LMI

The Annual Cost of Corrosion for the Facilities and Infrastructure of the Department of Defense

2012–2017 Update

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Eric F. Herzberg

Siwei Guo

Ariel Lai

Christopher J. Marquardt

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Executive Summary

LMI was tasked by the Corrosion Prevention and Control Integrated Product Team (CPC IPT) in September of 2018 to measure the effect of corrosion on the cost of Department of Defense (DoD) facilities and infrastructure (F&I). Using data from FY17,[1] we estimated the annual corrosion-related cost to be $2.447 billion. This total includes corrosion-related maintenance and construction costs. At $1.99 billion, the maintenance portion is the greatest corrosion cost and represents 13.6 percent of the total maintenance costs for all DoD F&I.[2]

This review is part of a multiple-year plan to measure the effect of corrosion on DoD weapon systems and F&I. Table ES-1 lists previous studies of the cost of corrosion for DoD F&I.

Table ES-1. Corrosion Costs by Fiscal Year ($ millions)

Data baseline	Annual total maintenance cost	Corrosion as a percentage of maintenance	Corrosion maintenance	Corrosion construction	Corrosion total
FY05	$10,216	11.4	$1,167	$205	$1,388
FY07	$10,648	10.1	$1,076	$444	$1,528
FY08	$12,879	12.3	$1,585	$395	$1,988
FY09	$16,225	13.7	$2,224	$428	$2,660
FY10	$15,394	13.9	$2,138	$540	$2,691
FY11	$15,936	14.4	$2,301	$685	$2,992
FY12	$15,575	12.4	$1,937	$795	$2,732
FY13	$13,719	14.0	$1,921	$718	$2,639
FY14	$16,761	14.9	$2,496	$707	$3,203
FY15	$13,521	14.6	$1,977	$469	$2,446
FY16	$15,174	13.6	$2,068	$487	$2,555
FY17	$14,654	13.6	$1,997	$450	$2,447
Total	$170,620	13.4	$22,887	$3,626	$26,513

[1] Although data was collected for FY12–17, LMI based the corrosion-related cost of DoD facilities on FY17 data, the most recent year for which study data was available.

[2] The maintenance costs include all sustainment, restoration, modernization, demolition, working capital fund, and military pay for all family housing and non-family housing facilities.

Corrosion costs and corrosion as a percentage of maintenance for F&I had steadily increased since the initial F&I study reaching a peak of $3.2 billion in FY14. In the last 3 years of study data (FY15 through FY17), corrosion costs have been reduced and have leveled off at approximately $2.5 billion per year. Comparatively speaking, F&I corrosion costs as a percentage of maintenance average of 13.4 percent are still lower than the average corrosion percentage for weapon systems (19.0 percent).

Study Method

To estimate corrosion's fiscal effect, we segregated costs by their source and nature using four schema groups:[3] Group 1—maintenance and construction costs; Group 2—facility analysis categories (FACs); Group 3—environmental severity index (ESI);[4] and Group 4—corrective versus preventive costs.

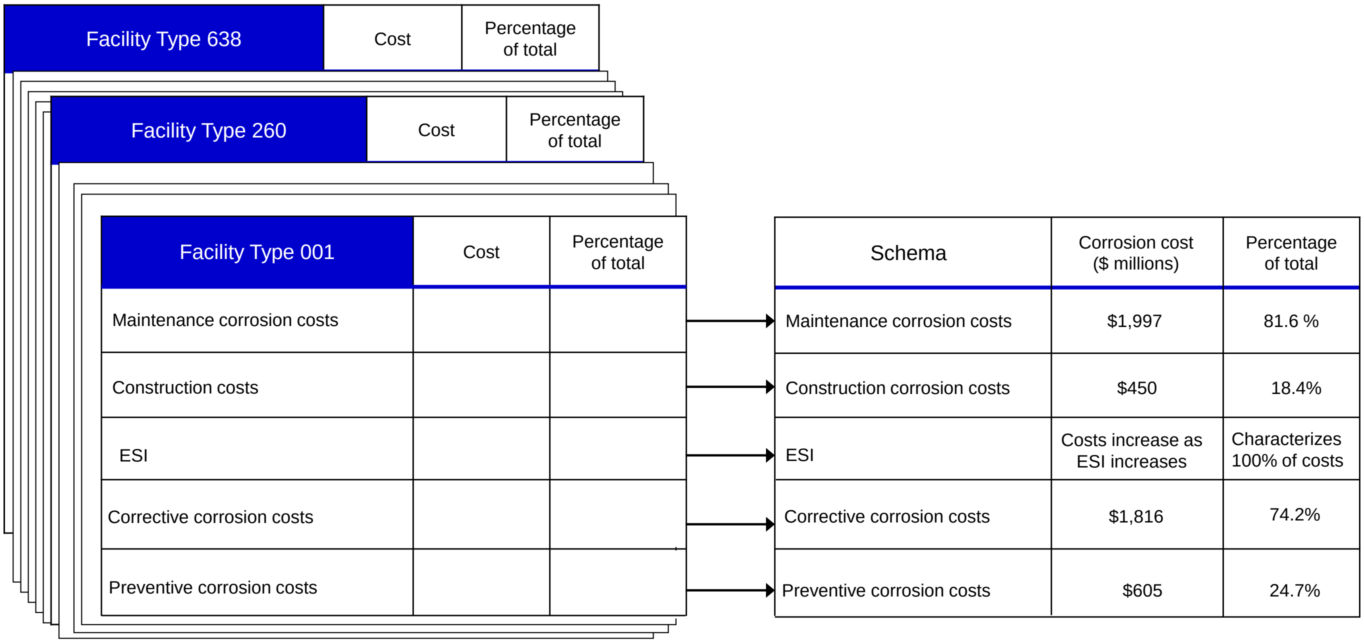
We estimated DoD F&I corrosion costs according to the four schema groups for each of 520 FACs, for a total of more than 433,301 facilities at 638 installations.

As we see in Figure ES-1, DoD incurs its highest corrosion-related costs during the performance of F&I maintenance. The corrosion-related maintenance costs are three to four times higher than corrosion costs associated with construction, even though overall construction costs are far higher than maintenance expenditures. There are two main reasons for this: corrosion is rarely identified as a justification for the construction of a new facility; and preventive corrosion measures are among the first considered for elimination if estimated construction costs need to be reduced to obtain project funding.

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

[4] Degradation because of corrosion generally increases as humidity and salinity content in the air increase. We developed the environmental severity zones for each installation using 10 years of degradation measurements from metallic coupons placed in differing climatic zones around the world. The study was conducted by Battelle. We used the readings from the study with their permission.

Figure ES-1. Cost of Corrosion for DoD Facilities/Infrastructure (FY17)



In FY17, DoD spent more than three times as much on corrective corrosion maintenance and construction ($1,816 million) as it did on preventive corrosion maintenance and construction ($605 million). This is largely driven by the nature of corrosion-related construction costs—99 percent of which are corrective.

Deferred Maintenance

Because deferred maintenance is a potential future cost but not a current cost, we did not include it in the study; however, we did observe the effect deferred maintenance can have in terms of corrosion-related restoration costs and military construction. Corrosion-related costs for military construction have increased significantly since the initial 2006 F&I study (from $205 million to $450 million). The majority of this increase is due to replacement of facilities that have degraded because of corrosion.

Opportunities to Reduce Costs

Facility and infrastructure types that are large in total size are generally among the greatest contributors to total corrosion costs, but they have a low corrosion cost per unit of measurement, as is evident in Table ES-2.

Table ES-2. Top Five Corrosion Costs by Facility Analysis Category

FAC	Total sq. ft. (in millions)	Corrosion cost per unit	Corrosion cost (in millions)	Maintenance cost (in millions)	Corrosion as a percentage of maintenance
6100—General Administrative Building	169,519,777	$0.76	$129	$955	13.6
7210—Enlisted Unaccompanied Personnel Housing	133,971,124	$0.90	$120	$520	23.1

Table ES-2. Top Five Corrosion Costs by Facility Analysis Category

FAC	Total sq. ft. (in millions)	Corrosion cost per unit	Corrosion cost (in millions)	Maintenance cost (in millions)	Corrosion as a percentage of maintenance
8910—Utility Building	17,471,428	$3.83	$67	$493	13.7
7213—Student Barracks	20,573,304	$2.33	$48	$123	39.1
7110—Family Housing Dwelling	49,191,498	$0.81	$40	$312	12.9

The top three FACs by total square footage (FACs 6100, 7210, and 7110) have the lowest corrosion cost per unit of measurement. The two FACS with the lowest total square footage (FACs 8910 and 7213) have the highest corrosion cost per unit of measurement.

Using Corrosion Cost Information to Improve Sustainment Cost Estimates

Each year the military services estimate what resources will be required to effectively maintain their F&I. This estimate is based on a combination of factors, including a sustainment cost factor, an area cost factor (ACF), and an escalation factor. The ACF includes the cost of corrosion for each FAC, but it does not differentiate among corrosion-related environmental effects. For example, the corrosion costs per square foot included in the ACF for a family housing dwelling (FAC 7110) in Hawaii or in Arizona are considered the same. The data from this study can help DoD refine and improve how it estimates maintenance costs for each FAC.

Contents

Figures

Tables

Chapter 1
Objectives, Method, and Background

Congress, concerned with the high cost of corrosion, enacted legislation in December 2002 that assigned the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) with policy and oversight responsibilities for preventing and mitigating the effects of corrosion on military equipment and infrastructure.[1] To perform its mission of preventing and mitigating corrosion, 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 the effect (in terms of both cost[3] and availability[4]) corrosion has on the Department of Defense's (DoD's) military equipment and infrastructure.

In April 2006, the CPC IPT published the results of the first corrosion-related cost study for Infrastructure and Facilities,[5] which used the standard corrosion-related cost estimation method. We present the results of the initial and all subsequent infrastructure and facilities cost studies in Table 1-1. Note the infrastructure and facilities studies do not include availability impacts because the services do not have a recurring availability reporting metric for all facilities and infrastructure (F&I).

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

Study year[a]	Data baseline	Study segment	Annual cost of corrosion
2006–2007	FY05	DoD facilities and infrastructure	$1.4 billion
2009–2010	FY07–08	DoD facilities and infrastructure	$2.0 billion
2012–2013	FY09–11	DoD facilities and infrastructure	$3.0 billion
2018–2019	FY12–17	DoD facilities and infrastructure	$2.5 billion

[a] Study period is 1 calendar year.

For the 2018–2019 study year, LMI was tasked by the CPC IPT to study corrosion's effect on DoD F&I using data from FY12 through FY17.

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[1] *The Bob Stump National Defense Authorization Act for Fiscal Year 2003*, Public Law 107-314, December 28, 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, January 28, 2008.

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

[3] Eric F. Herzberg et al., *Proposed Method and Structure for Determining the Cost of Corrosion for the Department of Defense*, Report SKT40T1, (Tysons, VA: LMI, August 2004).

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

[5] Eric F. Herzberg et al., *The Annual Cost of Corrosion for the Department of Defense Facilities and Infrastructure*, Report SKT50T2 (Revision 1) (Tysons, VA: LMI, May 2007).

Study Objectives

We had four specific objectives for this study:

- Measure the most recent annual cost of corrosion as it relates to DoD F&I.
- Analyze trends and draw conclusions using current and past DoD F&I cost-of-corrosion studies.
- Identify best practices that may lead to corrosion cost reduction opportunities for DoD F&I.
- Demonstrate how the findings from this study can be used to improve the accuracy of budgeting for facilities maintenance costs.

Study Method

The study method we applied is the same as what we detailed in the original report. For the sake of brevity, we do not repeat a full description of the method herein. Readers who want more information can refer to Chapter 1 of the original report, *The Annual Cost of Corrosion for the Department of Defense Facilities and Infrastructure*, May 2007.[6]

To ensure consistency, we used the same definition of corrosion as was used by Congress: "The deterioration of a material or its properties due to a reaction of that material with its chemical environment."[7] We have applied this definition of corrosion for each corrosion study.

Background

The DoD process for requesting that funds be authorized and appropriated by Congress is commonly referred to as programming and budgeting. The programming and budgeting process entails the assembly of a program objective memorandum (POM). The staffing of the POM provides the mechanism for debate and competition over fiscal resources within the DoD.

The first 2 years of the consolidated resource requirements in the POMs become DoD's portion of the President's budget, which is delivered to Congress in February of each year. Congress examines the President's budget request for resources and appropriates the necessary funds by the beginning of the following fiscal year.

Following appropriation by Congress, the funds are passed through comptroller channels within the DoD to make them available to the requesting services and agencies for execution.

Maintenance and Construction Funding and Execution

Before being consolidated into the service-level budget request, installation-level organizations initiate their plans for maintenance and construction requirements for DoD facilities. Since maintenance and construction funding requirements follow slightly

[6] Herzberg et al., May 2007, Chapter 1 of the original report.

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

different request and approval paths, we discuss them independently, beginning with maintenance requirements.

Maintenance Funding and Execution

The DoD separates facilities maintenance requirements into three main funding categories:[8]

1. *Sustainment*—the maintenance and repair activities necessary to keep an inventory of facilities in good working order. Sustainment includes regularly scheduled adjustments and inspections, preventive maintenance tasks, and emergency response and service calls for minor repairs. It also includes major repairs or the periodic replacements of facility components (usually accomplished by contract) that are expected throughout the facility's life. This work includes regular roof replacement, refinishing of wall surfaces, repair and replacement of heating and cooling systems, replacement of tile and carpeting, and other similar work. Sustainment does not include environmental compliance costs, facility leases, or other tasks associated with facility operations (such as custodial services, grounds services, waste disposal, and the provision of central utilities).
2. *Restoration*—the restoration of real property to such a condition that it can be used for its designated purpose. Restoration includes any repair or replacement work to restore facilities damaged by inadequate sustainment, excessive age, natural disaster, fire, accident, or other causes.
3. *Modernization*—the alteration or replacement of facilities solely to implement new or higher standards, accommodate new functions, or replace building components that typically last more than 50 years (such as the framework or foundation).

Installation-level organizations determine funding requirements for sustainment, restoration, and modernization (SRM) using various estimating tools and by analyzing current and prior-year execution data. These funding requirement estimates are forwarded to the military service and agency staffs through command channels. Along the way, installation, regional, and major command staffs and commanders review and often modify, or re-prioritize, the initial list of requirements.

Congress normally provides funding for the maintenance of existing facilities and infrastructure under the operations and maintenance (O&M) and family housing (FH) appropriations.

Although corrosion maintenance costs are a subset of SRM costs, the tools and analysis methods planners use to estimate SRM requirements do not specifically identify corrosion. Therefore, accurate measurement of corrosion costs could improve the precision of SRM resource planning. We present a summary of how planners currently estimate the maintenance requirements for SRM in Appendix A.

