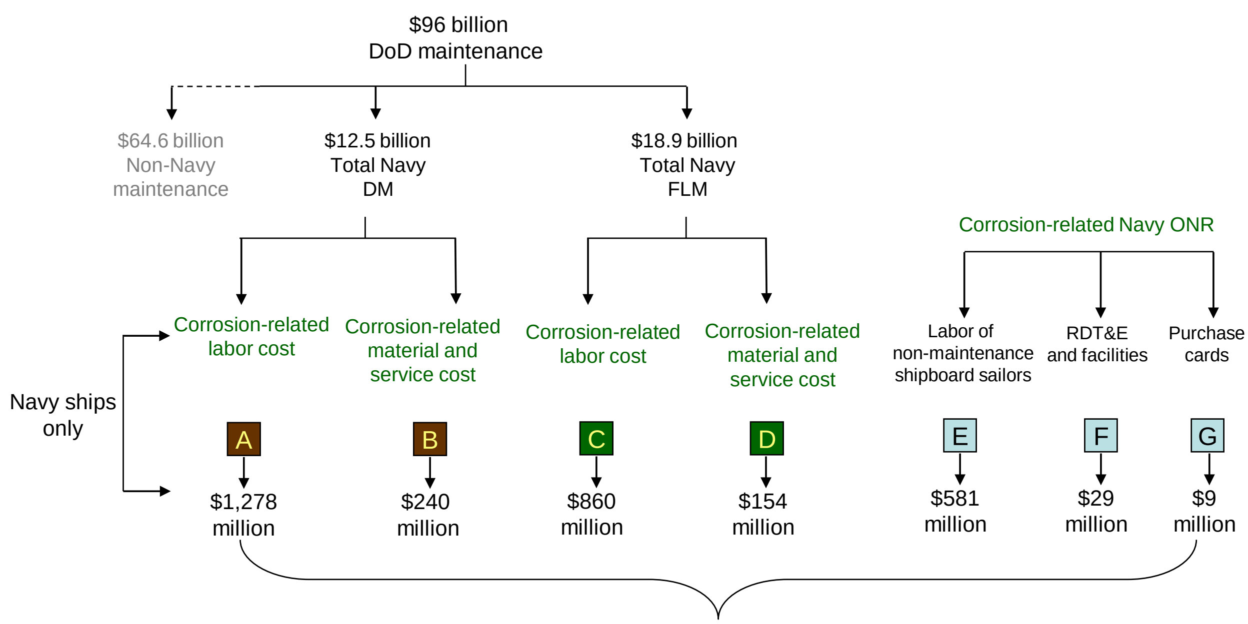
[13] WBS coding determines the ship subsystem on which work is being performed. LMI created a master three-digit WBS using the ships work line item number (SWLIN) and expanded ship work breakdown structure (ESWBS) coding structures for submarines and surface ships, respectively.

Chapter 2
Determining the Cost of Corrosion

We estimate the total annual sustainment cost of corrosion for Navy ships is $3.15 billion, based on FY2010 data, which is the most recent available.

To arrive at this estimate, we developed the cost tree in Figure 2-1. It serves as a guide for the remainder of this chapter.

Figure 2-1. Navy Sustainment Corrosion-Related Cost Tree (FY2010)



We developed the cost tree starting with the total FY2010 cost of maintenance throughout DoD of $96 billion.[1] Eliminating non-Navy costs and segregating the cost tree into three major groups—total Navy DM, total Navy FLM, and total Navy ONR—resulted in the second level of the tree. At this point in the analysis, the cost figures for DM and FLM represent total Navy maintenance costs.

We then split each of the three groups into the major pertinent cost categories. We labeled the cost categories as "cost nodes." Nodes A through G depict the main segments of corrosion-related cost. Using three separate detailed cost trees for DM, FLM, and ONR, we determined the overall corrosion-related costs by combining the costs at each node.

[1] "The Estimated Total Cost of DoD Material Maintenance for FY2010," LMI briefing to OSD, p. 2.

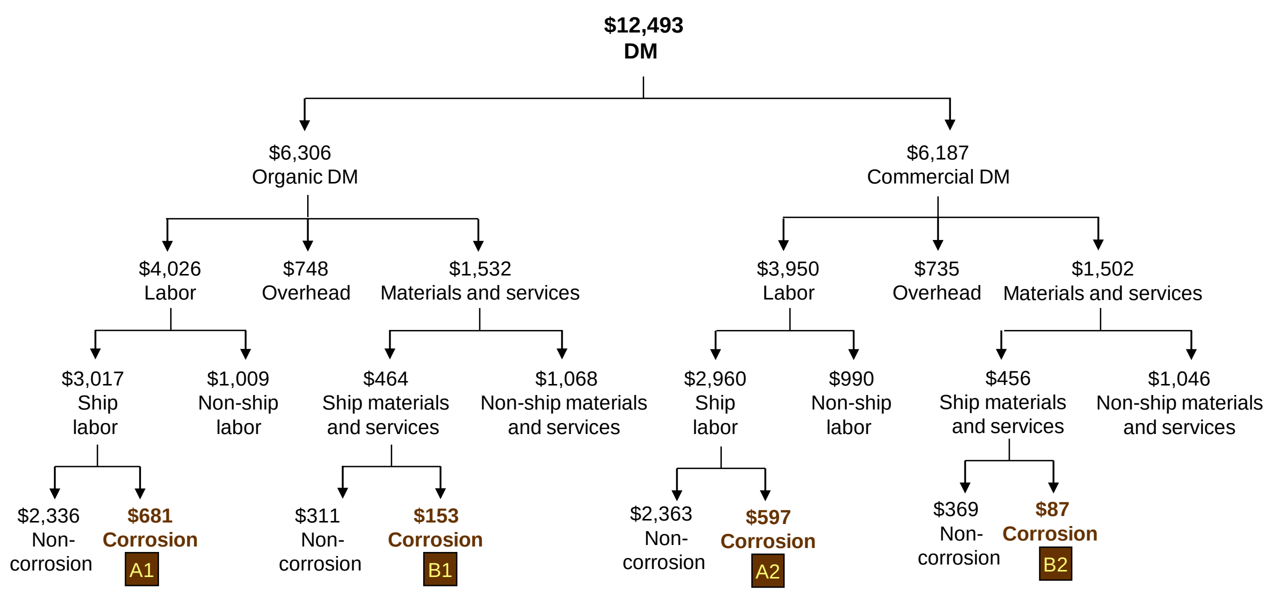
We present data sources for the cost figures at each node in Appendix B. We start the detailed analysis by first examining Navy ships DM costs—that is, nodes A and B.

Cost of Corrosion for DM (Nodes A and B)

Corrosion-related costs are significant for both organic and commercial DM. The total DM cost of corrosion for Navy ships is $1.52 billion. This is roughly 20 percent of the total DM cost for Navy ships of $7.60 billion.

As we detail in the original study, we used a combined top-down and bottom-up approach to determine the corrosion-related cost. The detailed cost tree in Figure 2-2 illustrates how we determine the DM cost of corrosion for Navy ships.

Figure 2-2. DM Cost of Corrosion for Navy Ships ($ in millions)



We start with a top-down cost of $12.493 billion for Navy DM costs. We use an annual DM congressional reporting requirement to determine this cost.[2] The same document details the split between organic depot costs ($6.306 billion) and costs incurred at commercial depots ($6.187 billion). This is reflected in the second level of the tree in Figure 2-2.

Through continued top-down analysis, we determined the cost at each level in the tree until we reached the cost-of-corrosion nodes. We then used detailed bottom-up data to determine the corrosion-related cost at each of these nodes. We outline these costs in Table 2-1.

[2] Deputy Under Secretary of Defense (Logistics and Materiel Readiness), *Distribution of DoD Depot Maintenance Workloads: Fiscal Years 2010 through 2012*, May 2011, p. 6.

Table 2-1. Cost of Corrosion for Navy Ships at Organic and Commercial Depots ($ in millions)

Maintenance provider	Total Navy ship DM costs				Corrosion-related DM costs		
	Materials and services	Labor	Overhead	Total	Materials and services	Labor cost	Total
Organic depot	$464	$3,017	$358	$3,839	$153	$681	$834
Commercial depot	$456	$2,960	$351	$3,767	$87	$597	$684
Total	$920	$5,977	$709	$7,606	$240	$1,278	$1,518

As Table 2-1 shows, a significant difference exists between the corrosion-related costs incurred for labor ($1,278 million) and those incurred for materials and services ($240 million). We provide explanations and other observations in detail later in this chapter.

Also, the total ships overhead cost in the organic depot ($358 million) and commercial depot ($351 million) are the ships' portions of the total organic depot overhead cost ($748 million) and commercial depot overhead cost ($735 million) from the depot corrosion-related cost tree in Figure 2-2.

Cost of Corrosion for Organic DM (Nodes A1 and B1)

We continued our top-down analysis, starting at the top of the organic depot side of the cost tree in Figure 2-2. We split the $6.306 billion of organic depot costs into labor, overhead, and materials and services costs using figures from the "1307" report, which is compiled annually for OSD.[3]

The contractual cost reported in the 1307 report contains labor, materials, overhead, and other contract-related costs. We used the actual reported total costs for labor, materials, and overhead to apportion the contractual costs into their respective labor, materials, and overhead schema. We then separate the costs into what is incurred at Navy shipyards and what is incurred at other-than-Navy shipyards. Because the Navy shipyards perform maintenance exclusively on ships, we included 100 percent of the reported shipyard costs in our study.

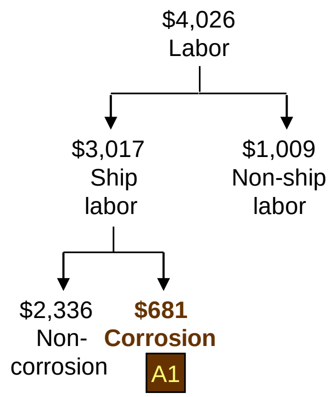
To this point, we determined the labor, materials and services, and overhead cost figures by using a top-down costing method. Our next task was to extract the organic DM labor cost of corrosion from the total organic DM labor cost (node A).

[3] An Accounting Report (M) 1307 is provided to the Office of the Secretary of Defense by all DoD components operating a Defense Working Capital Fund (DWCF) activity.

COST OF CORROSION FOR ORGANIC DM LABOR (NODE A1)

In Figure 2-3, we repeat the organic DM labor portion of the cost tree from Figure 2-2 for ease of comparison.

Figure 2-3. Corrosion-Related DM Labor Cost for Navy Ships ($ in millions)



As we depict in Figure 2-3, the top-down calculations for the organic DM labor costs are $3.017 billion. We accounted for $3.867 billion in labor costs from the bottom-up data—a total that is higher than our top-down cost of $3.017 billion. Because the text fields were removed from DM records before we fully completed our assessment, we cannot determine the exact cause of the labor cost overage. One logical assumption is the data records included deferred maintenance—that is, tasks that were fully estimated with labor hours but never executed.

We analyzed information provided by several Navy information systems that give detail on DM actions. We highlighted key corrosion-related words in the problem descriptions and corrective action text fields of the job orders to segregate the corrosion-related work from all other maintenance activities. We then applied the specified percentage to the labor cost for each record flagged for corrosion to determine the corrosion-related labor cost.[4]

Using this iterative method of flagging corrosion-related work and aggregating the corrosion-related labor costs, we estimated the overall organic DM aviation equipment corrosion-related labor costs initially as $873 million for Navy ships.

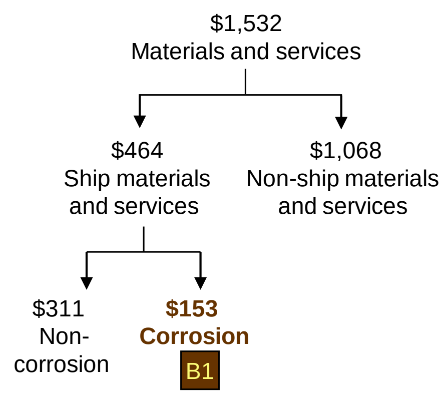
To calculate the final corrosion-related cost at node A1,we multiplied the corrosion-related labor cost of $873 million by the ratio of $3.017 billion to $3.867 billion (3.017 ÷ 3.867 = 0.78) to close the top-down–to–bottom-up gap. The result is $681 million (873 × 0.78), the corrosion-related cost in node A1.

[4] In Appendix C, we provide a complete list of the keywords we used to segregate corrosion-related job orders.

Cost of Corrosion for Organic DM Materials and Services (Node B1)

We continued our bottom-up approach by extracting the organic DM materials and services cost of corrosion from the total DM materials. In Figure 2-4, we repeat the organic DM materials and services portion of the cost tree from Figure 2-2 for ease of comparison.

Figure 2-4. Organic DM Materials and Services Costs for Navy Ships ($ in millions)



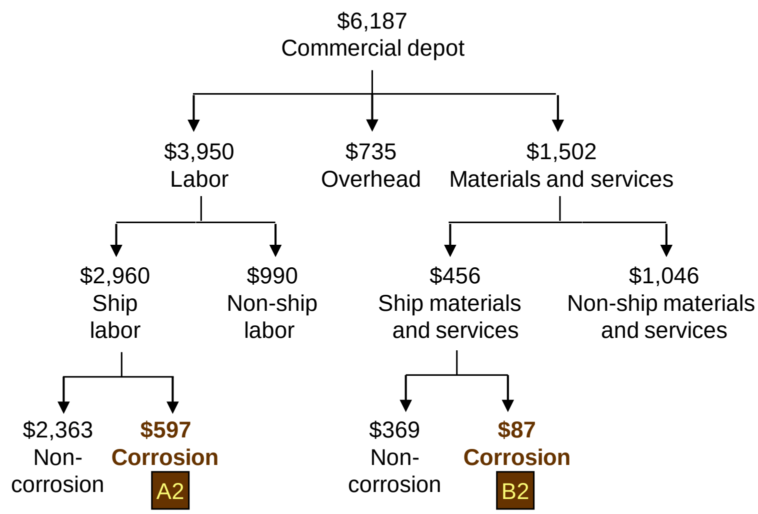
All materials and service costs are accounted for within each job order and, therefore, are linked to the job orders for organic DM labor. Because we assessed each job order to determine whether it was corrosion related, the process of determining corrosion-related material and service costs for these data records was straightforward. If a labor job order was corrosion related, the materials and services associated with that job order were also corrosion related.

As we depict in Figure 2-4, the top-down calculations for the organic DM materials and services costs are $464 million. We accounted for $189 million of these costs from the detailed bottom-up data. To calculate the final corrosion-related cost at node B1, we closed the top-down–to–bottom-up gap by multiplying the corrosion-related cost of $62 million that we aggregated within the material and service records by the ratio of $464 million to $189 million (464 ÷ 189 = 2.46) . The result is $153 million (62 million × 2.46), the corrosion-related cost at node B1.

Cost of Corrosion for Commercial DM (Nodes A2 and B2)

We followed a method similar to what we used for the cost of corrosion for organic DM to determine cost of corrosion for commercial DM. Figure 2-5 shows the commercial DM branch of the overall DM cost from Figure 2-2.

Figure 2-5. Commercial DM Costs for Navy Ships ($ in millions)



TOP-DOWN ANALYSIS FOR COST OF CORROSION FOR COMMERCIAL DM

We started our top-down analysis at the top of the cost tree in Figure 2-5. Because there is no reporting requirement similar to the 1307 reports for commercial depots, we applied the Navy's organic DM ratios for labor, overhead, and materials and services to the total commercial DM cost to determine the commercial DM labor, overhead, and material and service totals. For example, organic depot labor costs represent 64 percent of the organic DM total; we applied that same percentage to the commercial DM total, which resulted in a labor cost of $3,950 million. We depict the results of this extrapolation in the second row of Figure 2-5.

We then used the organic DM ratios of ships-related funding to non-ships-related funding for labor (74.9 percent) and materials and services (30.3 percent) to determine the corresponding totals for the Navy ships' commercial DM labor and materials and services. This yields the final top-down costs of $2.960 billion for commercial DM labor and $456 million for commercial DM materials and services, as shown in Figure 2-5.

Our next task was to extract the corrosion-related costs for labor (node A2) and materials and services (node B2) from the total costs for commercial DM labor and commercial DM materials and services for Navy ships.

BOTTOM-UP ANALYSIS FOR COST OF CORROSION FOR COMMERCIAL DM

We used the Navy Maintenance Database (NMD) as our primary source of detailed bottom-up data for commercial DM. We segregated the corrosion-related labor records from the non-corrosion-related labor records using the same corrosion-related keywords that we applied for our analysis of the organic DM data.

We accounted for $1.076 billion of the $2.960 billion of commercial DM labor for Navy ships from the detailed bottom-up labor data in NMD. To calculate the final corrosion-related cost for node A2, we closed the top-down–to–bottom-up gap by multiplying $217 million, the corrosion-related cost we segregated using the corrosion-related keyword search methods,[5] by the ratio of $2.960 million to $1.076 million (2.96 ÷ 1.076 = 2.75). The result is $597 million (217 × 2.75), the corrosion-related cost at node A2.

To determine the cost of corrosion for node B2, we aggregated the costs for materials and services associated with the labor maintenance records that we flagged through our corrosion-related search method. We then separated the corrosion-related costs for materials and services from the other maintenance costs listed in the NMD database.

We tallied $642 million for commercial DM materials and services through the bottom-up detailed data for commercial DM. To calculate the final cost of corrosion for node B2, we accounted for the top-down–to–bottom-up gap by multiplying $122 million, the corrosion-related cost we segregated using the corrosion-related keyword search method, by the ratio of $456 million to $642 million (456 ÷ 642 = 0.71). The result is $87 million (122 × 0.71), the corrosion-related cost at node B2.

COST OF CORROSION FOR FLM (NODES C AND D)

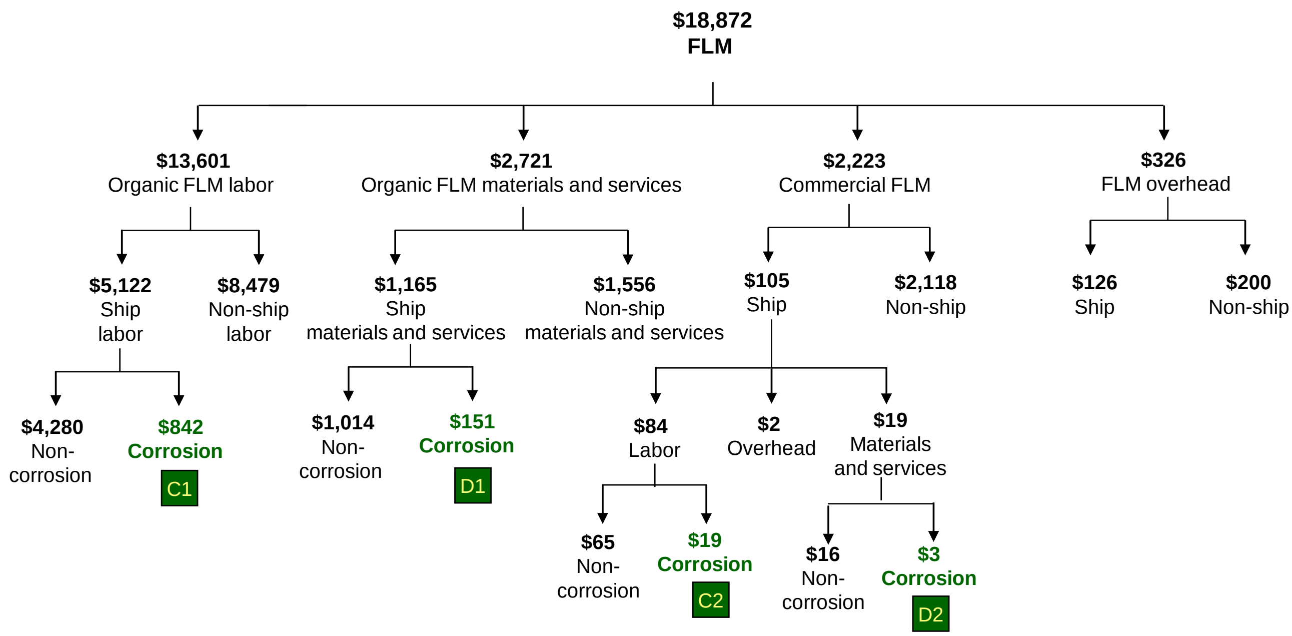
The cost of corrosion for FLM is significant but represents a lower percentage of overall maintenance cost than for DM.

The total FLM cost of corrosion for Navy ships is $1.015 billion. This represents 15.6 percent of the total FLM cost of $6.518 billion for Navy ships, less than the 20 percent corrosion-related cost rate for DM.

The detailed FLM corrosion-related cost tree in Figure 2-6 guides our discussion.

[5] We explain our corrosion-related keyword search method and provide an example in Appendix C.

Figure 2-6. FLM Corrosion-Related Costs for Navy Ships ($ in millions)



Top-Down Analysis for the FLM Cost of Corrosion

We started our top-down analysis by calculating the costs at the second level of the tree to determine the total Navy FLM costs. Unlike for DM costs, there is no legal requirement to aggregate FLM costs and report them at the military service level.

Once we determined the costs for organic FLM labor and materials and services, commercial FLM maintenance, and FLM overhead (the second level of the tree in Figure 2-6), we calculated the cost at each subsequent level until we reached the cost-of-corrosion nodes. We then used detailed bottom-up data to determine the corrosion-related cost at each of these nodes. We outline these costs in Table 2-2.

Table 2-2. FLM Cost of Corrosion for Navy Ships ($ in millions)

Field-level cost area	Total FLM for Navy ships				Corrosion-related FLM costs		
	Materials and ser-vices	Labor	Overhead	Total	Materials and services	Labor	Total
Organic	$1,165	$5,122	$126	$6,413	**$151**	**$842**	$993
Commercial	$19	$84	$2	$105	**$3**	**$19**	$22
Total	$1,185	$5,206	$128	$6,518	**$154**	**$861**	$1,015

We started with the FLM labor costs using data from the Defense Manpower Data Center (DMDC), to identify Navy personnel with maintenance skill specialties.

These personnel come from different service components: active duty, reserves, and the civilian workforce.

Based on staffing levels and per-capita pay rates,[6] the top-down organic FLM labor cost for the Navy is $13.601 billion. Table 2-3 details these staffing levels, rates, and costs.

Table 2-3. FLM Staffing Levels and Costs by Navy Component

Component	Staffing level	Per capita cost	Total cost (in millions)
Active duty	126,564	$91,531	$11,585
Reserve	17,951	$27,434	$492
Civilian	17,466	$87,258	$1,524
Total	161,981		$13,601

We then moved to materials and services, identifying the Navy's cost for organic FLM materials and services, using information from the Navy's OP-31 exhibit, "Spares and Repair Parts."[7] In Table 2-4, we summarize the OP-31 document for FY2010.

Table 2-4. FY2010 OP-31 Budget Exhibit for Navy Ships

Commodity category	Initial total (in millions)
Ships	$1,115
Aircraft airframes	$725
Aircraft engines	$483
Combat vehicles	$265
Other—missiles	$10
Other—communications equipment	$5
Other—miscellaneous	$118
Total	$2,721

As Table 2-4 shows, the Navy estimates its total FY2010 FLM cost for spares and repair parts, excluding contract maintenance costs, is $2.721 billion.

[6] Per-capita rates are derived from the *Department of Defense Fiscal Year 2010 President's Budget.*

[7] Operations and Maintenance, *Navy Data Book Submitted in Justification of Estimates,* February 2011, p. 96. This document was submitted as part of the *Department of the Navy Fiscal Year 2012 Budget Estimates*.

We next moved to commercial FLM. We identified Navy commercial FLM costs using the active duty and reserves OP-32 exhibits from the same budget documents we used for organic FLM costs for materials and services.[8] Commercial maintenance costs are captured inside budget line 922, "Equipment Maintenance by Contract." We isolated all costs associated with line 922 for the two FLM-related budget activities. The sum of the contract maintenance costs on line 922 yielded $2.223 billion in Navy commercial FLM costs.

Finally, we calculated the overhead costs for organic FLM. A previous study of FLM costs determined overhead to be approximately 2 percent of total FLM costs. This does not include indirect labor or materials and services, but it does include utilities, fuel, and other miscellaneous costs.[9] We, therefore, calculated the overhead cost to be $326 million.[10]

Adding the costs for FLM labor and materials and services, commercial FLM, and FLM overhead resulted in a total Navy FLM cost of $18.872 billion.

Having determined the total Navy FLM costs, we continued our top-down analysis with the organic FLM labor costs.

Cost of Corrosion for Organic FLM Labor (Node C1)

We split organic FLM labor costs by ships and non-ships. Using DMDC data, we were able to determine the maintenance staffing level for each of the 237 ships in the study, including other FLM maintainers not directly assigned to a ship. We show the active duty, reserve, and civilian staffing totals in Table 2-5.

Table 2-5. FLM Labor Cost for Navy Ships (FY2010)

Military component	Total staffing	Pay rate	Total cost (in millions)
Active duty	52,321	$91,531	$4,788
Reserve	5,057	$27,434	$139
Civilian	2,236	$87,258	$195
Total	59,614		$5,122

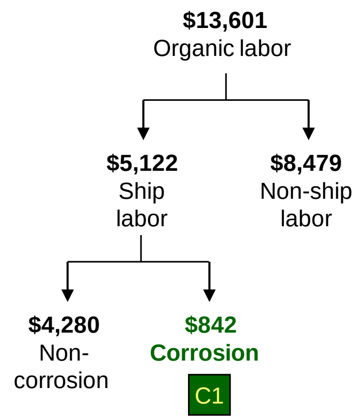
Using the same per-capita pay rate from Table 2-3, we determined the Navy ships' organic FLM labor cost to be $5.122 billion. Our next task was to extract the corrosion-related labor cost (node C1 from Figure 2-7) from this total using a bottom-up costing approach.

[8] Operations and Maintenance, multiple pages.

[9] Eric Herzberg et al., *FLM Cost Visibility*, Report LG301T7 (McLean, VA: LMI, March 2005), pp. 1–5.

[10] The $326 million is 2 percent of the organic FLM labor costs ($13.601 billion) plus organic FLM materials costs ($2.721 billion).

Figure 2-7. Cost of Corrosion for Organic FLM Labor for Navy Ships ($ in millions)



We used data from Maintenance and Material Management Open Architectural Retrieval System (3M/OARS), the Navy's primary FLM system, to determine the corrosion-related FLM labor cost for Navy ships. We analyzed information provided by 3M/OARS for all closed work orders for FY2010 for each of the 237 ships in the study. Including material purchase data, the number of individual data records totals approximately 1 million.

By aggregating the individual 3M/OARS labor hours, we accounted for $1.348 billion in ship-related labor costs from the detailed bottom-up labor data. This amount is approximately 26 percent of our top-down total of $5.122 billion, as shown in Figure 2-7.

At first glance, this gap appears large, yet we determined the top-down cost figure by multiplying a staffing level by a per-capita yearly rate. We then determined the bottom-up cost of $1.348 billion by aggregating direct hands-on maintenance labor hours and multiplying by $50.18 per hour—that is, the hourly equivalent of the per-capita rate.[11] In other words, the top-down cost is the total yearly cost of the 59,614 personnel with a ship-related maintenance skill specialty from Table 2-5. The bottom-up cost reflects only the hours recorded for hands-on maintenance by the same number of personnel.

We accounted for the gap between the top-down and bottom-up cost figures as follows:

- Roughly 48 percent of a typical maintainer's time is spent performing direct hands-on maintenance.[12] The remaining time is spent on leave, recovering from illness, in training, on travel, and performing other administrative duties.

[11] According to OMB Circular A-76 (March 2003), a civilian full-time equivalent (FTE) is 1,776 hours. Therefore, we used the per capita yearly rate divided by 1,776 hours to calculate the equivalent hourly rate.

[12] *Performance Measures for U.S. Pacific Fleet Ship Intermediate Maintenance Activities*, Deidre L. McLay, September 1992, p. 29. We used the utilization rates shown, subtracting 14.7 percent to account for leave, sickness, and other time personnel are planned to be away from their workplace that are not accounted for in the definition of utilization.

- According to a survey we administered to Navy personnel, roughly 20 percent of hands-on maintenance performed by maintenance personnel working aboard ships is not recorded in 3M/OARS. We include a summary of the survey results in Appendix D.