Construction Funding and Execution

Congress provides funding for new DoD F&I using either the military construction (MILCON) or FH construction appropriations. The installations determine their

[8] *DoD Financial Management Regulation*, Volume 2B, Chapter 8, Section 080105, June 2004, pp. 8-1–8-2.

requirements for new construction based on current missions, future missions or initiatives, and the condition of the current inventory.

Construction contracting, management, and supervision within DoD are usually done by the U.S. Army Corps of Engineers (USACE) or the Naval Facilities Engineering Command (NAVFAC), depending on the geographic location of the project. The Air Force and defense agencies use USACE and NAVFAC as their construction agents.

Corrosion construction costs are a subset of MILCON and FH construction costs. Typically, corrosion construction costs are the result of either preventive measures that are part of the new facility or are a corrective cost—at least a portion of the economic justification for the new facility was the failure of the existing facility as a result of corrosion.

Deferred Maintenance

Identified but unresolved maintenance issues that cannot be corrected because of a lack of funding, scheduling conflicts, or operational requirements are known as “deferred maintenance.” DoD’s identification and reporting of deferred maintenance on military equipment and real property is governed by guidance issued by the Federal Accounting Standards and Advisory Board (FASAB).

Although reporting of deferred maintenance per FASAB guidance is an annual requirement and may include potential future DoD facilities corrosion costs, we elected to exclude deferred maintenance from the study because, from an accounting standpoint, deferred maintenance is not a cost. It is noted as a potential future expense. The maintenance identified as deferred may never be performed. In addition, the facility’s deferred maintenance estimate does not provide cost information for individual issues, such as corrosion.

Corrosion-related costs of military construction have increased significant since the initial corrosion study in 2006 (up $245 million from the initial estimate of $205 million). The majority of this increase is due to replacement of facilities that have degraded because of corrosion. If maintenance is deferred as a common practice, eventually facilities will fail prematurely and have to be replaced.

Privatization

We calculated corrosion maintenance and construction costs for all government-owned facilities listed in the main asset tracking data repository called the Real Property Asset Database (RPAD). This includes all National Guard and Reserve facilities and any facilities in the area of operations and contingency environments that are listed in the RPAD.

We did not capture corrosion costs associated with assets that are not owned by DoD, such as leased office space, leased housing units, privatized housing, and privatized utilities. Private firms are responsible for the maintenance and associated funding for the upkeep for these facilities. Private sector costs are recouped through the lease rate, rental payment (by means of the basic allowance for housing), or the utility bill. In most instances, the bottom-up data necessary to capture corrosion costs for these assets was not accessible to the study team (e.g., work orders or detailed accounting showing corrosion-related expenses).

Facilities List

The RPAD contains descriptive data on all DoD facilities worldwide. We calculated the corrosion costs at the facility analysis category (FAC) level of detail. Of the 520 FACs, we list the top 10 recurring FACs by number of entries in Table 1-2.

Table 1-2. Ten Most Frequently Recurring FACs

Rank	FAC description	FAC code	Frequency of occurrence
1	Miscellaneous Paved Area	8526	20,771
2	Ammunition Storage, Depot and Arsenal	4211	17,452
3	Vehicle Parking, Surfaced	8521	14,435
4	Fence and Wall	8721	13,826
5	Utility Building	8910	13,188
6	Family Housing Dwelling	7110	12,356
7	General Administrative Building	6100	11,647
8	Covered Storage Building, Installation	4421	9,686
9	Road, Surfaced	8511	9,257
10	Sewer and Industrial Waste Line	8321	7,523

The scope of this study included all facilities and real property in the RPAD except privatized facilities and land. We excluded privatized facilities because they are not owned by DoD; we excluded land because it does not corrode according to the definition outlined by Congress.

Corrosion Cost Categories

It is advantageous to classify corrosion costs into major groupings that further describe their overall nature and origin. Using FY12–17 cost data, we identified the following four cost schemas for analysis:

- *Group 1*—Maintenance and construction costs
- *Group 2*—Costs by FAC code
- *Group 3*—Cost categorized by environmental severity index (ESI)
- *Group 4*—Corrective versus preventive costs.

Maintenance, Construction, and R&D Costs

We divided costs into maintenance, construction, or research and development (R&D) segments based on congressional definitions for the appropriation of funding.

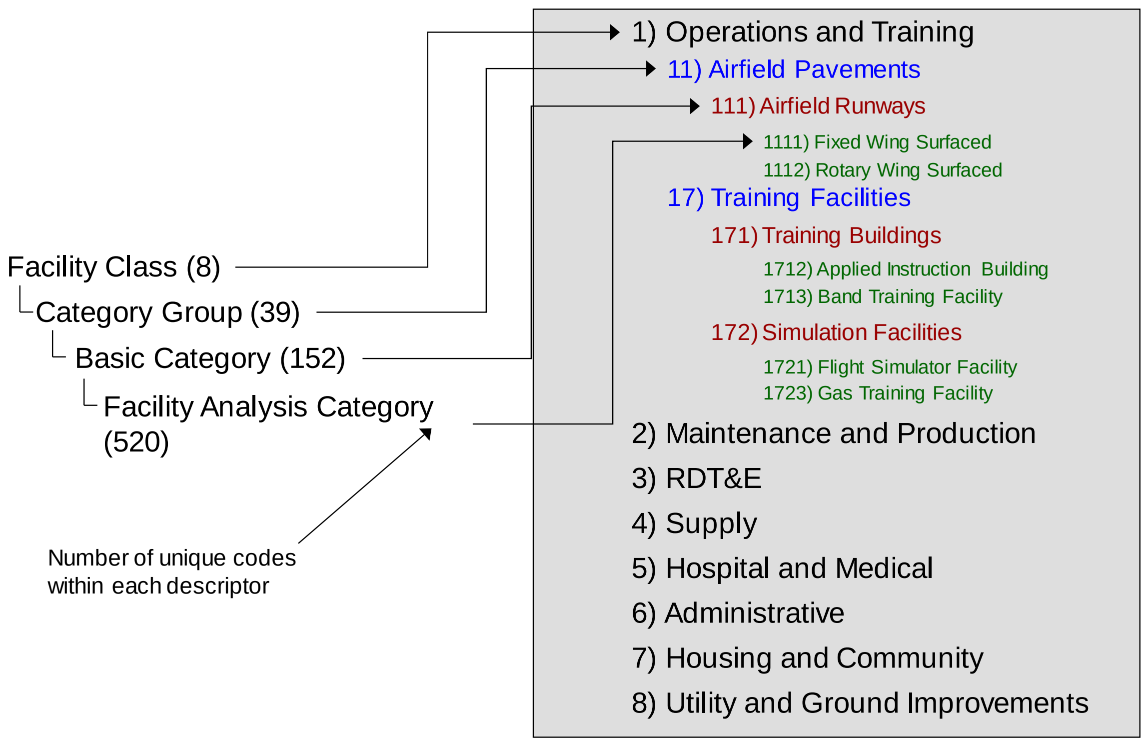
- *Maintenance* includes SRM and demolition or disposal of existing facilities. It is funded by the O&M and FH maintenance appropriations.
- *Construction* is defined as the building of new facilities and the post-acquisition improvements of existing FH units. Construction is funded under the MILCON and FH appropriations.
- *R&D* is funded primarily through the R&D appropriation.

Costs by Facility Analysis Category

The RPAD[9] contains an inventory of all DoD facilities. A common DoD taxonomy characterizes each facility type in the RPAD.

Each level of indenture provides a more thorough description of the facility, with the four-digit FAC providing the most detail. For example, in Figure 1-1, a fixed wing surfaced runway (FAC Code 1111) is a specific category of airfield runways. The airfield runway is a type of airfield pavement, which is a subset of the operations and training facility class.

Figure 1-1. Facilities Data Taxonomy



Note: RDT&E = research, development, testing, and evaluation.

As we depict in Figure 1-2, the Facilities Assets Database (RPAD) characterizes facilities into 520 different FAC codes (types of facilities). There are a total of 433,301[10] facility records for 638[11] DoD installations worldwide.

[9] A DoD-wide database maintained by the Office of the Deputy Under Secretary of Defense, Installations and Environment. We used the FY18 version of the RPAD in this study.

[10] The 433,301 facilities represent a record count within RPAD but the actual number of facilities is higher. For example, a utility pole record might appear once in RPAD but the quantity listed within RPAD might be 100. We found the quantity count to be an unreliable figure and therefore did not discuss it.

[11] These 638 installations represent the number of different installation master names (including 289 Navy ships). The number of unique installations is far greater than 638. For example, there may be 50 small Reserve unit installations in Pennsylvania. Some of these are as small as three or four buildings. In order to reconcile maintenance data, funding and installation assets listed in RPAD, we established a common installation name for each of these categories. In the case of the Pennsylvania Reserve installations, we grouped these together under the master name "Pennsylvania Reserves."

Figure 1-2. Number of Facilities, FAC Codes, and Installations in the RPAD (Extract)

Record Number	Facility ID Number	FAC Description	FAC Code	Installation
1	BA3245	Applied Instruction Building	1712	Fort Stewart, GA
2	TS1734	Applied Instruction Building	1712	Pearl Harbor, HI
3	AY67345	Applied Instruction Building	1712	Baumholder, Germany
4	BZ4563	Flight Simulator Facility	1721	Misawa, Japan
5	KR33R5	Flight Simulator Facility	1721	Lackland AFB, TX
6	BD88R9	Gas Training Facility	1723	Fort Bragg, NC
7	ZTRG456	Gas Training Facility	1723	Fort Richardson, AK
8	132567	Gas Training Facility	1723	Fort Huachuca, AR
9	DF23789	Dental Facility	5400	Norfolk, VA
10	45319	Dental Facility	5400	West Point, NY
11	TS1734	Family Housing Dwelling	7110	Fort Hood, TX
12	GH7856	Family Housing Dwelling	7110	Langley AFB, VA
⋮	⋮	⋮	⋮	⋮
1,255,000	BG3900	Family Housing Dwelling	7110	Wright-Patterson AFB, OH

Number of Total Facilities **(433,301)**

Number of Unique FAC Codes **(520)**

Number of Unique Installations **(638)**

We analyze corrosion costs at the FAC level for several reasons:

- DoD develops the annual facilities sustainment cost factors[12] at the FAC level. Calculating corrosion costs (a subset of sustainment costs) at this level ensures consistency.
- Improved knowledge of how corrosion costs affect sustainment cost factors may help to refine how DoD calculates sustainment cost factors for each budget cycle.
- Calculating corrosion costs at the FAC level provides sufficient detail to distinguish corrosion issues at different facility types. This helps DoD target problem areas more accurately and allocate resources accordingly.

[12] DoD uses sustainment cost factors to budget annual sustainment funding for each service and installation.

Environmental Severity Index

According to the International Organization for Standardization (ISO), three key factors[13] affect the atmospheric corrosion of metals and alloys:

- *Time of wetness*—the number of hours per year when the outdoor relative humidity is greater than 80 percent at a temperature greater than 0°C.
- *Airborne salinity*—the deposition rate of chloride in the atmosphere. Marine environments are the main contributor of chloride deposition.
- *Pollution by sulfur dioxide*—a combination of the deposition rate and concentration of sulfur dioxide in the atmosphere based on continuous measurements over at least 1 year.

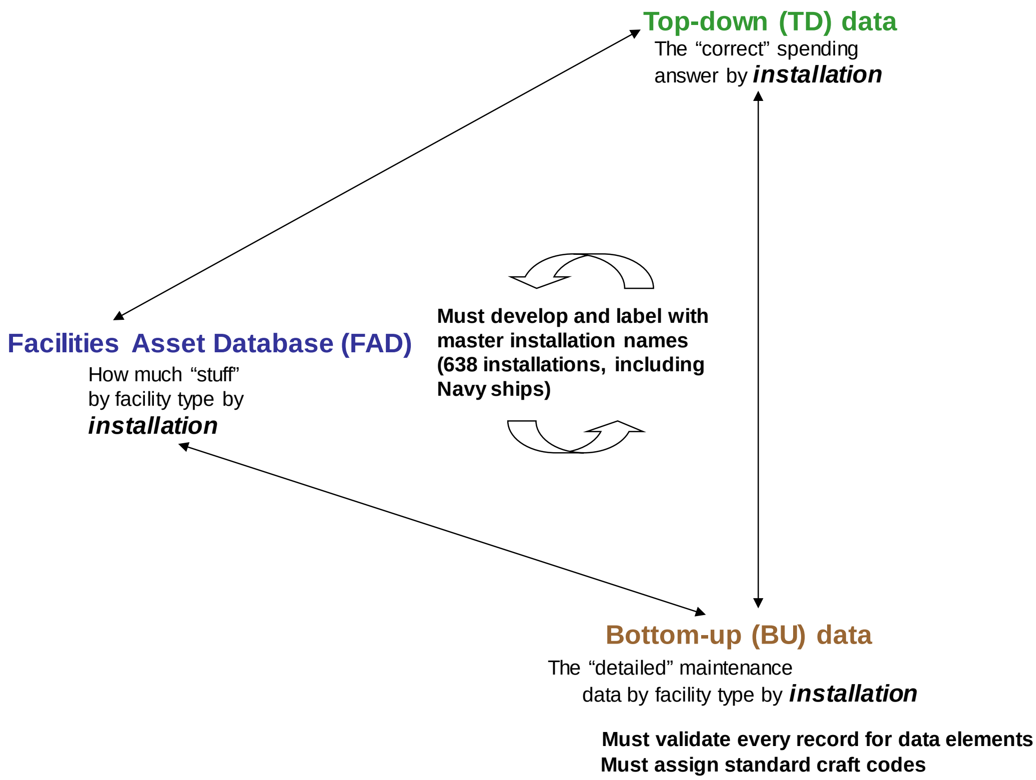
Using corrosion degradation data from coupons that contain samples of different metals placed at various DoD installations around the world over a 10-year period,[14] LMI developed an ESI to classify each military installation worldwide based on its location and corresponding environmental severity relative to corrosion.

Reconciling facilities data from the RPAD, maintenance spending for each installation (as documented by each service), and available detailed maintenance execution records for each installation (see Figure 1-3) yielded a total of 737 different DoD installations worldwide. These are the installations that needed to be classified within the ESI to suitably reflect the variation in environmental conditions between locations.

[13] ISO, *Corrosion of Metals and Alloys*: *Corrosivity of Atmospheres—Classification*, ISO 9223, February 15, 1992, p. 1.

[14] This study was conducted by Battelle. We used the raw data from their study with their permission to calculate the ESI.

Figure 1-3. Reconciliation of Assets, Top-Down Spending and Bottom-Up Maintenance Detail by Installation



The metallic coupon sampling racks were put in place at approximately 200 installations worldwide. Various metals were used on the coupons. The metal which showed the largest degradation in each case was steel. These were the results used to create the initial ESI zones because steel is most similar to materials present in facilities and installations (as opposed to aluminum alloys which are more germane to studies of weapons systems degradation) and steel coupons showed the greatest degradation and variance among different climatic zones. Twenty zones were chosen to adequately reflect variation from installation to installation.