- More than 15 percent of the shipboard maintainers (8,942 of 59,614) are both operators and maintainers. Their primary duty is to operate equipment, but to improve efficiency or because of space limitations, they also maintain equipment. The direct hands-on maintenance hours recorded for this group of operator-maintainers will be relatively small; their first responsibility is to operate equipment, though that information is typically not recorded in 3M/OARS.[13]

Based on these three factors, we expected to be able to account for approximately $1.671 billion in the direct labor costs recorded—$5.122 billion × 48 percent (actual hands-on maintenance time) × 80 percent (actual recorded hands-on maintenance time) × 85 percent (to eliminate operator-maintainers). The $1.348 billion in bottom-up labor costs that we did capture represents only 81 percent of the total recorded maintenance costs we analyzed. Although we had anticipated capturing a higher percentage, the amount we did capture was sufficient to derive a valid cost estimate.

3M/OARS records contain a data field ("Cause_Code") that allows maintenance personnel to designate corrosion as a cause for a maintenance action. We added "cause code" as a search criterion to extract corrosion-related work for FLM. We then applied the same corrosion-related keyword search technique we used to analyze the DM data.

By using the keyword search technique, including the cause codes, to flag and separate corrosion-related records from non-corrosion records, we accumulated a total corrosion-related labor cost of $221.7 million.

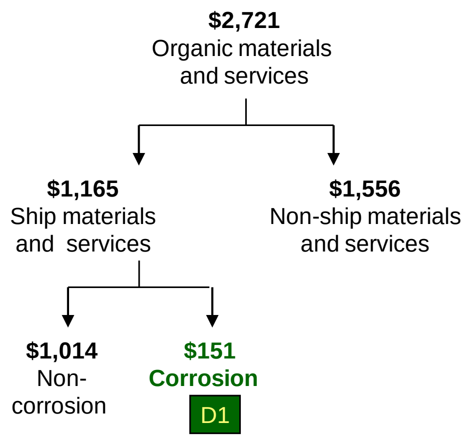
To calculate the final corrosion-related costs for node C1, we multiplied the flagged corrosion-related labor cost of $221.7 million by the ratio of $5.122 billion to $1.348 billion (5.122 ÷ 1.348 = 3.8) to account for the top-down–to–bottom-up gap. The result is $842 million (227.4 × 3.8), the corrosion-related cost at node C1.

[13] Although this group of personnel only partially performs maintenance, we are comfortable including their total yearly cost in the top-down information. Even during periods when they are operating equipment, they could be asked to perform maintenance tasks similar to the unrecorded tasks performed by the non-maintenance sailors we account for in node E.

Cost of Corrosion for Organic FLM Materials and Services (Node D1)

To analyze the corrosion-related cost for organic FLM materials, we started with our top-down estimate of $2.721 billion for the total cost of Navy FLM materials and services (see Figure 2-8).

Figure 2-8. Cost of Corrosion for the Navy's Organic FLM Materials and Services ($ in millions)



From Table 2-4. , we determined the ships-only portion of the $2.721 billion FLM materials total is $1,115 million. We also noted that a portion of the "Other–Miscellaneous" category listed in Table 2-4. ($118 million) represents a potential FLM materials cost for Navy ships.

We calculated the ratio of the budget amount for FLM materials and services from Table 2-4. for Navy ships ($1,115 million) to the total of the ships, aircraft, and combat vehicles amounts ($2,603 million) (1,115 ÷ 2,603 = 0.43). We then multiplied this ratio to the "Other–Miscellaneous" total of $118 million (0.43 × $118 million) to determine an additional Navy ships amount of roughly $50 million. We added this amount to the $1,115 million ships-only portrait from Table 2-4. to calculate the total top-down organic materials amount of $1,165 million for all Navy ships.

Next, we examined the total cost of materials and services in the 3M/OARS database. By aggregating the individual 3M/OARS materials costs, we accounted for $651 million in ships-related materials costs from the detailed bottom-up data for materials. This amount, $651 million, represents 56 percent of our top-down total of 1,165 million.

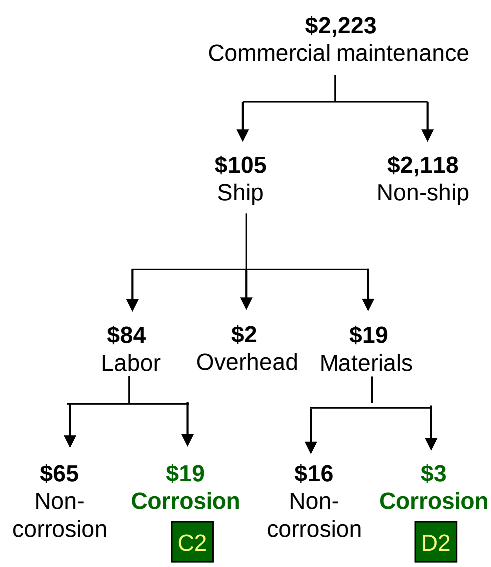
To determine the corrosion-related cost for node D1, we used a bottom-up approach and accumulated the FLM material and service costs associated with the FLM labor records we flagged through our corrosion-related search method. We then segregate these corrosion-related FLM material and service costs from the other FLM material and service costs listed in the 3M/OARS database.

By aggregating FLM materials costs associated with flagged corrosion-related FLM labor records, we identified $84.3 million for the cost of corrosion for organic FLM materials. Adjusting for the top-down–to–bottom-up difference, we multiplied the flagged costs of corrosion for FLM materials, to the ratio of $1,165 million to $651 million (1,165 ÷ 651 = 1.79). This yields a final corrosion-related cost for organic FLM materials of $151 million (84.3 × 1.79), as shown at node D1.

Cost of Corrosion for Commercial FLM Labor and Materials and Services (Node C2 and D2)

For commercial FLM labor and materials and services, we used the same method as we did to analyze the cost of corrosion for organic FLM. We began with our top-down estimate of $2.223 billion from Figure 2-9.

Figure 2-9. Cost of Corrosion for Navy Commercial FLM ($ in millions)



We refine our analysis to isolate the labor and materials costs for only the Navy ships FLM. Using the detailed budget information, we isolate all costs associated with line 922 of the OP-32 budget exhibit for each budget activity at the sub-activity level of detail. Examining the costs at this level of detail allowed us to determine, which commercial FLM costs are for Navy ships and which commercial FLM costs are for something other than Navy ships. Aggregating the Navy ships commercial FLM costs yielded a total of $105 million. This is the cost labeled as simply "ships" in the second level of Figure 2-9.

To further separate the Navy ships commercial FLM cost of $105 million into labor, materials and services, and overhead, we apportioned the Navy ships commercial

FLM cost using the Navy ships organic FLM cost ratios for labor, materials and services, and overhead. This costing approach resulted in $84 million for commercial FLM labor, $19 million in commercial FLM materials and services, and $2 million in commercial FLM overhead. The third row of Figure 2-9 shows these costs.

We then extracted the corrosion-related costs for commercial FLM (node C2) and the corrosion-related cost for commercial FLM materials and services specifically (node D2) from their respective labor and material and service totals. To accomplish this, we applied the corrosion-related keyword search technique, the same as did for the organic FLM data.

The commercial FLM labor records yielded a bottom-up labor total of $24 million. The corrosion-related keyword search through the commercial FLM labor records yielded an initial corrosion-related cost of $5.5 million. To account for the top-down–to–bottom-up difference, we multiplied that amount, $5.5 million, by a ratio of $84 million to $24 million (84 ÷ 24 = 3.5), yielding a final cost of corrosion for commercial FLM labor of $19 million (5.5 × 3.5), as shown at node C2.

The records for commercial FLM materials and services yielded a bottom-up total of $39 million in total costs for FLM materials and services. This amount is about double our top-down total of $19 million. Aggregating the material and service costs associated with the labor records flagged for corrosion from the previous step yielded an initial corrosion-related cost of $6.2 million for materials and services. To account for the difference in the top-down and bottom-up totals, we multiplied this amount, $6.2 million, by a ratio of $19 million to $39 million (19 ÷ 39 = 0.49), yielding a final cost of corrosion for commercial FLM materials and services of $3 million (i.e., 6.2 × 0.49), as shown at node D2.

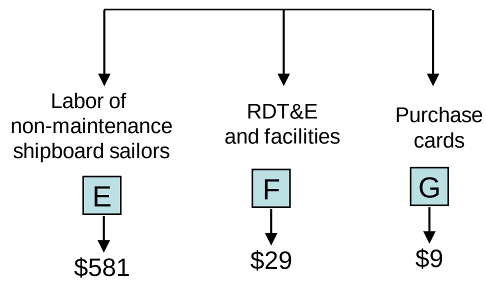
Because the commercial FLM labor bottom-up total was less than the top-down amount, and the commercial FLM materials and services bottom-up total exceeded the top-down total, we believe some data included in the bottom-up totals for commercial FLM materials and services likely represented labor services. Frequently, commercially performed labor is annotated as a service and purchased much like commercial materials. Inclusion of these records as a material and service purchase would cause the bottom-up commercial materials and services to be overestimated and the bottom-up commercial labor to be under-estimated.

Cost of Corrosion for Outside Normal Maintenance Reporting (Nodes E, F, and G)

We identified relatively high corrosion-related costs in this last area of our cost analysis in the previous cost study of Navy ships we performed in 2010 and again in this current study. The cost of corrosion for ONR is $617 million, with non-maintenance shipboard labor accounting for the overwhelming majority ($581 million).

The corrosion-related cost tree for ONR in Figure 2-10 guides our discussion about these corrosion-related costs.

Figure 2-10. Cost of Corrosion ONR for Navy Ships ($ in millions)



We calculated each of the corrosion-related costs for nodes E through G in a unique way, as they are not recorded as part of a standard maintenance reporting system.

Labor of Non-Maintenance Shipboard Sailors (Node E)

Node E contains the cost of shipboard Navy personnel with a non-maintenance specialty but who perform corrosion-related tasks, such as painting, cleaning, and inspecting. To estimate this cost, we first determined the staffing level of non-maintenance personnel for each of the 237 ships in the study. We provide this information in Appendix E.

We then used information from a survey we administered on the Navy Knowledge Online (NKO) website to determine the amount of time shipboard personnel spend performing both general maintenance tasks and corrosion-related maintenance tasks. We classified this information by each of the four ship types in the study: amphibious, carrier, surface warfare, and submarine. Nearly 25 percent of the survey non-maintenance specialty participants stated they do not perform any type of maintenance activity. The remaining 75 percent have performed some shipboard maintenance tasks, despite not having a maintenance specialty.

We summarize the amount of time these non-maintenance personnel spend on maintenance tasks (including those related to corrosion) in Table 2-6. We summarize the complete results of our survey in Appendix D.

Table 2-6. Summary of Time Spent on Corrosion-Related Maintenance by Non-Maintenance Shipboard Personnel

Ship category	Average number of hours spent on maintenance per day	Average number of hours spent on corrosion-related maintenance per day
Aircraft carrier	3.5	2.0
Amphibious	3.7	2.6
Surface warfare	3.8	2.8
Submarine	5.5	2.5

Based on the survey responses and staffing levels of Navy ships for the current study, and using an average pay rate for personnel at an E-4 grade, we determined the total cost estimate for node E is $581 million.

This level of corrosion-related cost exceeds that of the previous studies by approximately $253 million. The two main reasons for this cost increase are:

- The increase in the average hourly E-4 pay rate, from $32.07 in FY2007 (our previous measurement baseline) to $37.93 in FY2010 (our current measurement baseline), adding more than $90 million overall
- The increase in the average amount of corrosion-related work performed, from 1.7 hours per day in FY2007 to 2.6 hours per day in FY2010, adding more than $188 million overall.

We were able to allocate these costs to each Navy ship based on its staffing level.

RDT&E and New Facility Costs (Node F)

Node F shows two corrosion-related costs:

- Research, development, test, and evaluation (RDT&E)
- New facilities.

Corrosion-Related RDT&E Costs

Corrosion-related RDT&E costs are potentially traceable to an RDT&E program that the Navy uses to develop methods or technologies for mitigating or preventing the effects of corrosion on its ships.

We examined both the Navy's RDT&E requests contained in the FY2010 President's Budget and projects submitted through the CPC IPT. We also queried the budget documents for program elements containing possible corrosion-related terms, such as paint, corrosion, or coat.

We determined which RDT&E Navy ships projects from FY2010 are related to corrosion. We list them in Table 2-7.

Table 2-7. Corrosion-Related Navy Ships RDT&E Projects (FY2010, $ in millions)

Project number	Project description	Sub-element description	Sub-element funding	Amount related to corrosion	Corrosion as a percent-age of sub-element funding
0000	Defense research sciences	Hull life assurance	$50.4	$2.52	5
0000	Defense research sciences	Materials	$58.1	$2.91	5
0000	Defense research sciences	Fouling unmanned undersea vehicle	$18.6	$0.93	5
0000	Force projection applied research	Surface ship and submarine hull	$45.7	$11.4	25
0000	Warfighter sustainment applied research	Advanced Navy materials	$16.24	$1.62	10
0000	Warfighter sustainment applied research	Cost-reduction technologies	$8.18	$4.09	50
2033	Advanced submarine systems development	Total ownership cost life-cycle maintenance	$11.0	$0.55	5
3220	Sea-based strategic deterrence (SBSD) Advanced submarine system development	Cost-reduction corrosion analysis	$25.0	$1.25	5
0995	Naval facilities system	Modular hybrid pier	$1.6	$0.16	10
2316	Combat service support engineering	Corrosion-related prevention and control	$2.0	$2.0	100
W10NS03	Tool for quantifying hydrocarbon contamination	Tool for quantifying hydrocarbon contamination	$0.7	$0.7	100
W10NS08	Adhesive-based coatings for bilges	Adhesive-based coatings for bilges	$0.8	$0.8	100
Total			$238.32	$28.93	12.1

The total cost for these Navy ships corrosion-related RDT&E projects is $28.93 million.

CORROSION-RELATED FACILITY COSTS

Corrosion-related facility costs are expenditures on new facilities that have the primary purpose of preventing or correcting corrosion. Examples of these diverse types of costs include paint booths, paint-stripping equipment, and curing ovens to heat treat protective coatings.

We searched the Navy's Military Construction (MILCON) appropriation submission in the FY2012 President's Budget,[14] but this search did not yield any results for new corrosion-related facility expenditures. We then asked knowledgeable Navy representatives if they were aware of any new facilities whose primary purpose is to fight corrosion and that were constructed during FY2010. None of the representatives were aware of such costs. These representatives also stated that the cost of facilities may be included in major weapon acquisition programs, but they did not have access to this data.

We concluded from the information we were able to obtain that new corrosion-related facility costs were not broken out separately for FY2010. We did not have enough information to separate potential corrosion-related facility costs that may be embedded within the cost of acquisition programs for FY2010.

Purchase Cards (Node G)

The purchase card costs we show in the third row of the cost tree in Figure 2-10 are corrosion-related material or service expenditures made using a charge card.

We obtained a list of the FY2010 charge card purchases for the Navy. These records include information about the purchasing organization, merchant category code (MCC), transaction date, merchant description, and transaction amount. Similar to the government's Federal Supply Catalog (FSC) codes, the MCC describes the materials and services.

We began our analysis of these costs by first identifying FSC codes tracking corrosion-related consumables, such as paints, preservatives, cleaning supplies, and coatings. We then identified the potential corrosion-related purchase card items by segregating the MCCs that are similar to the corrosion-related FSC codes. We performed a keyword search to flag merchant descriptions that contain corrosion-related words, such as "paint," "wash," "coatings," and "clean," from among the millions of potentially corrosion-related purchase card records.

Finally, we examined each flagged transaction to determine whether it was a corrosion-related Navy ships material or service purchase. We did this by eliminating flagged merchant descriptions that are obviously not corrosion related (e.g., Bill's Dry Cleaning) or purchasing organizations that are obviously not associated with ships (e.g., aviation-related purchases).

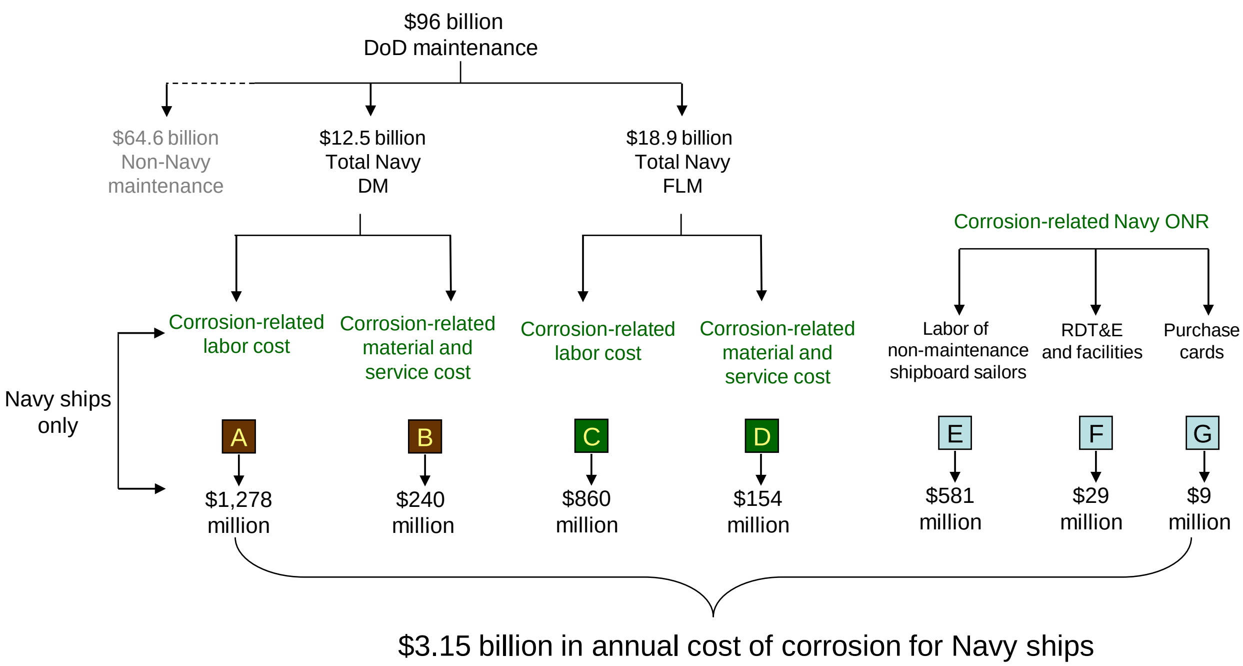
Based on the valid corrosion-related Navy ships transactions that remained, the estimated cost of corrosion based on purchase card expenditures from FY2010 is $9 million.

[14] FY2012 budgets included FY2010 expenditure data.

NAVY SHIPS CORROSION-RELATED COST TREE (NODES A THROUGH G)

In Figure 2-11, we recap the Navy ships corrosion-related cost tree with corrosion-related costs shown at each node. All told, the Navy ships corrosion-related cost (including both commercial and organic DM and FLM and ONR costs) is $3.15 billion.

Figure 2-11. Navy Sustainment Corrosion-Related Cost Tree (FY2010)



Chapter 3
Summary and Analysis

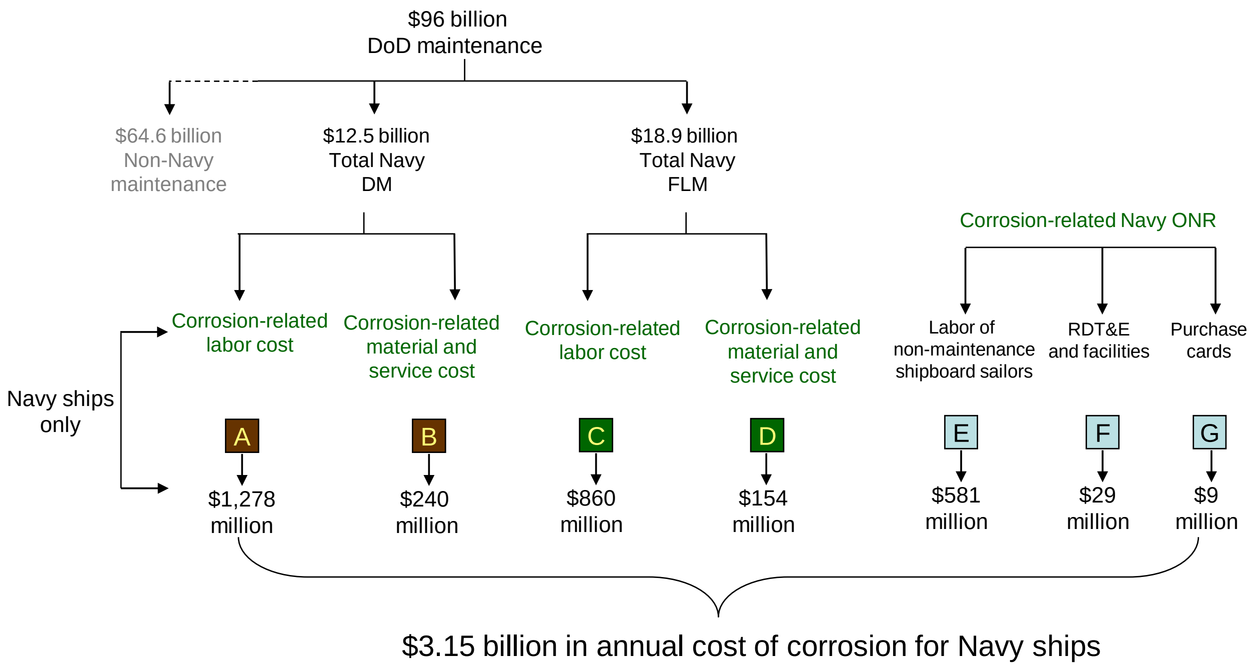
The total annual corrosion-related cost estimate for Navy ships in FY2010 is $3.15 billion.

During the execution of this study, we created a data structure that allows many different views of this cost—far too many to depict within the body of this report. In this chapter, we extract several of the more interesting summaries and discuss their significance. We also present trend analysis based on the 6 years of study data from this and our earlier study on the cost of corrosion for Navy ships.

CORROSION-RELATED COST COMPARISON BY NODE AND STUDY YEAR

We first present the cost of corrosion for Navy ships by node in Figure 3-1.

Figure 3-1. Breakouts of FY2010 Navy Ships Corrosion-Related Costs by Node



The cost of corrosion-related labor is significantly higher than all other corrosion-related costs. The labor costs of corrosion are the costs at nodes A, C, and E. The labor costs of these three nodes account for $2.72 billion, or more than 85 percent of the total corrosion-related cost for Navy ships.

Corrosion-related DM labor cost for Navy ships, $1,278 million or node A), represents the highest corrosion-related cost of any of the nodes we highlight.

We summarize the cost of corrosion for Navy ships by study year in Table 3-1. We excluded corrosion-related ONR costs from this analysis, because Table 3-1 shows only direct maintenance costs.

Table 3-1. Navy Ships DM and FLM Corrosion-Related Costs by Study Year ($ in millions)

Data baseline	DM and FLM cost	DM and FLM corrosion-related cost	Corrosion as a percentage of DM and FLM	Percentage change from FY2004		Percentage change from FY2009	
				DM and FLM cost	DM and FLM corrosion-related cost	DM and FLM cost	DM and FLM corrosion-related cost
FY2004	$10,317	$2,181	21%	—	—	—	—
FY2006	$11,697	$1,891[a]	16%	13%	−13%	—	—
FY2007	$10,768	$1,414[a]	13%	4%	−35%	—	—
FY2008	$11,330	$2,178	19%	10%	0%	—	—
FY2009	$11,842	$2,376	20%	15%	9%	—	—
FY2010	$13,325	$2,532	19%	29%	16%	13%	7%
Total	$69,278	$12,572	18%				

[a] These costs are most likely underestimated from the lack of usable organic shipyard data for surface ships in FY2006 and FY2007.

Pattern of Falling and Rising Corrosion-Related Costs

Corrosion-related costs incurred during the performance of Navy ships' DM and FLM decreased from $2.181 billion in FY2004 to $1.414 billion in FY2007, then steadily increased between FY2007 and FY2010. Maintenance expenditures followed a similar pattern.

Corrosion-related costs as a percentage of maintenance costs for Navy ships show a different trend. Between FY2004 and FY2007, corrosion-related costs as a percentage of maintenance costs decreased fairly significantly, from 21 percent to 13 percent. In FY2008, the percentage increased to 19 percent, just below the level from the initial FY2004 study, then remained relatively steady.

One reason for this disparity may result from the FY2006 and FY2007 data, which may be under-estimated because of a lack of usable organic shipyard data.

The Navy classified these data records as NNPI, which delayed the execution of this study, made analysis difficult, contributed to the poor data integrity from three of the four organic shipyards, and limited our ability to correct the results once Navy subject matter experts reviewed and updated the corrosion-related search algorithm. Therefore, for the purpose of our trend analysis, it is beneficial to analyze data comparisons between our most recent study years—FY2008 through FY2010—and the initial study we performed using FY2004 data and omit FY2006 and FY2007 study data.

Overall, corrosion-related costs have increased 16 percent since the initial FY2004 study, whereas maintenance costs have increased 29.2 percent. This indicates the Navy has made progress in mitigating the effects of corrosion on cost as corrosion-related costs specifically have risen at a more moderate pace than overall maintenance expenditures. We can further investigate this pattern of corrosion-related costs by node (see Table 3-2).

Table 3-2. Navy Ships Corrosion-Related Cost by Node and Sub-Node

Node	Description of cost node	Corrosion-related cost (in millions)			
		FY2004	FY2008	FY2009	FY2010
A1	Organic DM labor	$ 628	$ 685	$ 746	$ 681
B1	Organic DM materials and services	$ 85	$ 129	$ 116	$ 153
A2	Commercial DM labor	$ 417	$ 446	$ 594	$ 597
B2	Commercial DM materials and services	$ 38	$ 64	$ 64	$ 87
DM total		$1,168	$1,324	$1,520	$1,518
C1	Organic FLM labor	$ 840	$ 764	$ 758	$ 842
D1	Organic FLM materials	$ 166	$ 61	$ 73	$ 151
C2	Commercial FLM labor	$ 6	$ 27	$ 23	$ 19
D2	Commercial FLM materials	$ 2	$ 2	$ 2	$ 3
FLM total		$1,013	$ 854	$ 856	$1,015
E	Labor of non-maintenance shipboard personnel	$292	$523	$597	$581
F	Priority 2 and 3	$10	$21	$22	$27
G	Purchase cards	$10	$11	$8	$9
H	Scrap and disposal	$2	N/A [a]	N/A [a]	N/A [a]
ONR total		$314	$555	$627	$617
Total—all corrosion costs		$2,495	$2,733	$3,003	$3,150

[a] We did not calculate costs for scrap and disposal in the studies conducted after FY2004.

The shaded nodes in Table 3-2 account for the major cost changes between FY2004 and FY2010. We explore these nodes further in Table 3-3.

Table 3-3. Corrosion-Related Cost of Navy Ships by Fluctuating Cost Nodes ($ in millions)[a]

Node	Change in corrosion-related cost	Change in maintenance cost	Change in corrosion-related cost percentage
B1	$68	$82	+11%
A2	$180	$1,145	-3%
B2	$49	$94	+8%
E	$289	$129[b]	+22%
Total	$586	$1,450	

[a] Data represents FY2004 through FY2010, with FY2006 and FY2007 data omitted.

[b] This total is the labor of shipboard operators and sailors who are not maintainers by trade. More than 75 percent of this maintenance labor goes unrecorded.

The four nodes in Table 3-3 account for $586 of the $654 million increase in corrosion-related costs between FY2004 and FY2010.

The increase in maintenance costs for this node accounts entirely for the increase in corrosion-related costs for node A2. In fact, the corrosion-related costs as a percentage of maintenance costs for this node decreased by 3 percent. This indicates DoD has achieved some progress in containing corrosion-related labor costs for commercial DM.

Although the increase in corrosion-related costs for organic DM (nodes B1 and B2) has been relatively small, these areas bear scrutiny as these corrosion-related costs as a percentage of total organic DM cost has increased. One possible explanation for this increase is the use of more expensive but longer-lasting coatings. This may also explain the increase in the corrosion-related cost of materials and services and what may be a corresponding improvement in corrosion-related labor cost, as Table 3-3 shows.

As noted in Chapter 2, the increase in costs for node E are primarily attributable to the increase in the average pay rate of an E-4 and in the amount of corrosion-related maintenance being performed.