The steel degradation values (measured in micrograms per square centimeter) and corresponding zones are shown in Table 1-3. As the degradation values increase in the more severe environments, the spread from zone to zone increases, starting with zone 15. This is to include the most severe environments, the outliers, and still maintain a 20-zone schema. Maintaining an even spread of degradation (a corrosion loss of 1,999 micrograms per square centimeter) through all installations would have resulted in more than 40 zones, many of which would have had no associated installations.

Table 1-3. ESI Zone Schema (micrograms per square centimeter)

Zone	Steel corrosion loss (avg./month)		Zone	Steel corrosion loss (avg./month)	
	From	To		From	To
1	0	1,999	11	20,000	21,999
2	2,000	3,999	12	22,000	23,999
3	4,000	5,999	13	24,000	25,999
4	6,000	7,999	14	26,000	27,999
5	8,000	9,999	15	28,000	31,999
6	10,000	11,999	16	32,000	35,999
7	12,000	13,999	17	36,000	39,999
8	14,000	15,999	18	40,000	49,999
9	16,000	17,999	19	50,000	74,999
10	18,000	19,999	20	75,000	All

Once we calculated the ESI zones, the approximately 200 installations with coupon data inherited the ESI zone reflected by their coupon data. This left 438 installations that needed an ESI calculated. We assigned the most severe zone (ESI 20) to the 289 Navy ships. This left 149 installations that needed an ESI assignment.

Before the coupon data was available, each installation had a predictor of the environmental impact on corrosion, called a time of wetness (TOW) and salinity (S) indicator. TOW and S are two major factors that affect corrosion rates. The TOW is measured in five gradients, with 1 being the lowest number of hours and 5 being the highest.

The salinity measurement is simply whether the center of mass of the installation is within 1 mile of seawater. It is a yes or no measurement.

When we combine the TOW and S measures, we have 10 possible outcomes to predict the impact of the environment on corrosion. In our initial studies before the coupon data was available, we applied the TOW/S measurement to each of the 638 installations. We saw this as a good interim environmental impact measure until a more rigorous measure could be developed.

Because 200 of the original 638 installations had both a TOW/S measurement and an ESI zone assignment, we could assign a relationship between the ESI zone and the TOW/S measure. In Table 1-4, we show the correlation for a sampling of the 200 installations that with both coupon data and TOW/S assignment.

Table 1-4. Sample of Installations with Both an ESI and TOW/S Assignment

Installation	TOW measure	Within 1 mile of seawater?	ESI zone
MCB Hawaii Kaneohe	τ5	Yes	19
Fort Eustis	τ4	Yes	18
Wheeler Army Airfield	τ5	No	18
Savannah/Hilton Head International Airport	τ4	No	17
MCB Camp Pendleton	τ3	Yes	14
Dobbins Air Reserve Base	τ4	No	10
Charleston Air Force Base	τ4	Yes	10
Fort Campbell	τ4	No	9
Hickam Air Force Base	τ5	Yes	8
Camp Henry	τ4	No	7
Ramstein Air Base	τ3	No	6
Fairchild Air Force Base	τ2	No	3
Hill Air Force Base	τ2	No	3
Kirtland Air Force Base	τ1	No	1

Note: MCB = Marine Corps Base.

We used linear regression to find the correlation between the TOW/S and ESI measures for the 200 installations that had metallic coupon data. The results showed the correlation to be very high, with an R-squared of 91 percent. This gave us confidence that we could assign an ESI measure to the remaining 149 installations. The 289 Navy ships were automatically assigned to ESI zone 20. Table 1-5 shows the distribution of installations by ESI.

Table 1-5. Number of Installations by ESI Zone

ESI zone	Number of installations	ESI zone	Number of installations
1	21	11	13
2	30	12	15
3	12	13	3
4	11	14	16
5	28	15	7
6	41	16	7
7	31	17	5
8	32	18	16
9	25	19	17
10	19	20	289

We calculated corrosion costs for facilities maintenance and construction by ESI zone. We did not include the maintenance and corrosion costs for the 289 Navy ships in this study; they are included in a separate corrosion impact study.

Corrective and Preventive Costs

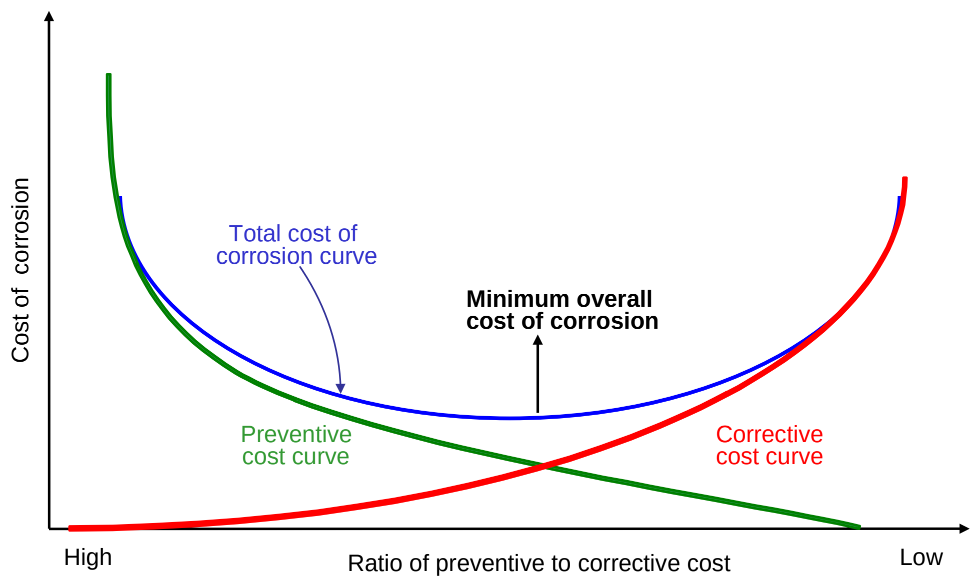
We also classified all corrosion costs as either corrective or preventive.

- *Corrective costs* are incurred when removing an existing nonconformity or defect. Corrective actions address actual problems.
- *Preventive costs* involve steps taken to remove the causes of potential nonconformities or defects. Preventive actions address future problems.[15]

From a management standpoint, it is useful to determine the ratio between corrective costs and preventive costs. Over time, it is usually more expensive to fix a problem than it is to prevent a problem. But it is also possible to overspend on preventive measures.

As shown in Figure 1-4, classifying the cost elements into categories helps decision makers find the proper balance between preventive and corrective expenses to minimize the overall cost of corrosion.

Figure 1-4. Preventive and Corrective Corrosion Cost Curves



The task of classifying each cost element as either preventive or corrective could become an enormously challenging undertaking; one that involves thousands of people trying to classify millions of activities and billions of dollars of cost in a standard method. The real value of classifying costs into preventive and corrective categories is to determine the ratio between the "nature" of these costs; the classification does not require precision. To simplify, we classified the preventive and corrective cost elements as depicted in Table 1-6.

[15] ISO 9000:2000 definition of corrective and preventive actions.

Table 1-6. Classification of Corrosion Cost Elements into Preventive or Corrective Natures

Cost element	Classification
Labor	Corrective or preventive
Materials and supplies	Corrective or preventive
R&D	Preventive

The classification of labor and the associated materials and supplies as corrective or preventive must be determined case by case.

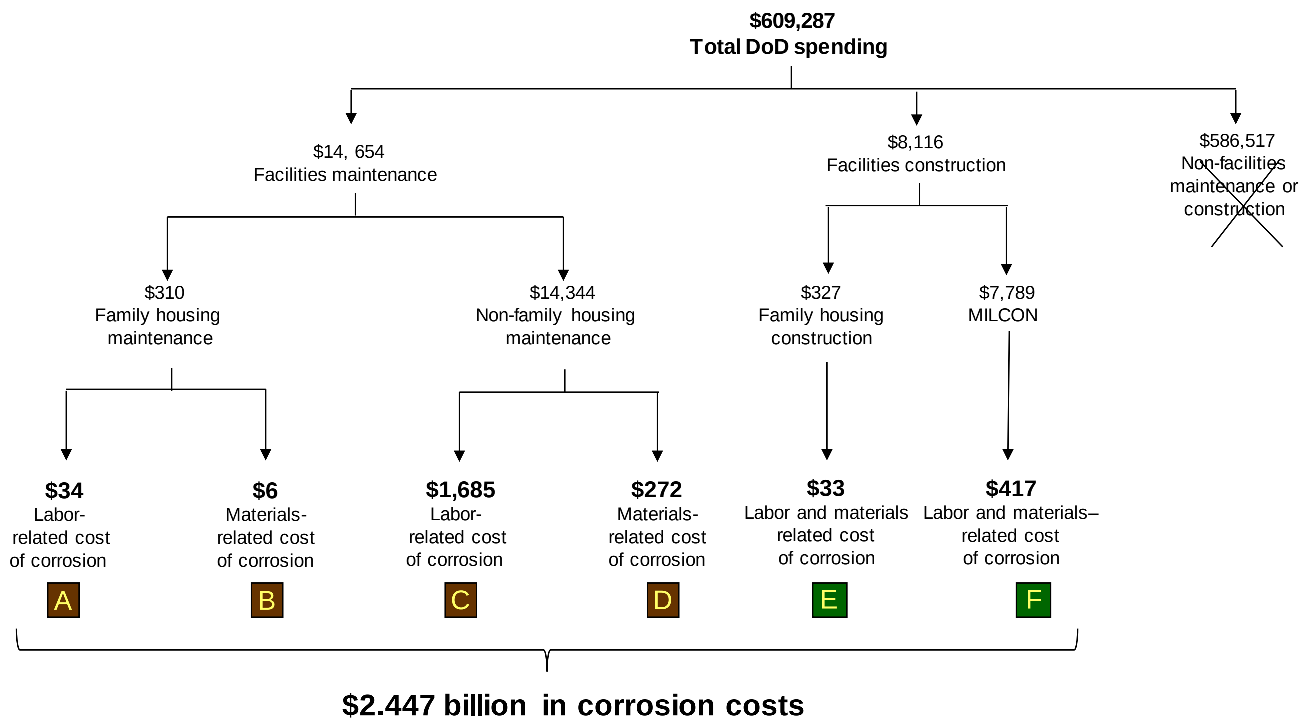
To ensure consistency, we classified direct labor and the associated materials and supplies cost based on the following convention:

- Labor and materials and supplies spent *repairing and treating corrosion damage*, including surface preparation, were classified as *corrective* costs.
- Labor and materials and supplies spent *gaining access to facilities locations that have corrosion damage* so that it can be treated were classified as *corrective* costs.
- Labor spent on *maintenance requests and planning* for the treatment of corrosion damage was classified as *corrective* costs.
- Labor and materials and supplies spent *cleaning, inspecting, painting, and applying corrosion prevention compounds* or other coatings were classified as *preventive* costs.
- Labor and materials and supplies spent on *cathodic protection, water treatment*, or other preventive measures were classified as *preventive* costs.

Chapter 2
DoD F&I Corrosion Costs

We estimated the total annual cost of corrosion for DoD F&I to be $2.447 billion. We show these costs, broken down by node, in Figure 2-1.

Figure 2-1. Final F&I Corrosion Cost Tree ($ in millions—FY17)



The $2.447 billion F&I corrosion cost figure includes $1,997 million in F&I maintenance corrosion costs (nodes A through D) and $450 million in F&I construction projects (nodes E and F).

As we outlined in the previous F&I study report, we used a combined TD and BU approach to determine corrosion costs. We first discuss the TD analysis and then detail the BU costs.

TD Analysis

We developed the cost tree illustrated in Figure 2-1 as a visual tool to help illustrate the cost of corrosion for DoD F&I. It serves as a guide for the remainder of this section.

At the top of the cost tree is $609 billion, DoD's total obligational authority (TOA) for FY17.[1] We used the POM and Future Years Defense Program (FYDP) budget structure to closely examine all DoD expenditures. We provide additional details of this analysis in Appendix B.

By separating costs into F&I maintenance, F&I construction, and remaining costs, we segregated the cost tree into three major groups, which resulted in the second level of the tree. The F&I maintenance and F&I construction groups contained potential F&I corrosion costs.

Decomposing the second-level F&I maintenance and F&I construction cost groups resulted in the four additional subgroups in the third level of the tree.

- Under F&I maintenance, the FH maintenance (FHM) subgroup identifies F&I maintenance expenditures in the FH appropriation. The non-FHM subgroup includes F&I maintenance expenditures primarily from the O&M and Working Capital Fund (WCF) appropriations.
- Under F&I construction, the FH construction subgroup identifies F&I construction expenditures in the FH appropriation. The MILCON subgroup includes F&I construction expenditures that are primarily from the MILCON appropriation.

We included funding from military pay (MILPAY) appropriations in the four subgroups when it was appropriate. We provide the documentation of mapping of appropriation funding for the cost figures in each subgroup in Appendix B.

We split each of the four subgroups into the major cost categories of interest, and then labeled the cost categories as "cost nodes." Cost nodes A through F depict the main segments of corrosion cost. Using separate cost trees for maintenance and construction, we determined the overall corrosion costs by combining the costs at each node. We provide these separate detailed cost trees in Appendix B.

We now explore the source of each of the TD F&I maintenance and construction expenditures in more detail, starting with FHM.

TD F&I Maintenance Expenditures

FHM

The funding and execution for FHM is administered through program element[2] (PE) 0808746. We show the breakdown of these costs by military service in Table 2-1.

[1] *Financial Summary Tables, Department of Defense Budget for FY2019,* http://comptroller.defense.gov/defbudget/fy2019/fy2019 summary_tables_whole.pdf, May 2019 and corresponding FYDP data.

[2] A program element is the primary data element in the FYDP. Program elements are the building blocks of the programming and budgeting system and may be aggregated and re-aggregated in a variety of ways. *Future Years Defense Program Structure*, DoD 7045.7-H, April 2006, p. 8.

Table 2-1. TD FHM Costs by Service
($ in millions—FY17)

Program element	Service	FHM
0808746A	Army	$76
0808746N	Navy/Marine Corps	$83
0808746F	Air Force	$123
Total		$282

Non-FHM

The preponderance of the FY17 costs for non-FH F&I maintenance was associated with funds in the O&M and WCF appropriation. We were able to categorize non-FH F&I maintenance funding (and ultimate expenditures) into five broad categories. In descending order of magnitude, these F&I funding streams are as follows:

- SRM and demolition funds directly appropriated to the services
- Defense Health Program (DHP) F&I maintenance funds passed through to the services
- Service WCFs earmarked for F&I maintenance
- Defense Logistics Agency (DLA) WCF earmarked for F&I maintenance at service installations (all F&I have a service affiliation in the FAD)
- F&I maintenance–related military pay.