CORROSION-RELATED COSTS BY SHIP CATEGORY

We calculated the total corrosion-related cost, including ONR costs, by ship category as well as the average corrosion-related cost per ship for each category. We show these results for each study year in Table 3-4.

Table 3-4. Corrosion-Related Cost by Ship Category

	FY2004		FY2008		FY2009		FY2010	
Ship category	Total	Per ship	Total	Per ship	Total	Per ship	Total	Per ship
Amphibious	$732	$20	$375	$13	$469	$16	$393	$13
Carrier	$540	$45	$355	$32	$352	$32	$418	$38
Submarine	$117	$2	$754	$11	$726	$11	$739	$11
Surface warfare	$793	$6	$694	$6	$830	$7	$981	$8
Total[a]	$2,181	$9	$2,178	$9	$2,376	$10	$2,532	$11

[a] The total corrosion-related cost by ship category in Table 3-4 will not equal the total corrosion-related cost from Table 3-2 because not all corrosion-related costs can be attributed to a ship category, as in the case of RDT&E and purchase card expenditures.

The corrosion-related cost per ship for submarines and surface warfare vessels has increased steadily since the first study in FY2004. This is significant because these two types of vessels are the most prevalent in the fleet, comprising 29.5 percent and 51.9 percent of the Navy fleet, respectively.

The corrosion-related cost per ship for carriers and amphibious ships has dropped since FY2004. Carriers still have the highest corrosion-related cost per ship by a large margin. For amphibious ships, the drop in corrosion-related costs is primarily attributable to lower maintenance costs. As we depict in Table 3-5, maintenance expenditure on amphibious vessels was about $1.2 billion lower in FY2010 than in FY2004—or on average, about $20 million per vessel.

Table 3-5. Maintenance Cost by Ship Category

	FY2004		FY2008		FY2009		FY2010	
Ship category	Total	Per ship	Total	Per ship	Total	Per ship	Total	Per ship
Amphibious	$3,362	$91	$1,978	$68	$2,356	$79	$2,130	$71
Carrier	$1,572	$131	$1,320	$120	$1,261	$115	$1,678	$153
Submarine	$767	$11	$3,605	$53	$3,363	$49	$3,632	$52
Surface warfare	$4,616	$34	$4,427	$37	$4,863	$40	$5,884	$48
Total [a]	$10,317	$40	$11,330	$48	$11,842	$50	$13,325	$56

[a] The total corrosion-related cost by ship category in Table 3-5 will not equal the total corrosion-related cost from Table 3-2 because not all corrosion-related costs can be attributed to a ship category, as in the case of RDT&E and purchase card expenditures.

Except for amphibious ships, maintenance costs per ship for each ship type were higher in FY2010 than FY2004.

CORROSION-RELATED COSTS BY WBS

Corrosion-related cost data is also viewable by expanded ships work breakdown (ESWBS) structure or ships work list item number (SWLIN). Navy submarines and surface ships each have a different coding for their WBS. In Table 3-6, we rank the top 20 corrosion-related costs for Navy submarines in FY2010 by SWLIN.

Table 3-6. Navy Submarines Corrosion-Related Cost Ranking by SWLIN (FY2010)

Rank	SWLIN	SWLIN description	Corrosion-related cost ($ in millions)	Maintenance cost ($ in millions)	Percentage of maintenance related to corrosion
1	631	Painting	$67	$176	38%
2	123	Trunks and enclosures	$49	$78	62%
3	100	Hull structure	$39	$77	50%
4	531	Desalination plant	$32	$94	34%
5	865	Production services and support	$25	$103	25%
6	560	Ship control systems	$21	$76	27%
7	112	Shell plating, non-pressure hull	$20	$41	50%
8	561	Steering and diving control	$17	$70	24%
9	156	Ballast	$17	$37	46%
10	515	Main oxygen system	$16	$91	18%
11	248	Hull structural survey	$15	$27	55%
12	414	Sonar systems and subsystems	$14	$64	22%
13	714	Launching devices	$14	$53	27%
14	860	Support services	$13	$81	16%
15	041	Quality assurance	$12	$54	22%
16	203	Shafting, bearings and propellers	$10	$43	24%
17	514	Air condition system	$9	$39	24%
18	552	Compressed gas system, nitrogen	$9	$33	27%
19	904	General support services	$9	$42	21%
20	750	Torpedoes	$8	$39	21%

Note: Percentages are not exact due to rounding.

A total of 224 SWLINs have associated corrosion-related costs. The total corrosion-related cost for Navy submarines (excluding ONR costs) is $739 million. The top 15 SWLINs from Table 3-6 account for $369 million in corrosion-related costs, which is 50 percent of the total corrosion-related cost for submarines that can be accounted for by a SWLIN. The top 15 SWLINs represent only 6.7 percent of the number of SWLINs with corrosion-related costs. This highlights a fairly significant localization of the corrosion-related costs for submarines.

Painting (SWLIN 631) has the highest corrosion-related cost. This may be somewhat underestimated, however, because of the Navy's work breakdown structure schema. Because a verb such as painting is included in the same schema with objects such as hull, it forces the maintenance technicians to choose between one code or the other when performing a task that contains both a verb and object in the schema. For example, when a hull is painted, the task could be noted using either SWLIN code 631 or SWLIN code 100. Therefore, the costs associated with painting are most likely higher than those noted in Table 3-6.

In terms of Navy surface ships, Table 3-7 depicts the top 20 corrosion-related costs ranked by ESWBS.

Table 3-7. Navy Surface Ships Ranked by ESWBS Corrosion-Related Cost (FY2010)

Rank	ESWBS	ESWBS description	Corrosion-related cost ($ in millions)	Maintenance cost ($ in millions)	Percentage of maintenance related to corrosion
1	123	Trunks and enclosures	$91	$206	44%
2	631	Painting	$53	$68	78%
3	311	Ship service power generation	$51	$338	15%
4	549	Compressed air systems	$38	$203	18%
5	593	Environmental control sewage and trash	$36	$155	24%
6	521	Fire main and flushing (sea water) system	$35	$124	28%
7	451	Radar system and components	$32	$361	9%
8	251	Combustion air system	$29	$147	20%
9	533	Potable water	$27	$120	23%
10	512	Ventilation system	$26	$152	17%
11	634	Deck covering	$25	$79	32%
12	587	Aircraft launch and launch support systems	$24	$77	32%
13	651	Commissary spaces	$23	$154	15%
14	531	Distilling plant	$23	$102	22%
15	245	Propellers and propulsions	$22	$128	17%
16	514	Air conditioning plant	$22	$137	16%
17	231	Propulsion steam turbines	$22	$53	41%
18	555	Fire extinguishing systems	$22	$77	28%
19	256	Circulating and cooling sea water system	$21	$66	32%
20	330	Lighting system and fixtures	$20	$164	12%

Note: Percentages are not exact due to rounding.

A total of 340 ESWBS codes have associated corrosion-related maintenance costs. The total corrosion-related cost (excluding ONR costs) for Navy surface ships is $1.79 billion. Half of the total corrosion-related cost of surface ships is accounted for by 35 ESWBS codes. This is also 10.3 percent of the total number of ESWBS codes that identify a corrosion-related cost for surface ships, which is not as significant a localization of corrosion-related costs as we found for submarines.

ESWBS codes 123 (trunks and enclosures) and 631 (painting) are the two ESWBS codes tracking the highest corrosion-related costs. These are the same two areas with the highest corrosion-related cost for submarines as well. The corrosion-related costs for ESWBS 631 are most likely underestimated for the same reasons we highlighted above—the work breakdown structure schema includes both verbs and objects.

CORROSION-RELATED COSTS—CORRECTIVE VERSUS PREVENTIVE

Another way to view the corrosion-related cost data is to segregate it into corrective versus preventive costs.[1] Table 3-8 depicts the breakout of corrosion-related costs of Navy ships into these two categories.

Table 3-8. Corrosion-Related Corrective and Preventive Costs for Navy Ships (FY2010)

	Category of corrosion-related cost	Corrosion-related cost ($ in millions)	Percentage of total cost
Depot-level maintenance	Corrective	$389	25.6%
	Preventive	$1,103	72.7%
	None[a]	$26	1.7%
	Total	$1,518	100.0%
Field-level maintenance	Corrective	$575	56.7%
	Preventive	$427	42.1%
	None	$12	1.2%
	Total	$1,014	100.0%
Total maintenance	Corrective	$964	38.1%
	Preventive	$1,530	60.4%
	None	$38	1.5%
	Total	$2,532	100.0%

[a] The category labeled None reflects costs that cannot be classified into corrective or preventive costs. Examples include dry-docking and field-level contract maintenance.

We can see from Table 3-8 that Navy ships incur a greater percentage of corrosion-related preventive costs than corrosion-related corrective costs for DM but that the situation is reversed for FLM. In total, corrosion-related preventive costs exceed corrosion-related corrective costs by nearly $600 million. This complements the data of Table 3-4 and Table 3-5, which list painting and trunks and enclosures as the highest corrosion-related cost drivers by SWLIN or ESWBS. Painting is a corrosion-related preventive measure. The majority of the work performed on trunks and enclosures is also deemed preventive (e.g., inspections, treatment, coatings). The data in Table 3-9 might suggest an opportunity to reduce the amount of preventive activity undertaken along with their associated costs.

Table 3-9 depicts the ratio of preventive to corrective costs. Corrosion-related preventive costs exceed corrosion-related preventive costs by more than 50 percent.

[1] We provide definitions of corrective and preventive costs in Chapter 1.

Table 3-9. Corrosion-Related Preventive-to-Corrective Cost Ratio for Navy Ships (FY2010)

	Ratio of preventive to corrective cost
Depot maintenance	2.84 to 1
Field-level maintenance	0.74 to 1
Total maintenance	1.59 to 1

The optimum ratio of corrosion-related preventive-to-corrective costs for Navy ships has not been determined, but for general maintenance, evidence suggests a ratio close to 1:1 minimizes total maintenance costs.[2] Given this hypothesis, there would appear to be an opportunity to decrease corrosion-related preventive costs without adversely affecting the corrosion-related corrective costs.

If we display corrosion-related corrective and preventive cost expenditures from the first study to the most recent studies, we see an interesting trend. as illustrated in Table 3-10. Total corrosion-related preventive maintenance expenditure for FY2010 ($1.530 billion) increased by approximately $370 million from FY2004 ($1.162 billion). During this same period, the total corrosion-related corrective costs remained about the same.

Table 3-10. Corrosion-Related Corrective and Preventive Cost for Navy Ships for Each Study Year

	Category	Corrosion-related cost ($ in millions)			
		FY2004	FY2008	FY2009	FY2010
DM	Corrective	$567	$348	$446	$389
	Preventive	$600	$952	$1,044	$1,103
	Total	$1,167	$1,300	$1,490	$1,492
FLM	Corrective	$440	$517	$512	$575
	Preventive	$562	$327	$333	$427
	Total	$1,002	$844	$845	$1,002
Total maintenance	Corrective	$1,007	$865	$958	$964
	Preventive	$1,162	$1,279	$1,377	$1,530
	Total	$2,169	$2,144	$2,335	$2,494

Of most interest is the pattern of corrosion-related costs for DM. Corrosion-related preventive costs have nearly doubled since FY2004, increasing by approximately $500 million. With that level of increase in preventive expenditures, we would expect to see a significant drop in corrective costs. Corrective costs incurred during the performance of DM have decreased by more than 30 percent during the time period from FY2004 to FY2010, but the increased preventive expenditure of $500 million far outweighs the decrease in corrective measures of $178 million (i.e., $567 million minus $389 million).

[2] Machinery Management Solutions Inc., *Five Steps to Optimizing Your Preventive Maintenance System*, Jim Taylor, available at www.reliabilityweb.com/art06/5_steps_optimized_pm.htm.

There appears to be an opportunity for the Navy to examine whether the amount of corrosion-related preventive measures it takes during the performance of DM is adequate or excessive. It may be possible to decrease some of these corrosion-related preventive costs without increasing the corrosion-related corrective costs.

CORROSION-RELATED COST COMPARISON—FY2004 AND FY2010

In 2004, the Navy ships corrosion-related cost estimate was $2.49 billion. In FY2010, it was $3.15 billion—an increase from FY2004 of $654 million, or 26.5 percent.[3]

Two significant factors account for the $654 million increase between the two studies.

- *Increase in labor rates* ($577 million in corrosion-related cost)—The rise in labor rates from an average of $40.94/hour in FY2004 to an average of $51.39/hour in FY2010 resulted in a 25.5 percent increase in labor costs. When we examine the labor hours associated only with corrosion-related work for Navy ships from FY2004 and FY2010, we see 55.3 million corrosion-related labor hours incurred in FY2004 and 56.8 million corrosion-related labor hours incurred during FY2010.[4] The increase in the labor rate applied to the number of hours dedicated to corrosion-related work in FY2004 accounts for an increase of $577 million in corrosion-related cost.

- *Increase in the amount of corrosion-related labor hours incurred* ($61 million in corrosion-related cost)—As stated in the previous bullet, the number of labor hours expended during the performance of corrosion-related maintenance increased from 55.3 million corrosion-related labor hours in FY2004 to 56.8 million labor hours in FY2010. This increase accounts for $61 million in additional corrosion-related costs in FY2010.

The improvement in corrosion-related cost as a percentage of maintenance cost between the FY2004 and FY2010 studies prevented the corrosion-related cost in FY2010 from rising even higher. We show these percentages in Table 3-1. In FY2004, the corrosion-related cost as a percentage of maintenance costs was 21.1 percent; for the FY2010 study, it was 19.0 percent. Without this improvement in the corrosion-related percentage, the corrosion-related costs for the FY2010 study would have been $280 million higher. We summarize this analysis in Table 3-11.

[3] These totals include ONR costs.

[4] We took the sum of the actual labor hours within each maintenance record for each fiscal year.

Table 3-11. Cost Comparison—Differences Between the FY2004 and FY2010 Corrosion-Related Cost Studies for Navy Ships

Study	FY2004 study	FY2010 study	Change	Difference
Labor rates	$40.94 per hour	$51.39 per hour	$10.45 per hour	+$577 million[a]
Corrosion-related labor hours	55.3 million	56.8 million	1.5 million	+$61 million[b]
Corrosion-related cost as a percentage of maintenance cost	21.1 percent	19.0 percent	2.1 percent	–$280 million[c]

[a] Applied to an FY2004 base of 55.3 million hours worked on corrosion-related maintenance.
[b] Applied to an FY2004 average labor rate of $40.94 per hour.
[c] Applied to an FY2010 maintenance cost of $13.325 billion.

EFFECT OF CORROSION ON AVAILABILITY

As noted earlier, the Navy does not report the availability or readiness of its ships in the same manner as the other services. In fact, except in very few instances, the only time a Navy ship is not ready to set sail is when it is in dry-dock status or other significant DM event.[5]

We estimated the effects of corrosion on this non-available time by assessing the work performed while each ship was in dry-dock status. Using the flagged corrosion-related records from our cost analysis, we can determine what portion of the maintenance performed on each ship while it was in dry-dock status was related to corrosion. We show these results in Table 3-12.

From Table 3-12, we can see that Navy carriers have the highest corrosion-related percentage of dry-dock work by a large margin. Amphibious ships and submarines have the next highest. Carriers and submarines have the highest average number of corrosion-related non-available days**.** For carriers, the high number of non-availability days is related to the high percentage of corrosion-related work; for submarines, the length of the dry-dock period, which often exceeds 1 year, drives this non-availability. This extended maintenance period, coupled with the average corrosion-related percentage, results in higher-than-average corrosion-related days per non-availability period.

[5] In other words, performance of FLM only rarely contributes to the loss of availability for Navy ships.

Table 3-12. Percentage of Corrosion-Related Work Performed on Navy Ships during Dry-Dock

No. of occurrences of DM	Maintenance action FY	Total cost during DM period (in millions)	Total corrosion-related cost during DM periods (in millions)	Percentage of maintenance cost related to corrosion	Duration of maintenance period (in days)	Corrosion-related non-available days	Average of corrosion-related non-available days[a]
Amphibious							
10	FY2008	$78	$15	19%	997	186	18.6
16	FY2009	$3011	$75	25%	2,777	691	43.2
3	FY2010	$83	$20	24%	470	114	38.1
Carriers							
13	FY2008	$422	$139	33%	1,803	593	45.6
9	FY2009	$222	$96	43%	1,147	498	55.3
13	FY2010	$564	$221	39%	2,368	926	71.2
Surface Warfare							
42	FY2008	$382	$48	12%	3,879	484	11.5
51	FY2009	$356	$61	17%	5,028	861	16.9
26	FY2010	$227	$38	17%	2,542	423	16.3
Submarines							
7	FY2008	$337	$77	23%	2,689	618	88.3
15	FY2009	$1,812	$458	25%	6,849	1,732	115.4
9	FY2010	$958	$163	17%	2,694	458	50.9
Total							
214		**$5,742**	**$1,411**	25%	**33,243**	**8,166**	**38.2**

[a] We calculate this number by taking the sum of the corrosion-related days and dividing it by the number of DM occurrences.

This estimate of Navy ships non-availability attributable to corrosion is just that—an estimate. It does not necessarily signify that reducing corrosion-related work performed during the dry-dock period will result in shortened maintenance intervals. A ship's commander, for instance, may choose to accomplish more maintenance during the same time period or choose to extend the time between dry-dock periods.

This analysis provides additional insight on the effect of corrosion on DM periods for Navy ships, the composition of DM work, and the length of time Navy ships are non-available. It is the first assessment to consider the effect corrosion has on Navy ship availability.

Appendix A
Ships Included in the Study

Table A-1 lists the 237 ships for which costs were accumulated in this study. The table lists the ships by category (i.e., aircraft carriers, amphibious warfare, surface warfare, and submarines), class, hull number, and name.

Table A-1. List of Ships

Class	Hull number	Name
Aircraft carriers		
CVN 65	CVN 65	ENTERPRISE
CVN 68	CVN 67	GEORGE H W BUSH
CVN 68	CVN 68	NIMITZ
CVN 68	CVN 69	DWIGHT D. EISENHOWER
CVN 68	CVN 70	CARL VINSON
CVN 68	CVN 71	THEODORE ROOSEVELT
CVN 68	CVN 72	ABRAHAM LINCOLN
CVN 68	CVN 73	GEORGE WASHINGTON
CVN 68	CVN 74	JOHN C. STENNIS
CVN 68	CVN 75	HARRY S. TRUMAN
CVN 68	CVN 76	RONALD REAGAN
Amphibious warfare		
LCC 19	LCC 19	BLUE RIDGE
LCC 19	LCC 20	MOUNT WHITNEY
LCS	LCS 1	FREEDOM
LCS	LCS 2	INDEPENDENCE
LHA 1	LHA 5	PELELIU
LHD 1	LHD 1	WASP
LHD 1	LHD 2	ESSEX
LHD 1	LHD 3	KEARSARGE
LHD 1	LHD 4	BOXER
LHD 1	LHD 5	BATAAN
LHD 1	LHD 6	BONHOMME RICHARD
LHD 1	LHD 7	IWO JIMA
LHD 1	LHD 8	MAKIN ISLAND
LPD 17	LPD 17	SAN ANTONIO
LPD 17	LPD 18	NEW ORLEANS
LPD 4	LPD 5	OGDEN

Table A-1. List of Ships

Class	Hull number	Name
LPD 4	LPD 7	CLEVELAND
LPD 4	LPD 8	DUBUQUE
LPD 4	LPD 9	DENVER
LPD 4	LPD 10	JUNEAU
LPD 4	LPD 12	SHREVEPORT
LPD 4	LPD 13	NASHVILLE
LPD 4	LPD 15	PONCE
LSD 41	LSD 41	WHIDBEY ISLAND
LSD 41	LSD 42	GERMANTOWN
LSD 41	LSD 43	FORT MCHENRY
LSD 41	LSD 44	GUNSTON HALL
LSD 41	LSD 45	COMSTOCK
LSD 41	LSD 46	TORTUGA
LSD 41	LSD 47	RUSHMORE
LSD 41	LSD 48	ASHLAND
LSD 49	LSD 49	HARPERS FERRY
LSD 49	LSD 50	CARTER HALL
LSD 49	LSD 51	OAK HILL
LSD 49	LSD 52	PEARL HARBOR
Surface warfare		
AS 39	AS 39	EMORY S LAND
AS 39	AS 40	FRANK CABLE
CG 47	CG 52	BUNKER HILL
CG 47	CG 53	MOBILE BAY
CG 47	CG 54	ANTIETAM
CG 47	CG 55	LEYTE GULF
CG 47	CG 56	SAN JACINTO
CG 47	CG 57	LAKE CHAMPLAIN
CG 47	CG 58	PHILIPPINE SEA
CG 47	CG 59	PRINCETON
CG 47	CG 60	NORMANDY
CG 47	CG 61	MONTEREY
CG 47	CG 62	CHANCELLORSVILLE
CG 47	CG 63	COWPENS
CG 47	CG 64	GETTYSBURG
CG 47	CG 65	CHOSIN
CG 47	CG 66	HUE CITY
CG 47	CG 67	SHILOH

Table A-1. List of Ships

Class	Hull number	Name
CG 47	CG 68	ANZIO
CG 47	CG 69	VICKSBURG
CG 47	CG 70	LAKE ERIE
CG 47	CG 71	CAPE ST GEORGE
CG 47	CG 72	VELLA GULF
CG 47	CG 73	PORT ROYAL
DDG 51	DDG 51	ARLEIGH BURKE
DDG 51	DDG 52	BARRY
DDG 51	DDG 53	JOHN PAUL JONES
DDG 51	DDG 54	CURTIS WILBUR
DDG 51	DDG 55	STOUT
DDG 51	DDG 56	JOHN S MCCAIN
DDG 51	DDG 57	MITSCHER
DDG 51	DDG 58	LABOON
DDG 51	DDG 59	RUSSELL
DDG 51	DDG 60	PAUL HAMILTON
DDG 51	DDG 61	RAMAGE
DDG 51	DDG 62	FITZGERALD
DDG 51	DDG 63	STETHEM
DDG 51	DDG 64	CARNEY
DDG 51	DDG 65	BENFOLD
DDG 51	DDG 66	GONZALEZ
DDG 51	DDG 67	COLE
DDG 51	DDG 68	THE SULLIVANS
DDG 51	DDG 69	MILIUS
DDG 51	DDG 70	HOPPER
DDG 51	DDG 71	ROSS
DDG 51	DDG 72	MAHAN
DDG 51	DDG 73	DECATUR
DDG 51	DDG 74	MCFAUL
DDG 51	DDG 75	DONALD COOK
DDG 51	DDG 76	HIGGINS
DDG 51	DDG 77	O'KANE
DDG 51	DDG 78	PORTER
DDG 51	DDG 79	OSCAR AUSTIN
DDG 51	DDG 80	ROOSEVELT
DDG 51	DDG 81	WINSTON S CHURCHILL
DDG 51	DDG 82	LASSEN

Table A-1. List of Ships

Class	Hull number	Name
DDG 51	DDG 83	HOWARD
DDG 51	DDG 84	BULKELEY
DDG 51	DDG 85	MCCAMPBELL
DDG 51	DDG 86	SHOUP
DDG 51	DDG 87	MASON
DDG 51	DDG 88	PREBLE
DDG 51	DDG 89	MUSTIN
DDG 51	DDG 90	CHAFEE
DDG 51	DDG 91	PINCKNEY
DDG 51	DDG 92	MOMSEN
DDG 51	DDG 93	CHUNG-HOON
DDG 51	DDG 94	NITZE
DDG 51	DDG 95	JAMES E WILLIAMS
DDG 51	DDG 96	BAINBRIDGE
DDG 51	DDG 97	HALSEY
DDG 51	DDG 98	FORREST SHERMAN
DDG 51	DDG 99	FARRAGUT
DDG 51	DDG 100	KIDD
DDG 51	DDG 101	GRIDLEY
DDG 51	DDG 102	SAMPSON
DDG 51	DDG 103	TRUXTUN
DDG 51	DDG 104	STERETT
DDG 51	DDG 105	DEWEY
DDG 51	DDG 106	STOCKDALE
DDG 51	DDG 108	WAYNE E MEYER
FFG 7	FFG 32	JOHN L HALL
FFG 7	FFG 36	UNDERWOOD
FFG 7	FFG 40	HALYBURTON
FFG 7	FFG 43	THACH
FFG 7	FFG 45	DE WERT
FFG 7	FFG 46	RENTZ
FFG 7	FFG 47	NICHOLAS
FFG 7	FFG 48	VANDEGRIFT
FFG 7	FFG 49	ROBERT G BRADLEY
FFG 7	FFG 50	TAYLOR
FFG 7	FFG 51	GARY
FFG 7	FFG 52	CARR
FFG 7	FFG 54	FORD

Table A-1. List of Ships

Class	Hull number	Name
FFG 7	FFG 55	ELROD
FFG 7	FFG 57	REUBEN JAMES
FFG 7	FFG 58	SAMUEL B ROBERTS
FFG 7	FFG 59	KAUFFMAN
FFG 7	FFG 61	INGRAHAM
MCM 1	MCM 1	AVENGER
MCM 1	MCM 2	DEFENDER
MCM 1	MCM 3	SENTRY
MCM 1	MCM 4	CHAMPION
MCM 1	MCM 5	GUARDIAN
MCM 1	MCM 6	DEVASTATOR
MCM 1	MCM 7	PATRIOT
MCM 1	MCM 8	SCOUT
MCM 1	MCM 9	PIONEER
MCM 1	MCM 10	WARRIOR
MCM 1	MCM 11	GLADIATOR
MCM 1	MCM 12	ARDENT
MCM 1	MCM 13	DEXTROUS
MCM 1	MCM 14	CHIEF
PC 1	PC 2	TEMPEST
PC 1	PC 3	HURRICANE
PC 1	PC 4	MONSOON
PC 1	PC 5	TYPHOON
PC 1	PC 6	SIROCCO
PC 1	PC 7	SQUALL
PC 1	PC 9	CHINOOK
PC 1	PC 10	FIREBOLT
PC 1	PC 11	WHIRLWIND
PC 1	PC 12	THUNDERBOLT
Submarines		
SSBN 726	SSBN 730	HENRY M JACKSON
SSBN 726	SSBN 731	ALABAMA
SSBN 726	SSBN 732	ALASKA
SSBN 726	SSBN 733	NEVADA
SSBN 726	SSBN 734	TENNESSEE
SSBN 726	SSBN 735	PENNSYLVANIA
SSBN 726	SSBN 736	WEST VIRGINIA
SSBN 726	SSBN 737	KENTUCKY

Table A-1. List of Ships

Class	Hull number	Name
SSBN 726	SSBN 738	MARYLAND
SSBN 726	SSBN 739	NEBRASKA
SSBN 726	SSBN 740	RHODE ISLAND
SSBN 726	SSBN 741	MAINE
SSBN 726	SSBN 742	WYOMING
SSBN 726	SSBN 743	LOUISIANA
SSGN 726	SSGN 726	OHIO
SSGN 726	SSGN 727	MICHIGAN
SSGN 726	SSGN 728	FLORIDA
SSGN 726	SSGN 729	GEORGIA
SSN 21	SSN 21	SEAWOLF
SSN 21	SSN 22	CONNECTICUT
SSN 21	SSN 23	JIMMY CARTER
SSN 688	SSN 698	BREMERTON
SSN 688	SSN 699	JACKSONVILLE
SSN 688	SSN 700	DALLAS
SSN 688	SSN 701	LA JOLLA
SSN 688	SSN 705	CITY OF CORPUS CHRISTI
SSN 688	SSN 706	ALBUQUERQUE
SSN 688	SSN 711	SAN FRANCISCO
SSN 688	SSN 713	HOUSTON
SSN 688	SSN 714	NORFOLK
SSN 688	SSN 715	BUFFALO
SSN 688	SSN 717	OLYMPIA
SSN 688	SSN 719	PROVIDENCE
SSN 688	SSN 720	PITTSBURGH
SSN 688	SSN 721	CHICAGO
SSN 688	SSN 722	KEY WEST
SSN 688	SSN 723	OKLAHOMA CITY
SSN 688	SSN 724	LOUISVILLE
SSN 688	SSN 725	HELENA
SSN 688	SSN 750	NEWPORT NEWS
SSN 688	SSN 751	SAN JUAN
SSN 688	SSN 752	PASADENA
SSN 688	SSN 753	ALBANY
SSN 688	SSN 754	TOPEKA
SSN 688	SSN 755	MIAMI
SSN 688	SSN 756	SCRANTON

Table A-1. List of Ships

Class	Hull number	Name
SSN 688	SSN 757	ALEXANDRIA
SSN 688	SSN 758	ASHEVILLE
SSN 688	SSN 759	JEFFERSON CITY
SSN 688	SSN 760	ANNAPOLIS
SSN 688	SSN 761	SPRINGFIELD
SSN 688	SSN 762	COLUMBUS
SSN 688	SSN 763	SANTA FE
SSN 688	SSN 764	BOISE
SSN 688	SSN 765	MONTPELIER
SSN 688	SSN 766	CHARLOTTE
SSN 688	SSN 767	HAMPTON
SSN 688	SSN 768	HARTFORD
SSN 688	SSN 769	TOLEDO
SSN 688	SSN 770	TUCSON
SSN 688	SSN 771	COLUMBIA
SSN 688	SSN 772	GREENEVILLE
SSN 688	SSN 773	CHEYENNE
SSN 774	SSN 774	VIRGINIA
SSN 774	SSN 775	TEXAS
SSN 774	SSN 776	HAWAII
SSN 774	SSN 777	NORTH CAROLINA
SSN 774	SSN 778	NEW HAMPSHIRE
SSN 774	SSN 779	NEW MEXICO
SSN 774	SSN 780	MISSOURI

Appendix B
Corrosion-Related Cost Data Sources for Navy Ships by Node

The following is the list of data sources by node LMI used to determine the annual cost of corrosion for Navy ships.