We explore each of these non-FHM funding streams in more detail below.

SRM and Demolition Funds

The services expended approximately $9.5 billion in directly appropriated O&M funding for non-FH F&I maintenance in FY17. These funds were identified in the following PEs:

- xxxxx78—F&I sustainment
- xxxxx76—F&I restoration and modernization
- xxxxx93—Demolition or disposal of excess F&I.

We depict the breakdown of these costs by service in Table 2-2.

Table 2-2. Directly Funded Non-FHM SRM and Demolition or Disposal Costs
($ in millions—FY17)

Service	Sustainment	Restoration and modernization	Demolition/disposal	Total SRM and demolition/disposal
Army	$2,702	$668	$48	$3,418
Navy	$1,317	$575	$10	$1,902
Marine Corps	$528	$248	$8	$784
Air Force	$2,602	$811	$31	$3,444
Total	$7,149	$2,302	$97	$9,548

DHP F&I Maintenance Funds

O&M appropriations to the DHP totaled $1.153 billion for non-FH F&I maintenance in FY17. The DHP passes the majority of these funds through to the military services, which routinely maintain the medical and dental facilities at their installations. We portray the service breakdown of these costs in Table 2-3.

Table 2-3. DHP-Funded Non-FH F&I Maintenance SRM Costs ($ in millions—FY17)

Service	DHP non-FHM
Army	$492
Navy and Marine Corps	$359
Air Force	$302
Total	$1,153

Service WCFs Earmarked for F&I Maintenance

Each of the services operates a number of F&I projects under its WCF as essentially "fee-for-service" operations.[3] The services earmark some of the user fees they collect for maintenance of these F&I projects.

The services spent $1.350 billion in WCF receipts for F&I maintenance in FY17. We show the service breakdown of these costs in Table 2-4.

Table 2-4. Service Working Capital–Funded Non-FH F&I Maintenance Costs ($ in millions—FY17)

Service	WCF non-FH F&I maintenance
Army	$293
Navy	$807
Marine Corps	$6
Air Force	$244
Total	$1,350

DLA WCFs Earmarked for F&I Maintenance at Service Installations

DLA also operates a number of facilities under the WCF mechanism. Examples include various supply warehouses, distribution points, and fuel storage facilities. Many of these operations are collocated with service installations.

DLA spent $605 million in WCF receipts for F&I maintenance in FY17. We attributed such expenses to the service associated with the facility or to the service identified in the FAD. We show the breakdown of these costs by service in Table 2-5.

[3] The preponderance of fees collected supports the services' depot maintenance operations.

Table 2-5. DLA Working Capital–Funded Non-FH F&I Maintenance Costs ($ in millions—FY17)

Service	DLA WCF non-FHM
Army	$226
Navy/Marine Corps	$219
Air Force	$160
Total	$605

F&I Maintenance-Related MILPAY

Military personnel execute DoD F&I maintenance. Because their funding comes from the MILPAY appropriation and not O&M, we considered labor costs separately. We estimated the total labor cost of military personnel who perform non-FH F&I maintenance to be $1.716 billion. We show the breakout by service in Table 2-6.

Table 2-6. Non-FH MILPAY Costs ($ in millions—FY17)

Service	Non-FHM MILPAY
Army	$886
Navy	$286
Marine Corps	$358
Air Force	$104
Other defense	$82
Total	$1,716

We provide a detailed summary of how we determined MILPAY contributions to F&I maintenance and construction in Appendix C.

Summary of F&I Maintenance Funding

Summing the O&M, WCF, and MILPAY funding sources, we calculated $14.344 billion in non-FH F&I maintenance. Adding the FH F&I maintenance costs from Table 2-1, we determined the total F&I maintenance costs were nearly $14.7 billion in FY17, as shown in Table 2-7.

Table 2-7. TD Total F&I Maintenance Costs ($ in millions—FY17)

Service	FHM	SRM and demolition	DHP	Service WCF	DLA WCF	MILPAY	Total
Army	$76	$3,418	$492	$293	$226	$886	$5,391
Navy	$83[a]	$1,902	$359[b]	$807	$219	$286	$3,656
Marine Corps	—	$784	—	$6	—	$358	$1,148
Air Force	$123	$3,444	$302	$244	$160	$104	$4,377

Table 2-7. TD Total F&I Maintenance Costs ($ in millions—FY17)

Service	FHM	SRM and demolition	DHP	Service WCF	DLA WCF	MILPAY	Total
Other defense	—	—	—	—	—	$82	$82
Total	$282	$9,548	$1,153	$1,350	$605	$1,716	$14,654

[a] Total includes the Marine Corps. The applicable FHM program element combines the Navy and Marine Corps funding.

[b] Total includes the Marine Corps. The applicable DHP program element for non-FHM combines the Navy and Marine Corps funding.

TD F&I Maintenance Costs with Installation Detail

Table 2-7 contains the breakout of total F&I maintenance costs for FY17 at service-level detail based on the FYDP. These are the *expenses*.

Since maintenance is executed at the installation level, we had to go a step further and decompose the service-level expenses to the installation level of detail. Accordingly, we asked the services, DLA, and the DHP staffs to provide installation detail for the various expenses shown in Table 2-7 with the exception of MILPAY. The installation-level totals from each of the services are the *receipts*. The total *receipts* we expect are $12.938 billion (the total [$14.654 billion] in Table 2-7 minus the MILPAY [$1.716 billion]).

The installation-level receipts we received equated to $12.191 billion in F&I maintenance spending, which accounts for 94.2 percent of the expected TD service-level expenses—an excellent result. We provide the summarized results of these detailed submissions in Table 2-8.

Table 2-8. Summary of Service Submissions of Top-Down F&I Maintenance Costs ($ in millions—FY17)

Service	Total		
	Expenses	Receipts	% of Expenses Received
Army	$4,505	$4,014	89.1
Navy/Marine Corps	$4,160	$4,117	99.0
Air Force	$4,273	$4,060	95.0
Total	$12,938	$12,191	94.2

We knew the total F&I maintenance expenses in FY17 were $12.938 billion, but the installation-level receipts we received totaled only $12.191 billion, so we needed to adjust the installation-level receipts to account for the $747 million difference.

To account for the gap, we used a scaling factor for each installation's TD total for each service and funding source from Table 2-7 (less MILPAY) to adjust the corresponding values of Table 2-8. For example, the total of the Army non-MILPAY receipts were $4.014 billion. We calculated the total non-MILPAY expenses to be $4.505 billion (see Table 2-7). Therefore, we applied the resulting factor of 1.122 (which is 4.505 ÷ 4.014) to all Army installations that receive F&I maintenance funding.

Applying this same technique for all service and funding source combinations that showed a gap between the expenses (Table 2-7) and the detailed installation-level receipts (Table 2-8) allowed us to account for the total F&I maintenance costs of $12.938 billion at the installation-level of detail. We then allocated the services' MILPAY amounts (in Table 2-7) to each installation based on their total F&I maintenance costs. The idea being, installations with higher maintenance costs require more manpower to execute those requirements. In this way, we accounted for all the expenses from Table 2-7 at the installation level of detail.

We then turned our attention to the TD expenditures for F&I construction.

TD F&I Construction Expenditures

FH Construction

The F&I appropriations cost tree for the FH appropriation (see Appendix B) contains four cost categories:

- Post-acquisition construction—$73 million
- New construction—$246 million
- Maintenance—$282 million
- Other (operations, debt payments, leasing, privatization, etc.)—$761 million.

We used the post-acquisition construction and new construction categories to calculate the TD FH construction expenditures. This total was roughly $319 million. When we added the MILPAY component of FH construction costs ($8.1 million from Table C-4 in Appendix C), the total TD FH construction costs rose to $327 million.

Non-FH Construction (MILCON)

Determining the MILCON TD expenditure was fairly simple because it equated to the congressional appropriation and the MILPAY component of MILCON. For FY17, the MILCON appropriation was $7.593 billion. When we added the MILPAY component of MILCON costs ($195.9 million from Table C-4 in Appendix C), the total TD MILCON cost was $7.789 billion.

We show the TD costs associated with non-FH construction in Table 2-9.

Table 2-9. TD Non-FH Construction Costs (FY17)

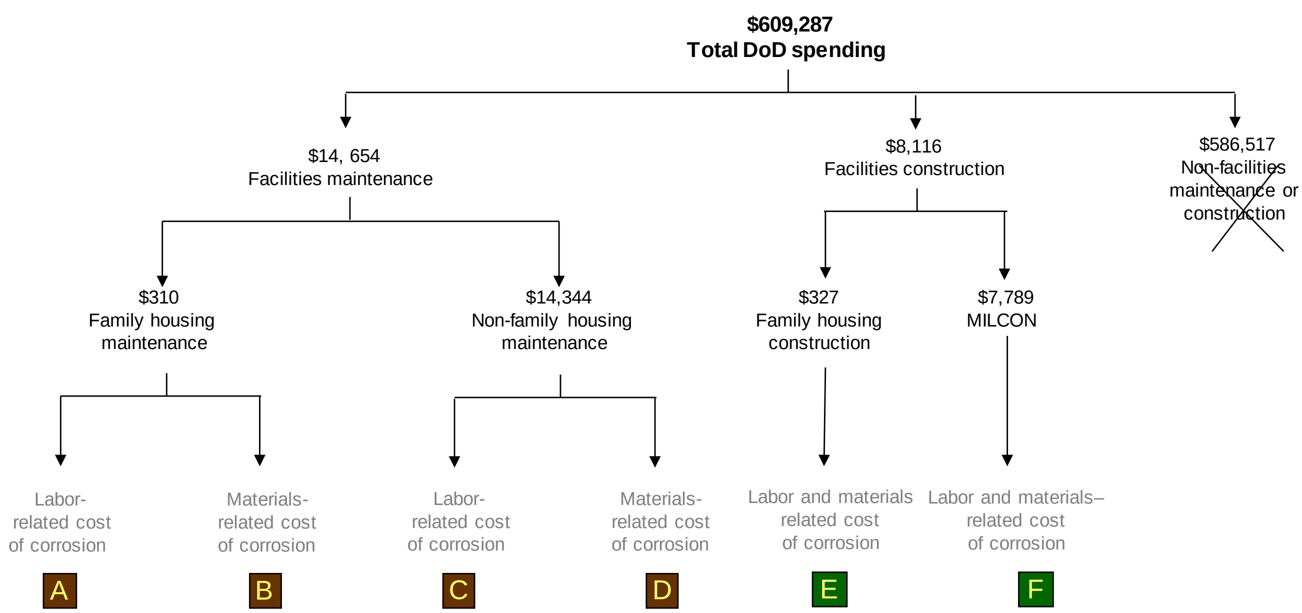
Source	Total expenditure
MILCON appropriation	$7.593 billion
Construction-related military pay	$0.196 billion
Total	$7.789 billion

Summary of TD Analysis

This concluded our TD analysis. We started with the TOA for DoD in FY17 of over $609 billion and narrowed the potential F&I corrosion costs into the two main groups: facilities maintenance and facilities construction.

The total costs in these two groups was approximately $22.7 billion (see Figure 2-2). These were not all corrosion costs; they are merely the new upper boundary of possible corrosion costs.

Figure 2-2. TD F&I Corrosion Cost Tree ($ in millions—FY17)



Note: The non-FHM, family housing construction, and MILCON cost figures include a portion of the MILPAY appropriation. We provide details of this calculation in Appendix C.

We next discuss our approach to calculating the BU amounts by node.

BU Analysis

As we did for the top-down analysis, we separated the detailed BU data into maintenance and construction costs. We address maintenance data first.

DoD F&I Maintenance Cost of Corrosion (Nodes A through D)

The cost of corrosion for DoD facilities maintenance was $1.997 billion. This was the combined corrosion cost for nodes A through D in our corrosion cost tree (see Figure 2-1). We developed this cost estimate from the BU.

Maintenance Data Collection

We collected data centrally from the primary F&I maintenance data collection systems of each service. We were able to coordinate this data call through the services' database administrators. We provide a list of the services' primary F&I maintenance databases we used in Appendix D.

We consolidated all the service and agency data to standardize the information in a central database. This created a total of 14,445,951 data records for the 6-year study period (FY12–17).[4]

Data Validation and Standardization

To be useful in our analysis, an individual record needed to contain the following data elements:

- Installation name
- Facility number or FAC code
- Shop code or description
- Labor hours or cost
- Materials cost
- Detailed narrative description of the work performed.

We removed data records from our dataset that were either missing any of the data elements listed above.

We then reclassified the remaining data records into a standard format for the installation name provided. For example, the RPAD may list Fort Stewart under "Fort Stewart," the BU data records may have had the installation name as "Ft Stewart," and the TD spending for Fort Stewart provided by the Army may have simply had "Stewart." We could not proceed with the analysis until we reconciled the names for F&I assets listed in the RPAD, the TD receipts, and the BU data.

Similarly, we needed to reclassify each complete data record for the craft code (the standard craft that performed the work). Knowing the craft (plumbing, electrical, fuels, etc.) that executed the maintenance task gave us some insight into the nature of the work and whether it was corrosion-related. Even though the services tend to use similar crafts to execute maintenance at different installations, the shop codes that identify those crafts in the data records used different naming conventions; sometimes there were differences between two installations of the same service. When available, we used the shop code or work description to assign the data record to one of the eight standard crafts as follows:

- Interior plumbing
- Exterior plumbing
- Interior electric
- Exterior electric
- Heating, ventilation, and air-conditioning (HVAC)
- Fuels

[4] There were 2,152,549 records for FY17.

- General building
- Roads and grounds.

We also developed a list of standard shop descriptions. This provided more detail for analysis. For example, the “roads and grounds” craft code is involved with different types of work, from repairing sidewalks or roads to repainting signage or exterminating pests. We developed a list of 42 shop codes and categorized each of the maintenance records according to those codes. We provide in Appendix E a complete list of the shop codes we used.

TD, BU Synthesis of Maintenance Data

Our next step was to adjust the maintenance expenditure totals from the remaining BU records based on our TD installation-level expenditure data.

Taking the total TD F&I maintenance expenditures of $14.654 billion, we classified the expenses by service and by funding category (FH and non-FH). We then aggregated the BU costs by the same categories, which gave us the scaling factor that we applied to each segment so the BU costs matched the TD costs. We present this information in Table 2-10.