COST OF CORROSION FOR ORGANIC DEPOT MAINTENANCE

Nodes A1 (corrosion-related costs for organic depot maintenance [DM] labor) and B1 (corrosion-related costs for organic DM materials and services):

- *Distribution of DoD Depot Maintenance Workloads: Fiscal Years 2010 through 2012* (also known as the 50-50 Report)
- Depot Maintenance Cost, called the "1307" report
- Shipyard Management Information System (SYMIS)
- Advanced Industrial Management (AIM)
- Depot Maintenance Cost System (DMCS)
- Defense Manpower Data Center (DMDC) information
- Dry-dock costs spreadsheet.

COST OF CORROSION FOR COMMERCIAL DEPOT MAINTENANCE

Nodes A2 (corrosion-related costs for commercial DM labor) and B2 (corrosion-related costs for commercial DM materials and services):

- 50-50 Report
- DMDC information
- Navy Maintenance Database (NMD)
- Maintenance Requirements System (MRS)
- Dry-dock costs spreadsheet.

Cost of Corrosion for Field-Level Maintenance

Nodes C (corrosion-related costs of field-level maintenance [FLM] labor) and D (corrosion-related costs of FLM materials and services):

- DMDC information
- Navy Maintenance and Material Management Open Architectural Retrieval System (3M/OARS)
- Operations and Maintenance, Navy Data Book, February 2011
- "Haystack" stocked parts and materials purchase system.

Cost of Corrosion Outside Normal Maintenance Reporting

Node E (corrosion-related costs of non-maintenance shipboard labor):

- DMDC information
- Survey information administered on Navy Knowledge Online (NKO) website.

Node F (corrosion-related costs for research, development, test, and evaluation [RDT&E] and facilities):

- Navy budget documents
- Discussions with Navy Corrosion Prevention and Control Integrated Product Team (CPC IPT) representatives.

Node G (corrosion-related costs for purchase cards):

- Navy credit card purchase records.

Appendix C
Corrosion-Related Search Method

We analyzed potential corrosion-related words with subject matter experts from the carrier, surface ships, and submarine maintenance communities. Using their input, we developed search algorithms related to corrosion and specific to each ship type. The algorithms contain both the corrosion-related keywords to search for within each maintenance record by ship type as well as the percentage of corrosion-related costs that would be applied to a record flagged because it contained a keyword.

In Figure C-1, we show how we used the problem description of each maintenance record to highlight job orders that involved corrosion. The words highlighted in red are corrosion-related keywords.

Figure C-1. Search Method Using Problem Descriptions to Flag Corrosion-Related Work

FY	Job control number	Problem description	Hull number	Labor cost	Corrosion percentage	Corrosion labor cost
10	21533EM022580	No.1 And No.2 Demineralizers Need Piping Modification To Comform To Ship Alt (Lhd1-468D). Dfs Lhd2-01-02 Is In Effect To Allow Continued Operation Of Fwd And Aft Boilers Until Demin Mods Can Be Completed.	LHD 2	$1,466.60		
10	21833CG030847	Mt 251 Has Extensive **Corrosion** To Fasteners And Fittings Do To Extended Time On Station And Conditions.	DDG 66	$1,099.95	100	$1,099.95
10	21833CG030847	Mt 251 Has Extensive **Corrosion** To Fasteners And Fittings Do To Extended Time On Station And Conditions.	DDG 66	$1,099.95	100	$1,099.95
10	21624ER040455	Ship Does Not Have A 300 Lb Scale, A 300 Lb Scale Is Needed To Complete Ships Pms.	CG 64	$366.65		
10	22202EA02A848	During Diesel **Inspection**, Dei Inspector Recommended That All 16 Fuel Injection Nozzles For Alco 251C Ship'S Service Emergency Diesel Be Removed, Disassembled, Cleaned, Reassembled And Nozzle Testing Performed..	LHD 6	$549.98	20	$110.00
10	21201CA030023	The Mk 1 Mod 1 Breech Mechanisms For The Mk 32 Svtt Are In Need Of Hydrostatic Testing.	FFG 49	$2,933.21		
10	21820CF040915	Mt 21Flow Switches. While Conducting Mrc 7112/R02 M-20, Ship'S Force Found 2 Faulty Flow Switches.	DDG 58	$6,416.39		
10	21388CF042949	Duringthe Performance Of Mrc M-20 Mip 7112, For Ciws Mt 21, A Faulty 3A4A9S1 Flow Switch Was Discovered.	CG 55	$916.63		
10	07184EM016100	Nr1 Lube Oil Purifier Has Numerous Small Lube Oil **Leaks** And Has Low Discharge Capacity.	LPD 10	$2,400.45	50	$1,200.23

We then applied the specified percentage to the labor cost for each record flagged for corrosion, as illustrated in Figure C-1, to determine the corrosion-related labor cost.

The corrosion-related search algorithm was reviewed by Navy ships subject experts in the fall of 2011. Different algorithms were created based on ship type. Table C-1 shows the general structure of the search algorithm.

Table C-1. Corrosion-Related Algorithm Steps by Ship Type

Step	Ship type	Record Set	Action
1a	All	All	Tag 'Modernization' Records
1b	All	All	Tag Cause code 8 as 100% corrosion
2a	Carriers	ESWBS 631XX	Tag CorroKeywords
2b	Carriers	ESWBS 1XXXX or ESWBS 63XXX	Tag CorroKeywords
2c	Carriers	All remaining carrier records	Tag CorroKeywords
3a	Surface Ships	ESWBS 123XX or ESWBS 631XX	Tag CorroKeywords
3b	Surface Ships	All remaining surface ship records	Tag CorroKeywords
4a	Submarines	Preservation	Tag CorroKeywords
4b	Submarines	Tanks	Tag CorroKeywords
4c	Submarines	Structural	Tag CorroKeywords
4d	Submarines	All remaining submarine records	Tag CorroKeywords

Although the corrosion-related words vary slightly by ship type, we include the following general list.

CORRECTIVE KEYWORDS

abatement
abradable
abrasive
acetone
acid
age harden
anti galling
beach mark
blast
bleach
blush
body work
breakdown potential
brittle fracture
caustic cracking
caustic dip
caustic embrittlement
cavitation
cold crack
contaminants
corro
crack
crateri
crawling
crazi
critical pitting potential
cure
deactivation
dealloy
decay
deioniz
denickelification
detergent
deterio
Dewett
dezincification
disbond
electrolysis

electrolytic cell
embrittl
environmental crack
erosion
exfoliate
exfoliation
filamentary
filiform
fish eye
flake
fogged metal
fouling
fracture
fretting
FSW
galling
gallionella ferruginea
grain drop
graphiti
green rot
GRIND
GRND
GTAW
hydraulic cement
hydrogen blister
hydrogen damage
hydroly
impinge
inclusion
induced cracking
intercrystalline
interdentric
intergranular
iron bacter
KISCC
knifeline attack
lamellar
leak
leakage
local cell
long-line current
LPPS
mechanical bond
metal dusting
metal polish
METAL WK
METAL WORK
microbial
mirobiological
moisture
molten salt
oxidat
oxide
oxygen attack
oxygen concentration cell
ozone
passivation
passive metal
passive-active cell
passivity
patina
peening
pickle
pickling
pitting
poultice
radiation damage
reactive metal
red water
reducing agent
reducing atmosphere
ringworm
rot
rust
saline water
salt
sand
scale
scaling
scrape
SHEET METAL
SHOTPEEN
sigma phase
sodium bicarbonate
sodium chloride
sohic

solder
solvent
spalling
specialty steel
spotting
stray current
stress
strip
substrate
sulfate-reducing bact
sulfidation
sulfide
surface active agent
surface preparation
surfacer
surfactant
threshold stress
tuberculation
tungsten arc
undercutting
underfilm
weld
wrinkling

PREVENTIVE KEYWORDS

acrylic
activated silica
aerosol
alclad
alkyd
alkyl benzene sulfonate
alloying
alodine
alodining
alternate-immersion
aluminiz
aluminum ion plat
Anneal
Anode
anodic
Anodiz
Anolyte
Arc wire spray
Autoclav
bainite
black oxide
booth
braz
CADMUIM
Calcareous
carbonitrid
carburiz
caseharden
CASS
cathode
cathodic
caulk
cementation coat
check
chemical conversion coat
chemical vapor deposition
chromium
CL/PREP/PT/FINAL EA
CL/PREP/PT/FINAL EACH
clad metal
cladd
clean
coat
copper accelerated salt spray
copper plat
corrodkote test
dehumidif
deposition
detonation gun
dielectric fitt
dielectric shield
diffusion coat
diluent
E&E

earth pigment
eggshell
ELECTRO PLATING
electrochemical cell
electrod
ELECTROLES
electroless nickel
electroplat
electropolish
electrostatic spray
emulsion paint
enamel
epoxy
eval
exempt solvent
extender
feedwater treat
FINAL TEST
FINISH
flame harden
flame spray
flowcoat
galfan
galv
gel zeolite
glazing
gloss
groundb
hardener
hardening
hardfac
hardness
haze
hiding power
high velocity oxy
hot crack
hot isostatic
huey test
humidity test
hydration
hydrostatic test
immunity
impregnat
impressed current
incubation period
induction harden
induction heat
inert anode
inhibit
inorganic zinc
INSP
insulation
intensiostatic
Ion
ion implant
ion nitrid
Ioniz
isopropyl
Lacquer
langelier ind
lanthanide
lapping
latex
lithopone
lubrica
luggin
magnetic particle exam
manganese greensand
manganese zeolite
MASK
matte
METAL SPRAY
metallizing
metallurgical bond
methylene blue active
micrograph
mineral spirit
MMA
Moneypenny-Strauss
mottle
MTL SPR
MTL SPRAY
MTL SPY SURF
naphtha
NDI
neutraliz

nirtrocarb
nitrid
nitrocarburizing
noble metal
noble potential
open-circuit potential
orange peel
overspray
PAINT
passivator
pearlite
penetrant exam
permanganate
permeability
phophatizing
phosphatizing
photo-thermal
physisorption
pigment
PLATING
polarization
polish
polymer
Polyphosphate
Polyurethane
polyvinyl chloride
porosity
post-weld
pot life
potentio
powder coat
prechlorinat
precious metal
PREP
PREP/BRUSH
PREP/CAD
PREP/PROCESS/PLATE
prepare
PRESERV
prime
priming
protect
protection potential
pull-out
QA
QC
QUALIF
QUALITY
quenching
rabbit ears
radiography
rapid charcoal
refractory
regenerant
regeneration
repaint
re-paint
resin
retarder
rosin
ROTTED
salinity
salt fog
seeds
semipermeable membrane
shrinkage
shroud
silica
siliceous
silicone
silking
SILVER
skinning
slow strain rate
soda ash
softening
specific conductance
splat
splat cooling
spray
spraying
sputtering
standard electrode potential
sulfonate
surfacing
T.I.

T/I
telegraphing
tempering
terne
test
thermocouple
thermography
thinner
tinplate
titanium dioxide
TITANIUM ET
topcoat
TOUCH UP
treat
tribo charging
U-bend specimen
ultrasonic
urethane
UV stabilizers
vapor deposit
varnish
WASH
wetting Agent
wrap around
X-ray
zinc

Appendix D
Summary of Survey Results for Navy Ships

We created a short multiple-choice survey to gather the information we needed to analyze the corrosion-related cost data for Navy ships. We deployed the survey to Navy personnel over the Internet on the Navy Knowledge Online (NKO) website and received 919 responses.

We used the information gleaned from this survey to calculate the following:

- The percentage of time spent on corrosion-related maintenance, to validate the average percentage of corrosion-related maintenance, which we calculated from maintenance data for both maintainers and non-maintainers.
- The percentage of corrosion-related maintenance time split between preventive and corrective, to validate the average split calculated from maintenance data.
- The percentage of work reported in the Navy's Maintenance and Material Management Open Architectural Retrieval System (3M/OARS), to estimate the completeness of maintenance and material management (3M) data for corrosion-related maintenance.

Table D-1 and Table D-2 summarize the survey responses from those Navy personnel with a maintenance specialty and those without a maintenance specialty.

Table D-1. Summary of Survey Responses from Navy Personnel with a Maintenance Specialty

Level of maintenance	Number of responses	Average maintenance hours per workday	Average corrosion-related maintenance hours per workday	Average ratio of corrective vs. preventive corrosion-related maintenance	Average percentage of maintenance reported in 3M
Aircraft carriers	62	5.2	3.4	50/50	45
Submarines	64	5.5	2.5	45/55	30
Amphibious	61	5.3	3.5	55/45	45
Surface warfare	237	5.4	3.2	65/35	40

Table D-2. Summary of Survey Responses from Navy Personnel without a Maintenance Specialty

Level of maintenance	Number of responses	Average maintenance hours per workday	Average corrosion-related maintenance hours per workday	Average ratio of corrective vs. preventive corrosion-related maintenance	Average percentage of maintenance reported in 3M
Aircraft carriers	81	3.5	2.0	55/45	35
Submarines	18	5.5	2.5	60/40	25
Amphibious	75	3.7	2.6	60/40	35
Surface warfare	165	3.8	2.8	60/40	30
Does not perform maintenance	156	0	0	N/A	

Corrosion-Related Maintenance

Vessel operators and maintainers differ in the amount of total maintenance they perform during an average workday. Those with a maintenance specialty spend about 1.5 hours more per day on maintenance than operators without a maintenance skill specialty. Operators without a maintenance skill specialty, however, spend a higher percentage of their maintenance hours working on corrosion than do maintainers.