Table 2-10. TD Total Maintenance Expenditures by Service and Funding Category (FY17)

Service	Family housing?	BU cost (in millions)	TD cost (in millions)	Scaling factor (TD to BU)
Air Force	No	$1,427	$4,252	3.0
	Yes	$46	$125	2.7
Army	No	$604	$5,301	8.8
	Yes	$5	$90	18.0
Navy/Marine Corps	No	$433	$4,709	10.9
	Yes	$7	$95	13.6
Other defense	No	$0	$82	N/A
	Yes	$0	$0	N/A
Total	No	$2,522	$14,344	5.7
	Yes	$58	$310	5.3
	All	$2,522	$14,654	5.8

The TD expenditures exceeded the aggregated BU data for each service and funding category. This is because it is extremely difficult to acquire every maintenance record from every source, and we only included in our analysis the records that contained all necessary data elements. Additionally, the TD labor cost are the salaries paid to those service members who perform facilities maintenance. These salaries are fully burdened in that they contain cost for benefits, vacation, sick leave, etc. The BU labor costs only include those direct hours spent maintaining infrastructure and facilities. Therefore, by design, there will always be a shortfall between the TD and BU labor costs.

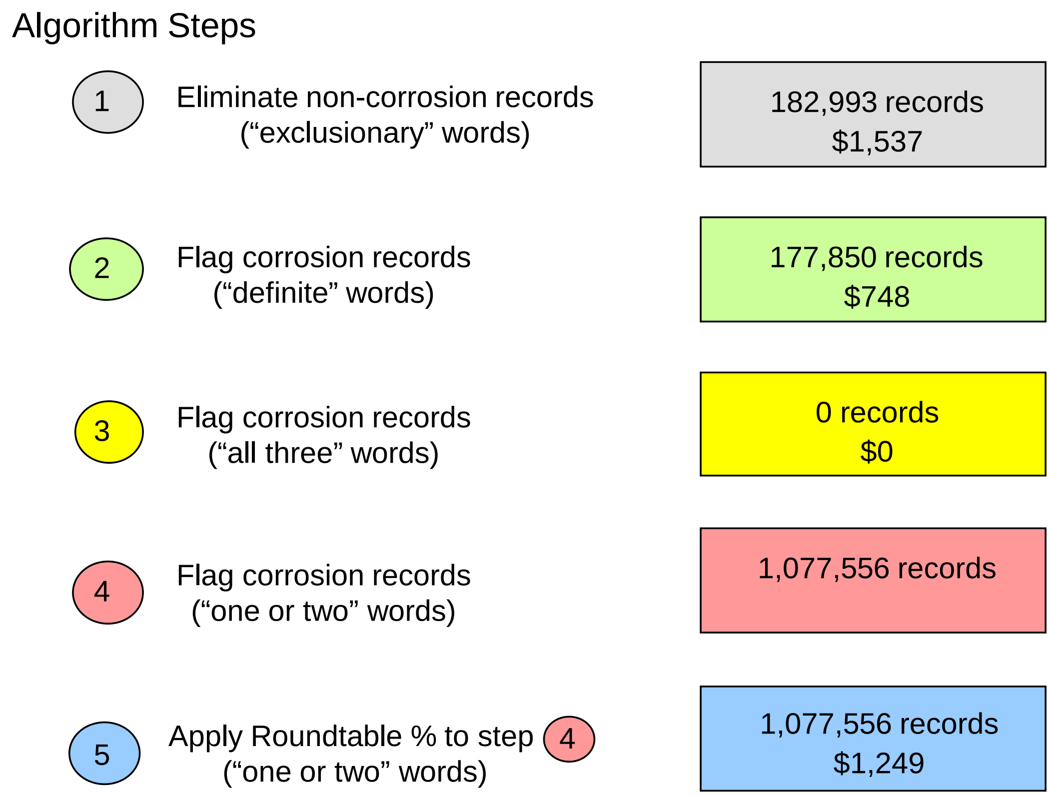
We did not have data from the other defense agencies and therefore did not pursue BU data records.

Corrosion Search Algorithm

Once we completed the data validation, classification, and scaling of data records, we were ready to analyze the corrosion costs. Using the feedback from the roundtable discussions with craftsmen and F&I expertise within the study team, we developed a search algorithm to distinguish the corrosion-related records from all other maintenance records.

The search algorithm looks for combinations of keywords to identify corrosion-related maintenance tasks. When the narrative description of the work performed contained the keywords in the search algorithm, the record was flagged as a possible corrosion cost. Figure 2-3 illustrates the five steps of the algorithm. We explain the search algorithm fully in Appendix F.

Figure 2-3. Summary of Corrosion Search Algorithm Steps with Number of Records and Cost Impact ($ in millions—FY17)



The first step was to exclude BU data records that are not related to corrosion. We developed a list of “exclusionary” words, such as mice, lock, and bee. We provide a listing of these words in Appendix G.

We removed from consideration records that contained these exclusionary words—a total of 177,850 data records. We summarize the records we excluded in Table 2-11.

Table 2-11. BU Data Records Flagged by Exclusionary Corrosion Keywords ($ in millions—FY17)

Service	Records searched		Records flagged for exclusion		Excluded records as percentage of total	
	Number of records	Maintenance cost	Number of records	Potential corrosion cost excluded	Number of records	Cost
Air Force	3,079	$4,377	581	$596	19	14
Army	969,486	$5,391	81,337	$489	8	9
Navy/Marine Corps	1,179,984	$4,804	101,075	$452	9	9
Total	2,152,549	$14,572	182,993	$1,537	9	11

Note: Numbers may not add due to rounding.

We then searched the remaining records for what we call “definite” corrosion words. These keywords include rust, corrode, and mold. We provide a listing of all corrosion definite keywords in Appendix H. We flagged records that contain these words as having corrosion costs, and then segregated them. We present a summary of these records in Table 2-12.

Table 2-12. Records with Definite Corrosion Keywords Flagged ($ in millions—FY17)

Service	Records searched		Records flagged with corrosion-definite words		Corrosion-definite records as percentage of total	
	Number of records	Maintenance cost	Number of records	Corrosion cost	Number of records	Corrosion-related cost
Air Force	2,498	$3,780	325	$246	13	7
Army	888,149	$4,903	71,873	$156	8	3
Navy/Marine Corps	1,078,909	$4,352	105,652	$347	10	8
Total	1,969,556	$13,035	177,850	$749	9	6

Note: Numbers may not add due to rounding.

Of the 177,850 data records that were flagged by keyword as a definite corrosion-related maintenance record, 56,204 were flagged by the keyword inspect or similar words. These records account for $116 million of the $749 million of corrosion cost in Table 2-12. “Inspect” and its synonyms were the only definite corrosion keywords for which we did not include 100 percent of the recorded cost.[5]

The search algorithm also contains sections that search for combinations of key corrosion-related verbs, adjectives, and nouns. Key corrosion verbs include paint, remediate, and repair. Key corrosion adjectives include scaling, leaking, and cracked. Key corrosion nouns include pipe, roof, and barracks. We provide a listing of these words in Appendix I.

We isolated records that contained combinations with all three types of corrosion keywords. For example, we would have flagged a record with “repair [verb] leaking

[5] Inspection flagged records had a 50 percent corrosion cost factor applied.

[adjective] pipe [noun]" as corrosion-related and segregated it. We did not find any records which contained all three corrosion words.

The next step was to flag and segregate all records that contain one or two of the keywords, regardless of whether it was a verb, adjective, or noun. We summarize the results in Table 2-13.

Table 2-13. Records with One or Two Corrosion Keywords Flagged

Service	Number of records searched	Number of records flagged with 1–2 corrosion keywords	Corrosion-related records as percentage of total
Air Force	2,173	670	30.8
Army	816,276	541,742	66.4
Navy/Marine Corps	973,257	535,144	55.0
Total	1,791,706	1,077,556	60.1

Site Visits and Roundtable Discussions

Our data-gathering process normally includes installation visits and teleconference roundtable sessions to learn firsthand of the installation corrosion issues. Due to significant delays in receiving the transactional BU and TD data, we did not conduct the site visits for this study. We used the aggregated results from the craftsman roundtable visits of previous corrosion impact studies to assess the corrosion cost of those records flagged by the one or two keyword approach. The corrosion percentages applied to these records we determined through interviews with the eight craftsman in locations from differing ESI zones. The interview consisted of asking each craftsman the same three questions:

- Based on the congressional definition of corrosion, what corrosion issues do you face in your area of expertise?
- What percentage of your workload was due to these corrosion challenges? How would you separate these percentages by corrective work as compared to preventive work?
- What "keywords" might describe the corrosion-related issues in the narrative descriptions of the maintenance data records?

Using the feedback from the previous roundtable sessions with craftsmen, we applied the corrosion-related percentages by craft, ESI zone, and nature of work to the costs contained in the records flagged by one or two corrosion words to estimate a corrosion cost. We show an example of this calculation in Table 2-14.[6]

[6] We applied the corrosion percentages by craft to only these records because we have enough information within the work description of each to assess the corrosion status of "exclusionary," "definite," and "all three" corrosion records. The "one or two" corrosion keyword records are only possibly related to corrosion. We relied on the craftsmen's expertise to assess these records.

Table 2-14. Notional Example of Craftsmen Roundtable Percentages Applied to Flagged Records by Craft, ESI Zone, and Nature of Work

Craft	ESI	Preventive or corrective	Corrosion percentage	Flagged records	Maintenance cost of flagged records	Corrosion cost of flagged records
Exterior electric	10	Preventive	10	150	$200,000	$20,000
Roads and grounds	6	Corrective	18	300	$150,000	$27,000
Interior plumbing	2	Preventive	20	200	$500,000	$100,000
HVAC	12	Corrective	25	40	$10,000	$2,500
Fuels	17	Preventive	15	10	$50,000	$7,500

Table 2-15 shows the service-specific results after we applied the craftsmen-recommended corrosion cost percentages to the records that were flagged as having one or two key corrosion words.

Table 2-15. Corrosion Costs Flagged Records after Roundtable Corrosion Percentages Applied ($ in millions—FY17)

Service	All records searched		Records flagged with 1–2 corrosion words		Corrosion-related records as percentage of total	
	Number of records	Maintenance cost	Number of records	Corrosion cost	Number of records	Cost
Air Force	2,173	$3,500	670	$283	30.8	8.1
Army	816,276	$4,672	541,742	$575	66.4	12.3
Navy/Marine Corps	973,257	$3,866	535,144	$391	55.0	10.1
Total	1,791,706	$12,869	1,077,556	$1,249	60.1	9.7

Note: Numbers may not add due to rounding.

When we combined the costs from the flagged records from Table 2-12 (definite corrosion words) and Table 2-13 (one or two corrosion words), we obtained the total corrosion costs of F&I maintenance by service. We show these results in Table 2-16.

Table 2-16. Total F&I Maintenance Corrosion Costs by Service ($ in millions—FY17)

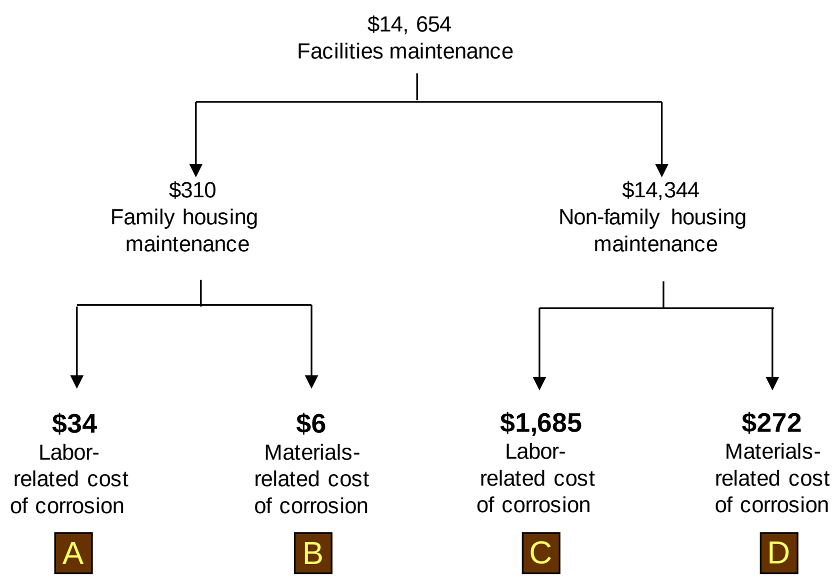
Service	All records searched		Records flagged for corrosion		Corrosion-related as a percentage of total	
	Number of records	Maintenance cost	Number of records	Corrosion cost	Number of records	Cost
Air Force	3,079	$4,376	995	$529	32.3	12.1
Army	969,486	$5,392	613,615	$730	63.3	13.5
Navy/Marine Corps	1,179,984	$4,805	640,796	$738	54.3	15.4
Total	2,152,549	$14,573	1,255,406	$1,997	58.3	13.7

Note: Numbers may not add due to rounding.

Summary of DoD F&I Maintenance Cost of Corrosion (Nodes A through D)

We found the cost of corrosion for nodes A through D in Figure 2-4 by aggregating the labor and materials costs associated with flagged corrosion records. We separated FHM costs from non-FHM costs through the use of FAC codes from the BU records. Records with FAC codes beginning with "71" are FHM. All others are non-FHM.

Figure 2-4. Summary of F&I Maintenance Corrosion Costs
($ in millions—FY17)

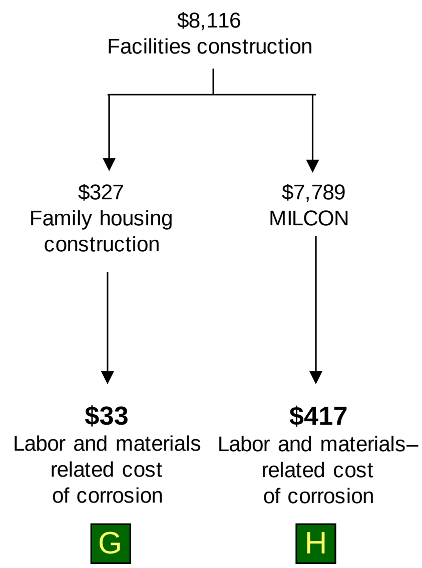


Because we classified every record by ESI zone, installation, FAC code, craft code, shop code, and nature of work, we could also segregate corrosion costs by these parameters. We present some of this analysis in the next chapter.

DoD F&I Construction Cost of Corrosion (Nodes E and F)

We next turned our attention to calculating the cost of corrosion associated with construction of DoD F&I, which were the costs contained in nodes E and F from our corrosion cost tree in Figure 2-1. We repeat the construction cost section in Figure 2-5 for ease of discussion. The cost of corrosion for F&I construction was $450 million. We provide a detailed summary of how we determined the corrosion cost in the following sections.

Figure 2-5. Final F&I Construction Corrosion Cost Tree ($ in millions—FY17)



MILCON and FH Construction Project Data

We began our construction cost analysis with a comprehensive list of all MILCON and FH construction projects for FY17.[7] We used reporting data from FY19 because it contained actual expenditures from planned FY17 projects and, therefore, ensured a more accurate assessment.

We categorized each of the 299 projects by originating service and whether it was a MILCON or FH construction appropriation, as shown in Table 2-17.

Table 2-17. Total Number of FY17 MILCON and FH Construction Projects

Service	MILCON	FH
Army	47	4
Navy and Marine Corps	54	4
Air Force	117	2
Other defense agency[a]	71	0
Total	289	10

[a] Includes Special Operations Command, National Security Agency, DLA, TRICARE Management Activity, and the Department of Defense Educational Activity.

The best source of data for analysis of potential construction corrosion costs was the full (long form) Defense Department Form 1391 (DD1391), Military Construction Project Data. The DD1391 includes a description and justification of the proposed construction as well as a description of the current situation and a breakdown of the

[7] http://comptroller.defense.gov/defbudget/Budget2019.html.

cost estimate. This form is required for each MILCON and FH construction project and is available on each service's comptroller website.

The service comptroller sites contain only information for a portion of the MILCON and FH construction projects. Table 2-18 shows the percentage of project dollars for both FH construction and MILCON projects for which we were able to locate data in sufficient detail to determine corrosion costs.

Table 2-18. Summary of Costs of FY17 MILCON and FH Construction Projects

Service	Number of corrosion-related projects	Total project costs	Project costs with supporting data	Percentage of project costs with supporting data	Scaling factor
Army	51	$1,326	$1,437	108	0.92
Navy and Marine Corps	58	$1,989	$1,720	86	1.16
Air Force	119	$2,375	$2,362	99	1.01
Other defense agencies	71	$2,426	$2,371	98	1.02
Total	299	$8,116	$7,890	97	1.03

From a project cost standpoint, we were able to obtain data on 97 percent of the total FH construction and MILCON projects. For both the Army, the project funding amounts listed in the DD 1391 exceeded the congressional appropriation. Although slightly unusual, this is not a major concern as the totals in the DD1391 form reflect engineering estimates.

TD, BU Synthesis of Construction Data

For each project with DD1391 information, we applied a scaling factor to the project's cost to account for the gap between our BU totals ($7.890 billion) and our TD total ($8.116 billion). We depict these scaling factors by service and defense agency in the last column of Table 2-18.

With a scaling factor of 1.16, the Department of the Navy had the largest gap between the TD constructions expenditure ($1.989 billion) and its cost figures accounted for in available DD1391 information ($1.720 billion). Relatively speaking, these scaling factors constitute minor adjustments.

Determination of Corrosion-Related Construction Costs

To determine which projects contained potential corrosion costs, we conducted a keyword search of the DD1391 for each project using the words listed in Table 2-19. We used the words listed, as well as their root and potential misspellings.

We developed this list of words to highlight potential corrosion activities from our field visits and discussions with F&I craftsmen. We segregated the keywords by their preventive or corrective nature of cost.

Table 2-19. Corrosion Keywords

Preventive corrosion cost	Corrective corrosion cost	
cath*	deterior*	crack
dehumidi*	corro*	moisture
paint	repair	water damage
air conditioning	1930s	pier
corrosion control	1940s	climate control
	1950s	fouling
	1960s	wharf
	leak	waterfront
	rust	sheet metal
	mold	age
	rot	HVAC
	weld	
	blast	
cath*	deterior*	crack

We searched all construction projects for these potential corrosion words, flagged the DD1391s that contained the keywords, and segregated them from the DD1391s that did not contain any of the keywords.

Preventive Corrosion Costs

To determine specific preventive costs, we looked at each project DD1391 flagged by the keyword search. We examined the detailed cost breakdown for each project and extracted the preventive corrosion cost depending on which keyword was highlighted.

We present a summary of the preventive corrosion costs for construction projects in Table 2-20.

Table 2-20. Preventive Corrosion Costs for MILCON and FH Construction Projects ($ in millions—FY17)

Service	Number of construction projects	Projects with preventive corrosion costs only	Percentage of projects with preventive corrosion costs only	Total project costs	Preventive corrosion cost	Percentage of preventive corrosion costs
Army	51	12	23.5	$1,326	$6.7	0.5
Navy	58	2	3.4	$1,989	$3.6	0.2
Air Force	119	0	0.0	$2,375	$0.0	0.0
Other defense agencies	71	0	0.0	$2,427	$0.0	0.0
Total	299	14	4.7	$8,117	$10.3	0.1

Based on this categorization, we found that $10.3 million was spent on preventive construction, or 0.1 percent of the total. There were many projects that were corrosion-related that had both corrective and preventive costs but we did not include those preventive corrosion costs here.

Corrective Corrosion Costs

To determine corrective corrosion costs for MILCON and FH construction projects costs, we used the corrective corrosion search words from Table 2-19 and searched the DD1391s for all construction projects, segregating those that contained corrective corrosion keywords. Of the 299 MILCON and FH construction projects, we flagged 148 projects through the corrective keyword search.

Based on the roundtable discussions with craftsmen and our own experience from the initial F&I cost of corrosion study, we assigned baseline corrective corrosion percentages to each of the 20 ESI zones. We present these percentages in Table 2-21.

Table 2-21. Baseline Corrective Corrosion Cost Percentage by ESI Zone

ESI zone	ESI 1–5	ESI 6–10	ESI 11–15	ESI 16–19
Baseline corrective corrosion percentage	0%	3%	6%	9%

We carefully reviewed the DD1391 for each of the 148 projects that contained corrective corrosion cost keywords. We then assessed the severity of corrosion as a contributing cause to the construction project based on the project description and the "current situation" section of the form. We assigned each project a corrosion contribution score from one to four as follows:

- Minor (1) — 1–2 corrosion keywords were found. It was a minor contributor to the project. To determine the corrosion cost we multiplied the baseline percentage by the project cost.
- Moderate (2) — 3–4 corrosion keywords were found. We added 10 percent to the baseline corrosion figure. This total was then multiplied by the project cost to determine the corrosion cost.
- Significant (3) — 5–6 corrosion keywords were found. We added 25 percent to the baseline corrosion figure. This total was then multiplied by the project cost to determine the corrosion cost.
- Major (4) — 7–9 corrosion keywords were found. We added an additional 50 percent to the baseline corrosion figure. This total was then multiplied by the project cost to determine the corrosion cost.

The corrosion contribution score did not imply a lack of maintenance, although it could have been a contributing factor. The corrosion contribution score was merely a reflection of the role corrosion on the current facility played in the justification of the new construction project. There was not enough information available in the DD1391s to make conclusions beyond this. We show the results of this corrosion severity assessment in Table 2-22.

Table 2-22. Corrosion Severity Assessment for Construction Projects

Service	Projects flagged as corrective	Corrosion severity (number of projects)			
		Minor	Moderate	Significant	Major
Army	30	19	9	1	1
Navy	31	22	7	2	0
Air Force	63	45	14	4	0
Other defense agencies	24	11	9	4	0
Total	148	97	39	11	1

We show the corrective corrosion costs for MILCON projects in Table 2-23.

Table 2-23. Corrective Corrosion Costs for MILCON Projects ($ in millions—FY17)

Service	Number of MILCON projects	Projects with corrective corrosion costs	Percentage of projects with corrective corrosion costs	Total project costs	Corrective corrosion cost	Percentage of corrective corrosion costs
Army	51	30	58.8	$1,326	$48.7	3.7
Navy	58	31	53.4	$1,989	$93.3	4.7
Air Force	119	63	52.9	$2,375	$102.0	4.3
Other defense agencies	71	24	33.8	$2,427	$195.3	8.0
Total	299	148	49.5	$8,117	$439.3	5.4

We estimated the corrective corrosion costs for both MILCON and FH projects to be $449.6 million.

Summary of DoD F&I Construction Corrosion Costs (Nodes E and F)

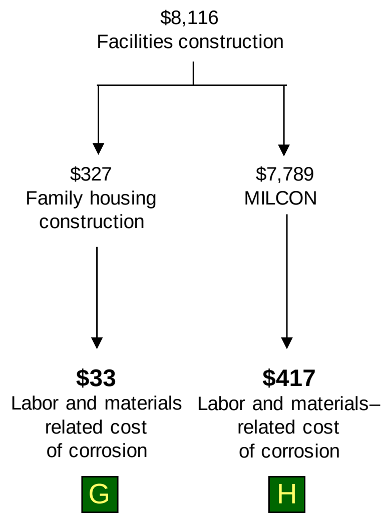
By summing the preventive and corrective corrosion construction costs, we determined the final construction corrosion costs. We show these in Table 2-24.

Table 2-24. Final Total of Construction Corrosion Costs ($ in millions—FY17)

Service	Preventive construction cost	Corrective construction cost	Total corrosion construction cost	Total FH construction corrosion cost	Total MILCON corrosion cost
Army	$6.7	$48.7	$55.4	$14.8	$40.6
Navy	$3.6	$93.3	$96.9	$18.6	$78.3
Air Force	$0.0	$102.0	$102.0	$0.0	$102.0
Other defense agencies	$0.0	$195.3	$195.3	$0.0	$195.3
Total	$10.3	$439.3	$449.6	$33.4	$416.2

We show these final costs for nodes E and F in the cost tree in Figure 2-6.

Figure 2-6. Final Construction Corrosion Cost for Nodes E and F
($ in millions—FY17)



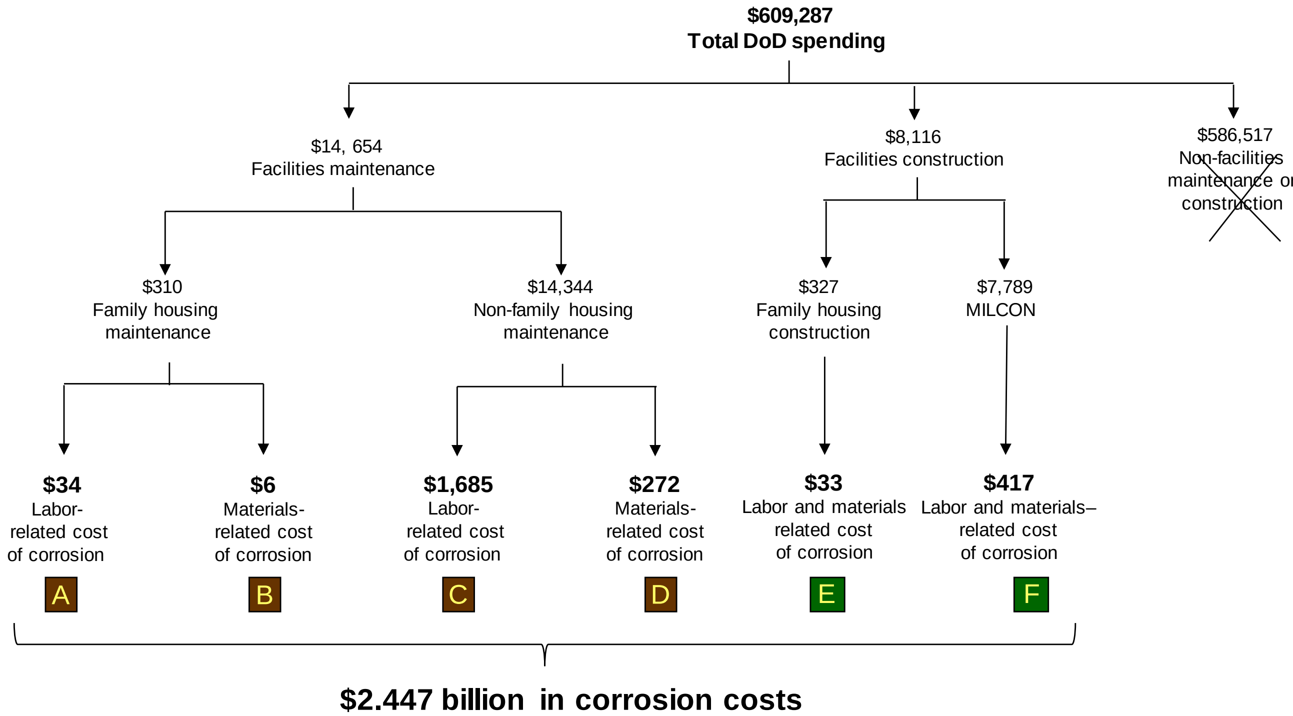
FH construction corrosion costs were $33 million, or 10.1 percent of the total FH construction expenditures of $327 million for FY17.

MILCON corrosion costs are $417 million, just 5.3 percent of the total MILCON expenditures of $7.789 billion for FY17.

Final F&I Corrosion Cost Tree (Nodes A through F)

In Figure 2-7, we present the F&I corrosion cost tree with corrosion costs at each node determined.

Figure 2-7. Final F&I Corrosion Cost Tree ($ in millions—FY17)



Chapter 3
Summary and Analysis of DoD F&I Corrosion Costs

In this chapter, we fulfill three objectives:

- Extract several of the more interesting data views and discuss their significance.
- Present a list of best practices to minimize the cost and impact of F&I corrosion.
- Develop a method by which the actual cost findings from the study can be used for determining future sustainment requirements as they pertain to corrosion.

Data Views and Their Significance

During the execution of this study, we add this data to a repository called the DoD Maintenance and Availability Data Warehouse (MADW). The MADW is available to the services' installation management representatives for review and analysis. The MADW allows for many different views of F&I corrosion costs—far too many to depict within the body of this report. We present a few of these views here and discuss their significance.

FY17 F&I Corrosion Costs by Node

We present the FY17 DoD F&I corrosion costs by node in Table 3-1.

Table 3-1. Breakout of DoD F&I Corrosion Costs by Node ($ in millions—FY17)

Node	Description	Total facilities maintenance cost	Corrosion cost	Corrosion as a percentage of total maintenance cost
A	FHM labor	$263	$34	12.9%
B	FHM materials	$47	$6	12.8%
A + B	*FHM subtotal*	$310	$40	12.9%
C	Non-FHM labor	$12,422	$1,685	13.6%
D	Non-FHM materials	$1,922	$272	14.2%
C + D	*Non-FHM subtotal*	$14,344	$1,957	13.6%
Total facilities maintenance		$14,654	$1,997	13.6%
E	FH construction (labor and materials)	$327	$33	10.1%
F	MILCON (labor and materials)	$7,789	$417	5.4%
Total facilities construction		$8,116	$450	5.5%
Total all facilities costs		$22,770	$2,447	10.7%

Note: Numbers may not add because of rounding.

The cost of corrosion-related F&I maintenance ($1.997 billion) accounted for over 80 percent of the total F&I corrosion costs, dwarfing the corrosion cost due to construction. We estimated the corrosion costs for F&I construction was $450 million, 5.5 percent of total construction spending. This was significantly lower than the ratio of maintenance corrosion cost to total maintenance, which was 13.6 percent. There are two main reasons for this corrosion percentage difference:

- Typically, when costs need to be reduced from an initial construction cost estimate, corrosion preventive measures tend to be among the first areas to be reduced or removed from the construction project.
- The descriptions for maintenance actions had significantly greater detail than for the descriptions of construction projects. As a result, the construction project descriptions may not have contained the keywords to flag the work as a corrosion cost.