Surprisingly, vessel operators and maintainers divide their corrosion-related maintenance time between preventive and corrective work in similar ways, with most of the work being corrective in nature. The most popular response for both groups is a 60 percent corrective and 40 percent preventive maintenance split.

3M Reporting

The respondents answered additional questions about how much maintenance and corrosion-related work is reported in 3M/OARS. Not surprisingly, those with a maintenance skill specialty reported a higher percentage of their maintenance and corrosion-related work into 3M/OARS than operators who perform similar work but do not have a maintenance skill specialty. Both groups reported a fairly low percentage of the total maintenance work into a maintenance reporting system. This means more than half of the organizational maintenance work is not being captured.

Appendix E
Non-Maintainer Staffing Level by Ship Category

Table E-1 shows the number of non-maintenance personnel and overall crew size for each ship in our study. We used this information to calculate the unrecorded corrosion-related labor cost of non-maintenance-specialty sailors working aboard Navy ships. Although we determined staffing levels separately by fiscal year, we show only FY2010 staffing levels.

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
Amphibious			
LCC 19	BLUE RIDGE	400	618
LCC 20	MOUNT WHITNEY	76	173
LCS 1	FREEDOM	—	—
LCS 2	INDEPENDENCE	—	—
LHA 5	PELELIU	463	984
LHD 1	WASP	476	1,025
LHD 2	ESSEX	485	1,043
LHD 3	KEARSARGE	469	983
LHD 4	BOXER	494	1,044
LHD 5	BATAAN	482	1,023
LHD 6	BONHOMME RICHARD	457	1,020
LHD 7	IWO JIMA	441	938
LHD 8	MAKIN ISLAND	509	1,026
LPD 7	CLEVELAND	192	364
LPD 9	DENVER	220	385
LPD 15	PONCE	193	347
LPD 17	SAN ANTONIO	209	343
LPD 18	NEW ORLEANS	189	331
LPD 19	MESA VERDE	208	356
LPD 20	GREEN BAY	213	344
LPD 21	NEW YORK	219	348
LSD 41	WHIDBEY ISLAND	202	306
LSD 42	GERMANTOWN	182	299
LSD 43	FORT MCHENRY	180	288
LSD 44	GUNSTON HALL	182	296

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
LSD 45	COMSTOCK	184	296
LSD 46	TORTUGA	186	309
LSD 47	RUSHMORE	186	290
LSD 48	ASHLAND	175	290
LSD 49	HARPERS FERRY	187	300
LSD 50	CARTER HALL	191	295
LSD 51	OAK HILL	189	294
LSD 52	PEARL HARBOR	201	310
Carriers			
CVN 65	ENTERPRISE	1,111	3,108
CVN 68	NIMITZ	977	2,723
CVN 69	DWIGHT D EISENHOWER	1,054	2,848
CVN 70	CARL VINSON	1,056	2,824
CVN 71	THEODORE ROOSEVELT	860	2,528
CVN 72	ABRAHAM LINCOLN	1,045	2,728
CVN 73	GEORGE WASHINGTON	1,164	3,001
CVN 74	JOHN C STENNIS	1,016	2,777
CVN 75	HARRY S TRUMAN	985	2,779
CVN 76	RONALD REAGAN	1,103	2,925
CVN 77	GEORGE H W BUSH	1,014	3,065
Submarines			
SSBN 730	HENRY M JACKSON	40	150
SSBN 731	ALABAMA	39	150
SSBN 732	ALASKA	39	153
SSBN 733	NEVADA	37	146
SSBN 734	TENNESSEE	23	108
SSBN 735	PENNSYLVANIA	19	102
SSBN 736	WEST VIRGINIA	31	145
SSBN 737	KENTUCKY	36	151
SSBN 738	MARYLAND	38	158
SSBN 739	NEBRASKA	40	157
SSBN 740	RHODE ISLAND	40	158
SSBN 741	MAINE	40	152
SSBN 742	WYOMING	38	161
SSBN 743	LOUISIANA	40	154
SSGN 726	OHIO	57	160
SSGN 727	MICHIGAN	59	170

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
SSGN 728	FLORIDA	57	163
SSGN 729	GEORGIA	61	166
SSN 21	SEAWOLF	38	154
SSN 22	CONNECTICUT	39	143
SSN 23	JIMMY CARTER	46	161
SSN 698	BREMERTON	45	145
SSN 699	JACKSONVILLE	39	131
SSN 700	DALLAS	33	137
SSN 701	LA JOLLA	35	138
SSN 705	CITY OF CORPUS CHRISTI	40	147
SSN 706	ALBUQUERQUE	41	132
SSN 711	SAN FRANCISCO	38	132
SSN 713	HOUSTON	39	148
SSN 714	NORFOLK	37	142
SSN 715	BUFFALO	38	143
SSN 717	OLYMPIA	35	132
SSN 719	PROVIDENCE	33	129
SSN 720	PITTSBURGH	34	143
SSN 721	CHICAGO	39	166
SSN 722	KEY WEST	37	163
SSN 723	OKLAHOMA CITY	40	152
SSN 724	LOUISVILLE	36	137
SSN 725	HELENA	39	154
SSN 750	NEWPORT NEWS	37	139
SSN 751	SAN JUAN	37	154
SSN 752	PASADENA	44	145
SSN 753	ALBANY	42	142
SSN 754	TOPEKA	35	143
SSN 755	MIAMI	40	141
SSN 756	SCRANTON	41	139
SSN 757	ALEXANDRIA	44	130
SSN 758	ASHEVILLE	43	145
SSN 759	JEFFERSON CITY	38	138
SSN 760	ANNAPOLIS	41	145
SSN 761	SPRINGFIELD	37	134
SSN 762	COLUMBUS	31	139

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
SSN 763	SANTA FE	34	136
SSN 764	BOISE	40	138
SSN 765	MONTPELIER	39	142
SSN 766	CHARLOTTE	38	137
SSN 767	HAMPTON	38	135
SSN 768	HARTFORD	37	137
SSN 769	TOLEDO	40	132
SSN 770	TUCSON	37	141
SSN 771	COLUMBIA	35	148
SSN 772	GREENEVILLE	37	141
SSN 773	CHEYENNE	38	150
SSN 774	VIRGINIA	46	156
SSN 775	TEXAS	44	132
SSN 776	HAWAII	51	128
SSN 777	NORTH CAROLINA	51	114
SSN 778	NEW HAMPSHIRE	55	140
SSN 779	NEW MEXICO	50	127
SSN 780	MISSOURI	49	126
Surface Warfare			
AS 39	EMORY S LAND	103	130
AS 40	FRANK CABLE	161	199
CG 52	BUNKER HILL	181	319
CG 53	MOBILE BAY	181	315
CG 54	ANTIETAM	181	317
CG 55	LEYTE GULF	170	303
CG 56	SAN JACINTO	178	312
CG 57	LAKE CHAMPLAIN	183	322
CG 58	PHILIPPINE SEA	186	325
CG 59	PRINCETON	183	310
CG 60	NORMANDY	173	317
CG 61	MONTEREY	180	301
CG 62	CHANCELLORSVILLE	176	308
CG 63	COWPENS	179	322
CG 64	GETTYSBURG	181	319
CG 65	CHOSIN	185	333
CG 66	HUE CITY	178	314

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
CG 67	SHILOH	178	321
CG 68	ANZIO	177	314
CG 69	VICKSBURG	175	337
CG 70	LAKE ERIE	176	326
CG 71	CAPE ST GEORGE	177	304
CG 72	VELLA GULF	164	316
CG 73	PORT ROYAL	176	311
DDG 51	ARLEIGH BURKE	160	277
DDG 52	BARRY	151	267
DDG 53	JOHN PAUL JONES	146	274
DDG 54	CURTIS WILBUR	141	268
DDG 55	STOUT	144	256
DDG 56	JOHN S MCCAIN	145	274
DDG 57	MITSCHER	139	252
DDG 58	LABOON	142	255
DDG 59	RUSSELL	159	282
DDG 60	PAUL HAMILTON	144	260
DDG 61	RAMAGE	144	272
DDG 62	FITZGERALD	145	267
DDG 63	STETHEM	145	260
DDG 64	CARNEY	153	291
DDG 65	BENFOLD	153	278
DDG 66	GONZALEZ	143	262
DDG 67	COLE	145	271
DDG 68	THE SULLIVANS	160	287
DDG 69	MILIUS	147	281
DDG 70	HOPPER	149	275
DDG 71	ROSS	147	257
DDG 72	MAHAN	146	263
DDG 73	DECATUR	153	276
DDG 74	MCFAUL	163	296
DDG 75	DONALD COOK	155	284
DDG 76	HIGGINS	164	289
DDG 77	O'KANE	145	274
DDG 78	PORTER	150	278
DDG 79	OSCAR AUSTIN	162	269

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
DDG 80	ROOSEVELT	171	278
DDG 81	WINSTON S CHURCHILL	166	263
DDG 82	LASSEN	154	260
DDG 83	HOWARD	169	273
DDG 84	BULKELEY	173	284
DDG 85	MCCAMPBELL	150	260
DDG 86	SHOUP	165	265
DDG 87	MASON	158	258
DDG 88	PREBLE	170	273
DDG 89	MUSTIN	166	277
DDG 90	CHAFEE	167	273
DDG 91	PINCKNEY	175	275
DDG 92	MOMSEN	172	277
DDG 93	CHUNG-HOON	172	264
DDG 94	NITZE	163	253
DDG 95	JAMES E WILLIAMS	167	263
DDG 96	BAINBRIDGE	175	272
DDG 97	HALSEY	159	265
DDG 98	FORREST SHERMAN	187	283
DDG 99	FARRAGUT	185	281
DDG 100	KIDD	188	294
DDG 101	GRIDLEY	171	278
DDG 102	SAMPSON	173	272
DDG 103	TRUXTUN	186	283
DDG 104	STERETT	191	276
DDG 105	DEWEY	182	281
DDG 106	STOCKDALE	198	303
DDG 108	WAYNE E MEYER	188	276
FFG 32	JOHN L HALL	121	191
FFG 36	UNDERWOOD	128	190
FFG 40	HALYBURTON	131	197
FFG 43	THACH	124	196
FFG 45	DE WERT	128	200
FFG 46	RENTZ	123	196
FFG 47	NICHOLAS	123	195
FFG 48	VANDEGRIFT	116	191

Table E-1. Staffing Level of Non-Maintainers by Ship Category (FY2010)

Hull	Name	Ship's non-maintainers	Total crew size
FFG 49	ROBERT G BRADLEY	127	202
FFG 50	TAYLOR	116	188
FFG 51	GARY	120	193
FFG 52	CARR	140	205
FFG 54	FORD	117	197
FFG 55	ELROD	118	180
FFG 57	REUBEN JAMES	120	189
FFG 58	SAMUEL B ROBERTS	120	187
FFG 59	KAUFFMAN	127	192
FFG 61	INGRAHAM	118	190
MCM 1	AVENGER	37	79
MCM 2	DEFENDER	47	83
MCM 3	SENTRY	—	—
MCM 4	CHAMPION	—	—
MCM 5	GUARDIAN	44	85
MCM 6	DEVASTATOR	—	—
MCM 7	PATRIOT	44	92
MCM 8	SCOUT	—	—
MCM 9	PIONEER	—	—
MCM 10	WARRIOR	—	—
MCM 11	GLADIATOR	—	—
MCM 12	ARDENT	—	—
MCM 13	DEXTROUS	—	—
MCM 14	CHIEF	—	—
PC 2	TEMPEST	—	—
PC 3	HURRICANE	—	—
PC 4	MONSOON	—	—
PC 5	TYPHOON	—	—
PC 6	SIROCCO	—	—
PC 7	SQUALL	—	—
PC 9	CHINOOK	—	—
PC 10	FIREBOLT	—	—
PC 11	WHIRLWIND	—	—
PC 12	THUNDERBOLT	—	—

Appendix F
Abbreviations

3M	maintenance and material management
3M/OARS	Maintenance and Material Management Open Architectural Retrieval System
AIM	Advanced Industrial Management
CCPE	Corrosion Control and Prevention Executives
CPC IPT	Corrosion Prevention and Control Integrated Product Team
DL	Depot level
DM	depot maintenance
DMCS	Depot Maintenance Cost System
DMDC	Defense Manpower Data Center
ESWBS	expanded ships work breakdown structure
FLM	field-level maintenance
FSC	Federal Supply Catalog
FY	Fiscal Year
GAO	Government Accountability Office
IPT	integrated product team
ISO	International Organization for Standardization
Line 922	equipment maintenance by contract
MCC	merchant category code
MILCON	military construction
MRS	Maintenance Requirements System
MSC	Military Sealift Command
NAVSEA	Naval Sea Systems Command
NKO	Navy Knowledge Online
NMD	Navy Maintenance Database
NNPI	Navy Nuclear Propulsion Information
NSAs	naval support activities
OARS	Open Architectural Retrieval System
ONR	outside normal maintenance reporting

OP-31	spares and repair parts
OP-32	costs for materials and services
OSD	Office of Secretary of Defense
RDT&E	research, development, test, and evaluation
RMCs	regional maintenance centers
SBSD	sea-based strategic deterrence
SEA 04	Logistics, Maintenance, and Industrial Operations
SEA 04Y	Regional Maintenance Centers Management Office
SEA 05	Naval Systems Engineering
SEA 05P	Ship Integrity and Performance Engineering Division
SEA 5P23	Corrosion Control Branch
SSBNs	submersible, ballistic, and nuclear ship
SSGN	submersible, guided missile, nuclear ship
SSNs	nuclear-propulsion attack submarines
SWLIN	ships work line item number
SYMIS	Shipyard Management Information System
TO	task order
USD(A&TL)	Under Secretary of Defense for Acquisition, Technology and Logistics
WBS	work breakdown structure