We see from Table 3-1 that the corrosion-related maintenance costs for non-FH facilities (nodes C and D) were significantly higher than the corrosion-related maintenance costs for FH F&I (nodes A and B), $1,957 million versus $40 million. This is true from a total cost standpoint. The corrosion-related maintenance costs for non-FH are only slightly higher than the corrosion costs for FH from a percentage of maintenance standpoint (13.6 percent compared to 12.9 percent). The maintenance and corrosion costs for non-FH facilities and infrastructure greatly exceed the same costs for FH F&I because there are significantly fewer FH facilities owned by DoD. Each service within DoD is moving to privatize FH. The ownership of these facilities is being transferred to private companies, which are responsible for the maintenance and upkeep. In exchange, the private companies receive the occupant's basic allowance for housing pay.

Because corrosion-related F&I maintenance costs ($1.997 billion) were over 80 percent of the total corrosion costs ($2.447 billion) and presented a greater opportunity for improvement, we focus on F&I maintenance corrosion costs in the remainder of our analysis. We first present a summary of the maintenance corrosion costs for each study year.

Multiple-Year Corrosion Costs

We present a summary of DoD F&I maintenance corrosion costs by study year in Table 3-2.

Table 3-2. F&I Maintenance Costs and Corrosion-Related Maintenance Costs by Data Year ($ in millions)

Data baseline year	Maintenance cost	Corrosion cost	Corrosion as a percentage of maintenance	Change from FY05		Change from FY11	
				Maintenance cost	Corrosion cost	Maintenance cost	Corrosion cost
FY05	$10,216	$1,167	11.4	—	—	—	—
FY07	$10,648	$1,076	10.1	4.2%	−7.8%	—	—
FY08	$12,879	$1,585	12.3	26.1%	35.8%	—	—
FY09	$16,225	$2,224	13.7	58.8%	90.6%	—	—
FY10	$15,394	$2,138	13.9	50.7%	83.2%	—	—
FY11	$15,936	$2,301	14.4	56.0%	97.2%	—	—
FY12	$15,575	$1,937	12.4	52.5%	66.0%	−2.3%	−15.8%
FY13	$13,719	$1,921	14.0	34.3%	64.6%	−13.9%	−16.5%
FY14	$16,761	$2,496	14.9	64.1%	113.9%	5.2%	8.5%

Table 3-2. F&I Maintenance Costs and Corrosion-Related Maintenance Costs by Data Year ($ in millions)

Data baseline year	Maintenance cost	Corrosion cost	Corrosion as a percentage of maintenance	Change from FY05		Change from FY11	
				Maintenance cost	Corrosion cost	Maintenance cost	Corrosion cost
FY15	$13,521	$1,977	14.6	32.4%	69.4%	−15.2%	−14.1%
FY16	$15,174	$2,068	13.6	48.5%	77.2%	−4.8%	−10.1%
FY17	$14,654	$1,997	13.6	43.4%	71.1%	−8.0%	−13.2%
Total	$170,620	$22,887	13.4				

Note: We excluded construction corrosion costs from this analysis.

A Tale of Two Corrosion Cost Trends

DoD F&I corrosion costs incurred during the performance of maintenance had been steadily increasing from both a total cost and percentage of maintenance standpoint for the first 4 years of the study (FY05 through FY09). However since that time, the corrosion cost as a percent of maintenance cost has averaged 13.9 percent with all study years showing a corrosion percent no more than 1 percent different than the average. This indicates corrosion costs have plateaued and are more likely to rise and fall as the maintenance spending changes. In fact since FY11, both maintenance costs and corrosion costs have actually declined, with the corrosion cost decreasing at a faster rate than maintenance costs. This is good news.

F&I FY17 Maintenance Corrosion Costs by FAC

We calculated the total corrosion cost by FAC and depict the top 10 contributors to F&I corrosion-related maintenance costs in Table 3-3.

Table 3-3. Top 10 F&I Maintenance Corrosion Costs by FAC ($ in millions—FY17)

FAC	Description	Total maintenance cost	Total corrosion cost	Corrosion as a percentage of maintenance
BLDM	General Building Maintenance	$1,784	$363	20.4
6100	General Administrative Building	$955	$129	13.6
7210	Enlisted Unaccompanied Personnel Housing	$520	$120	23.1
SIGN	Signage	$643	$75	11.7
INEL	Interior Electric	$816	$72	8.8
8910	Utility Building	$493	$67	13.7
INPL	Interior Plumbing	$344	$48	14.1
7213	Student Barracks	$123	$48	39.1
7110	Family Housing Dwelling	$312	$40	12.9
8111	Electrical Power Source	$175	$39	22.4

It is no surprise that FACs associated with building maintenance and enlisted personnel housing such as 6100 and 7210 are among the highest corrosion cost contributors. These are high-use, high-occupancy type of facilities. It is reasonable to conclude that corrosion issues are more noticeable in such facilities because of the increased number of occupants and users. In addition, these facilities sustain heavy traffic and use; therefore, corrosion issues may receive earlier intervention and a higher percentage of maintenance costs than similar issues in other FAC types. These two facility types are also among the highest maintenance expenditures from those facility types listed in Table 3-3.

Corrosion costs alone do not tell the complete story concerning the degree corrosion affects these FACs. It is useful to also portray the corrosion cost per unit of area measurement for each of these FACs. We show this in Table 3-4.

Table 3-4. Top 10 F&I Maintenance Corrosion Costs by FAC by Unit of Measurement

FAC	Description	Corrosion cost (in millions)	Unit of measure	Total size	Corrosion cost per unit of measure
6100	General Administrative Building	$129	SF	169,519,777	$0.76
7210	Enlisted Unaccompanied Personnel Housing	$120	SF	133,971,124	$0.90
8910	Utility Building	$67	SF	17,471,428	$3.83
7213	Student Barracks	$48	SF	20,573,304	$2.33
7110	Family Housing Dwelling	$40	SF	49,191,498	$0.81
8111	Electrical Power Source	$39	KW	331,406	$117.68

Note: Numbers may differ due to rounding. KW = kilowatt; SF = square feet.

We do not show FACs BLDM, SIGN, INEL and INPL in Table 3-4 above as these FACs were assigned to those records for which a standard FAC did not exist. For example, if there was maintenance involved in replacing signage, the standard FAC tables do not contain a code for this. As such, there is not an area measurement available for these FACs as well.

For the FACs listed in Table 3-4, we see an interesting pattern in the data. There is generally an inverse relationship between total size of the facility type and the corrosion cost per unit of measurement. The three largest FACs by total size (FACs 6100, 7210, and 7110) all have corrosion cost per square foot under $1.00. The next closest FAC in terms of corrosion cost per square foot is FAC 7213–Student Barracks at $2.33 per square foot. The smallest three FACS by total size (FACs 8910, 7213, and 8111) have the highest corrosion cost per unit measurement.

The top two FACs by corrosion cost per unit of measurement (FACs 8111 and 8910) in Table 3-4 have a corrosion cost per unit of measurement that is significantly higher than that of the other FACs listed in Table 3-4. These FACs must have a special cause driving their higher-than-average corrosion cost per unit of measurement. Both contain electrical components that are fragile and susceptible to electrical shorts when corroded. The replacement cost of these components can be substantial.

F&I Corrosion Costs by Craft

We sorted the total F&I maintenance and corrosion costs by craft, as shown in Table 3-5.

Table 3-5. Total F&I Maintenance Corrosion Costs by Craft ($ in millions—FY17)

Craft code	Total maintenance cost	Total corrosion cost	Corrosion as a percentage of maintenance
General building maintenance	$4,790	$858	17.9
HVAC	$2,477	$342	13.8
Roads and grounds	$2,653	$242	9.1
Interior electric	$1,513	$163	10.8
Exterior plumbing	$1,040	$142	13.7
Interior plumbing	$808	$117	14.5
Exterior electric	$807	$109	13.5
Administration	$356	$13	3.7
Fuels	$127	$10	7.9

General building maintenance saw the highest total corrosion cost. General building maintenance had more than twice the corrosion-related maintenance cost as the craft with the next highest corrosion cost (HVAC), mainly because significantly more was spent on general building maintenance ($4.790 billion) as was spent on HVAC ($2.477 billion).

General building maintenance was also the craft with the highest percentage of its work related to corrosion, 17.9 percent.

In Table 3-6, we show the corrosion and maintenance costs for each craft at 3-year study intervals to assess trends.

Table 3-6. Total F&I Maintenance Corrosion Costs by Craft across Years ($ in millions)

Craft code	FY11			FY14			FY17		
	Maint.	Corr.	Corr. %	Maint.	Corr.	Corr. %	Maint.	Corr.	Corr. %
General bldg. maint.	$5,975	$1,046	17.5	$5,168	$1,079	20.9	$4,790	$858	17.9
HVAC	$2,163	$344	15.9	$3,070	$483	15.7	$2,477	$342	13.8
Roads and grounds	$2,838	$282	9.9	$2,494	$218	8.7	$2,653	$242	9.1
Interior electric	$1,579	$176	11.1	$1,927	$152	7.9	$1,513	$163	10.8
Exterior plumbing	$1,103	$167	15.1	$1,216	$179	14.7	$1,040	$142	13.7
Interior plumbing	$819	$166	20.2	$1,402	$200	14.3	$808	$117	14.5
Exterior electric	$1,048	$104	10.0	$902	$155	17.2	$807	$109	13.5

Table 3-6. Total F&I Maintenance Corrosion Costs by Craft across Years ($ in millions)

Craft code	FY11			FY14			FY17		
	Maint.	Corr.	Corr. %	Maint.	Corr.	Corr. %	Maint.	Corr.	Corr. %
Administration	$411	$3	0.8	$352	$2	0.6	$356	$13	3.7
Fuels	$88	$11	12.5	$229	$27	11.8	$127	$10	7.9
Total	$16,023	$2,300	14.4	$16,761	$2,496	14.9	$14,572	$1,997	13.7

The corrosion costs for all crafts had been increasing during the 6-year period, but showed a significant decline in FY17. The most prominent decline was in General Building Maintenance which is significant because it is the craft code with the largest corrosion cost.

F&I Corrosion Costs—Corrective versus Preventive Costs

We also segregated the data into corrective and preventive costs.[1] We depict the breakout of F&I corrosion-related maintenance costs into these two categories by ESI zone in Table 3-7.

We can see from Table 3-7 that DoD expended significantly more on corrective corrosion maintenance ($1,376 million) than it did for preventive corrosion maintenance ($595 million). The ratio of corrective to preventive corrosion spending was, in fact, 2.3 to 1. Not all ESI zones contained facilities which had maintenance costs. Zones 1, 2, and 14 did not. Additionally, there were some maintenance tasks which were categorized as neither preventive nor corrective. Planning is an example of such a task. These accounted for $910 million in maintenance costs and $26 million in corrosion costs.

Table 3-7. Total F&I Maintenance Corrosion Costs by ESI Zone—Corrective versus Preventive Costs ($ in millions—FY17)

ESI zone	Total maintenance cost		Corrosion cost		
	Corrective	Preventive	Corrective	Preventive	Corrective to preventive ratio
1	$0	$0	$0	$0	—
2	$0	$0	$0	$0	—
3	$354	$113	$59	$43	1.4
4	$932	$163	$117	$28	4.2
5	$63	$38	$3	$6	0.5
6	$544	$113	$32	$19	1.7
7	$2,374	$945	$188	$164	1.1
8	$1,291	$363	$360	$42	8.6
9	$1,111	$287	$97	$58	1.7
10	$849	$236	$68	$39	1.7

[1] We defined corrective and preventive costs in Chapter 1.

Table 3-7. Total F&I Maintenance Corrosion Costs by ESI Zone—Corrective versus Preventive Costs ($ in millions—FY17)

ESI zone	Total maintenance cost		Corrosion cost		
	Corrective	Preventive	Corrective	Preventive	Corrective to preventive ratio
11	$376	$173	$23	$31	0.7
12	$250	$122	$77	$19	4.1
13	$272	$128	$49	$30	1.6
14	$0	$0	$0	$0	—
15	$718	$133	$55	$18	3.1
16	$115	$58	$17	$11	1.5
17	$145	$60	$31	$14	2.2
18	$441	$54	$58	$16	3.6
19	$721	$200	$144	$57	2.5
Total	$10,557	$3,187	$1,376	$595	2.3

Note: Not all maintenance or corrosion costs can be definitively categorized as corrective or preventive.

Of the total preventive maintenance expenditures ($3,187 million), 18.7 percent was spent on corrosion ($595 million); only 13.0 percent of corrective maintenance expenditures were for corrosion.

The optimum ratio of corrective to preventive cost for corrosion maintenance of DoD facilities and infrastructure has not been determined; however, there is evidence to suggest a ratio close to 1:1 is desirable to minimize total maintenance costs.[2] This requires more study to determine the optimum corrective to preventive corrosion cost ratio for maintenance of DoD F&I.

Corrosion expenditures in ESI zones 4, 8, and 12 reflect an interesting pattern and a potential opportunity. In each zone, the corrective-to-preventive corrosion cost ratio exceeded 4-to-1. This may suggest an opportunity to increase preventive corrosion measures to reduce the overall corrosion-related maintenance costs.

We see similar trends when we break out preventive and corrective maintenance by FAC (Table 3-8) and craft code (Table 3-9). There is significantly more corrective corrosion maintenance than preventive.

Table 3-8. Top 10 F&I Maintenance and Corrosion Costs by FAC—Preventive versus Corrective Costs ($ in millions—FY17)

FAC	Description	Total maintenance cost		Corrosion cost	
		Corrective	Preventive	Corrective	Preventive
BLDM	General Building Maintenance	$1,170	$532	$251	$109
6100	General Administrative Building	$639	$205	$83	$45

[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.

Table 3-8. Top 10 F&I Maintenance and Corrosion Costs by FAC—Preventive versus Corrective Costs ($ in millions—FY17)

FAC	Description	Total maintenance cost		Corrosion cost	
		Corrective	Preventive	Corrective	Preventive
7210	Enlisted Unaccompanied Personnel Housing	$398	$99	$88	$31
SIGN	Signage	$422	$200	$40	$35
INEL	Interior Electric	$681	$117	$57	$14
8910	Utility Building	$339	$134	$40	$27
INPL	Interior Plumbing	$176	$40	$27	$12
7213	Student Barracks	$94	$27	$40	$8
7110	Family Housing Dwelling	$277	$30	$34	$6
8111	Electrical Power Source	$157	$17	$38	$1

Table 3-9. Total F&I Maintenance Corrosion Costs by Craft—Preventive versus Corrective Costs ($ in millions—FY17)

Craft code	Total maintenance cost		Corrosion cost	
	Corrective	Preventive	Corrective	Preventive
General building maintenance	$3,416	$1,081	$610	$238
HVAC	$1,859	$547	$248	$91
Roads and grounds	$1,998	$548	$163	$78
Exterior plumbing	$619	$304	$79	$53
Interior electric	$1,209	$252	$112	$51
Exterior electric	$580	$193	$62	$46
Interior plumbing	$591	$149	$84	$32
Administration	$223	$68	$9	$4
Fuels	$61	$44	$8	$2

F&I Corrosion Costs by ESI Zone

Another way to view the corrosion cost data is by ESI zone. As a reminder, the lower the ESI zone, the more moderate and, theoretically, less corrosive environment. We would expect a pattern of increasing corrosion cost percentages as the ESI zones increase.

In Table 3-10, we show the actual F&I corrosion-related maintenance costs by ESI zone along with the corrosion cost as a percentage of maintenance cost.

Table 3-10. Total F&I Maintenance Corrosion Costs by ESI Zone (\$ in millions—FY17)

ESI zone	Total maintenance cost	Total corrosion cost	Corrosion as a percentage of maintenance	
1	\$0	\$0	0.0	Average of 12.8% corrosion
2	\$0	\$0	0.0	
3	\$485	\$102	21.0	
4	\$1,140	\$146	12.8	
5	\$144	\$9	6.3	
6	\$782	\$60	7.7	
7	\$3,623	\$356	9.8	
8	\$1,689	\$403	23.9	
9	\$1,460	\$155	10.6	
10	\$1,129	\$109	9.7	
11	\$581	\$55	9.5	Average of 15.6% corrosion
12	\$394	\$97	24.6	
13	\$432	\$81	18.8	
14	\$0	\$0	0.0	
15	\$924	\$74	8.0	
16	\$181	\$28	15.5	
17	\$215	\$45	20.9	
18	\$530	\$75	14.2	
19	\$945	\$202	21.4	
Total	\$14,654	\$1,997	13.6	

From an ESI zone standpoint, the pattern of actual corrosion costs generally fit the expected pattern; total corrosion costs as a percentage of maintenance was generally higher as the ESI zones increased. Note the average corrosion percentage of the first 10 ESI zones (12.8 percent) compared to the average corrosion percent of the last 9 zones (15.6 percent).

Based on the FY17 corrosion expenditures by ESI zone, it appears the environment generally affects corrosion costs as would be expected.

Corrosion Prevention Best Practices

During our installation site visits and roundtable discussions, we had the opportunity to observe a wide variety of maintenance practices and staffing organizations. Throughout the study, we developed a list of corrosion best practices that proved applicable across all services, ESI zones, and installations.

1. Perform all scheduled recurring work and maintenance. Doing so will help control costs related to corrosion damage as well as other F&I life-cycle costs.
2. Use anti-scaling, anti-fouling, and anti-corrosion water treatment in closed-loop heating and cooling systems.

3. Use cathodic protection on steel storage tanks and pipelines. Find adequate resources for the cathodic protection program so these systems are maintained and function appropriately.
4. Choose appropriate corrosion-resistant materials for new construction and repair by replacement. For example, replace corroded galvanized duct work with corrosion resistant stainless steel, and replace outside ladders with fiberglass if possible.
5. When a system (such as a pipeline) begins to fail due to corrosion, make the necessary repairs, then plan and program funds for total system replacement, preferably with a corrosion-resistant material.
6. Government staff should review new construction project designs to ensure maintenance is properly considered and preventive measures (such as corrosion-resistant materials, closed system water treatment, and cathodic protection) are not eliminated to bring the project's life-cycle cost down.
7. Treat domestic water when the pH is less than 6.5 or greater than 8.5. This will diminish the effects of corrosion on systems that distribute or use domestic water.
8. Use corrosion-resistant concrete embeds and equipment mounting brackets in water treatment plants, sewage treatment plants, sewage lift stations, swimming pool chlorination rooms, etc. In addition, consider using remote sensing instruments so only the sensor must be mounted in areas that are humid or have corrosive environments.
9. Install roofing with electrical substations to help prevent deterioration.

Using Corrosion Cost Data to Plan Future Sustainment Requirements

The DoD uses the sustainment cost factor (SCF), area cost factor (ACF), and escalation factor (EF) to estimate the total sustainment costs by FAC. We provide definitions of these factors, as well as an overview of the current method DoD uses to calculate estimated sustainment costs in Appendix A.

Current Sustainment Cost Calculation

We believe the current sustainment cost estimation method can be refined and improved by using the corrosion cost information contained in this study. Table 3-11 shows an example of how typical sustainment costs are estimated.

Table 3-11. Notional Sample Sustainment Cost Calculation

FAC	Location	Size	SCF	ACF	EF	Sustainment cost
7110—FH dwelling	Kaneohe Bay	2,000 SF	$2.38	$2.15	$1.02	$10,439
7110—FH dwelling	Fort Huachuca	2,000 SF	$2.38	$1.05	$1.02	$5,098
8321—Sewer and industrial waste line	Fort Greely	5,000 ft.	$1.81	$2.28	$1.02	$21,047

The total sustainment cost is the size of the FAC multiplied by the product of the SCF, ACF, and EF. The SCF is FAC-specific, the ACF is location specific, and the EF is applied to all FACs equally. While the SCF has an unknown part of corrosion included in it, the corrosion piece is not identified and is the same for each FAC, regardless of location.

Proposal to Modify the Sustainment Cost Calculation

One possible refinement to the current sustainment cost calculation is to add a factor that accounts for the effects various environments can have on maintenance costs related to corrosion. This would leave an SCF for each location that contains sustainment costs, but not corrosion costs. The next step would be to add a separate corrosion cost factor (CCF) to account for the varying cost effects of corrosion by ESI zone. We show this option in Table 3-12.

Table 3-12. Sustainment Cost Calculation Using a CCF (in FY17 dollars)

FAC	Location	ESI zone	Size	SCF	ACF	EF	CCF[a]	Sustainment cost
7110—FH dwelling	Kaneohe Bay	18	2,000 SF	$2.38	$2.15	$1.02	$1.08	$11,274
7110—FH dwelling	Fort Huachuca	1	2,000 SF	$2.38	$1.05	$1.02	$0.91	$4,639
8321—Sewer and industrial waste line	Fort Greely	2	5,000 ft.	$1.81	$2.28	$1.02	$0.92	$19,363

[a] These CCFs are for illustration purposes only.

Although some portion of corrosion is already contained in the SCF, adding a CCF would not be duplicating corrosion's effect. Rather, adding the CCF would separate the effect of corrosion so that it is visible by location and FAC.

We can see this effect in the notional case presented in Table 3-12. The sustainment cost projection would increase for a location with potentially severe environmentally caused corrosion (Kaneohe Bay—which is in a high ESI zone), and the projected sustainment costs could actually decrease for facilities in lower ESI zones (Fort Huachuca and Fort Greely). The net effect of the sustainment cost estimate across all FACs and services would be zero, but the allocation of costs would more accurately reflect the effect of corrosion.

The advantage of having a separate factor for corrosion is that users of the information can identify the specific cost effect corrosion has by location and ESI zone. The disadvantage is an extra factor must be added to the existing database.

From the extensive corrosion cost data contained in this study, it would be fairly routine to develop corrosion cost factors by ESI zone. The corrosion cost factor could be applied to all FACs, or it could be determined that some facility types (for example, those underground) should be excluded. The exclusion of underground facilities is legitimate since the ESI is an environmental severity index and the data on soil content is insufficient to determine a separate indicator.

Appendix A
Estimating Facilities Sustainment Maintenance Requirements

Installations estimate their sustainment maintenance requirements in different ways.

The military services annually provide facilities inventory data to the Office of the Secretary of Defense (OSD). OSD compiles the service data into the RPAD. The Program, Analysis, and Evaluation Office (PA&E) within OSD analyzes the RPAD for anomalies, including unusual changes, missing data, and data entry errors. PA&E returns to the service for further review of records that exceed the size expected for a facility. The service either confirms the reported size or resets the record to the expected value for the FAC. Once PA&E confirms all records through this review process, the validated RPAD forms the dataset upon which sustainment costs are estimated.

To correlate cost data to military facilities, the size of the military facilities within the FAC must be known. To obtain the size, PA&E analyzes the entire RPAD inventory by FAC and selects a representative size.

The sustainment cost estimation for each FAC is a function of three factors:

- *Sustainment cost factor*—the estimated cost per unit of measurement of the FAC for the maintenance and repair activities necessary to keep the DoD inventory of that FAC in good working order. As an example, an SCF for FH dwelling (FAC 7110) would be $2.38 per square foot. This SCF is the same for each FAC of the same type.
- *Area cost factor*—the estimated cost per unit of measurement of the FAC that accounts for the regional differences in cost of labor and materials. As an example, the ACF for Kaneohe Bay in Hawaii might be $2.15 per unit of measure; the ACF for Fort Huachuca, AZ, could be $1.05 per unit of measure. The ACF is the same per unit of measure for each FAC type at the same installation.
- *Escalation factor*—the annual cost of inflation. As an example, the EF was $1.02 in FY13. The EF is applied to each FAC equally.

The SCF is the most complex of the three factors to calculate. PA&E calculates the SCF for each FAC using one of the following methods (listed in order of preference):

1. Parametric cost models are used whenever possible. Parametric models are calculated using Washington, DC, as a location baseline for costs. These models include corrosion costs as part of sustainment.
2. Data from commercially published sources must be filtered to ensure similarly sized facilities are being compared and non-sustainment costs are excluded. Data from these sources necessarily includes industry-wide experiential costs; therefore, the data includes normal corrosion costs for the FAC.

3. Data from unpublished commercial sources involves research through contacts to obtain contract prices or experiential data. When commercial sources are used, data from multiple sources are preferred. Examples include states' departments of transportation for pavements and commercial ports for piers and wharves. As with published sources, data from these sources necessarily includes industry-wide experiential costs, and, therefore, includes normal corrosion costs for the FAC. For example, data from commercial port authorities on piers reflects the fact that piers are exposed to salt water.
4. Experiential data from the military services is obtained and used for facilities that are unique to the military. As with published sources, data from the services includes experiential costs; therefore, it includes corrosion costs normal for the FAC.
5. When no data is available from private sector or military service sources, a ratio of the sustainment cost factor to construction cost factor for a similar FAC is applied.

Appendix B
Detailed Cost Trees

We used the following schema to map the funding appropriation and program elements into the two major branches of the corrosion cost tree (facilities maintenance and facilities construction).

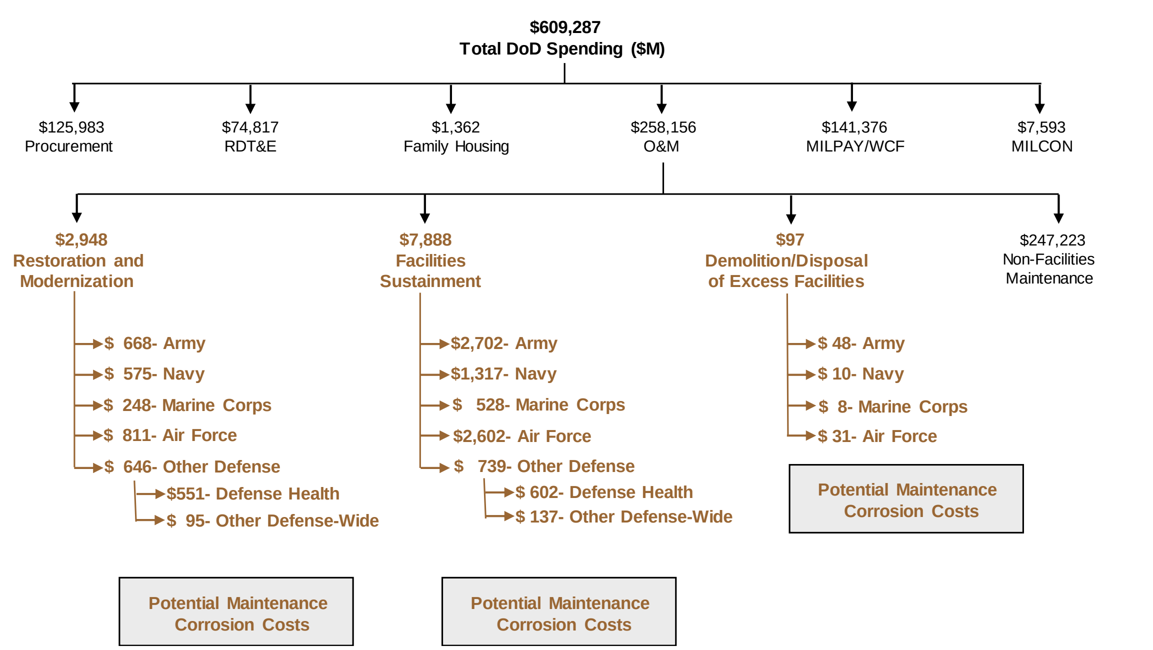
Represents F&I maintenance costs

Represents F&I construction costs

We examined each congressional appropriation category and looked for PEs within the categories that contained facilities maintenance or construction funding. For example, within the O&M appropriation, we retained only the PEs that end in 76, 78, or 93, which possibly included corrosion costs. We excluded all other PEs. We repeated this process with each congressional appropriation category.

In Figure B-1, Figure B-2, and Figure B-3, we provide the detailed cost trees by category of funding appropriation, starting with O&M. We show the costs we excluded on the far right side of each cost tree.

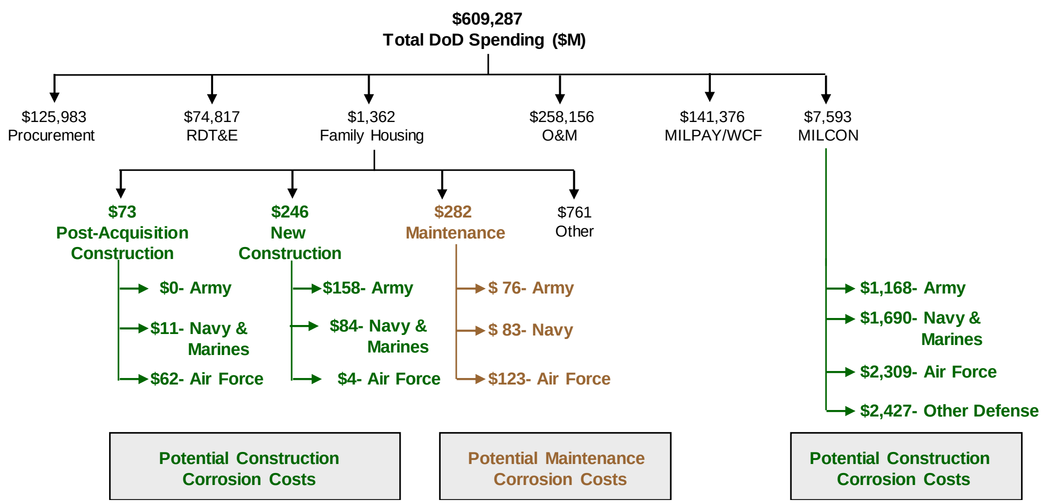
Figure B-1. O&M Appropriation Mapping ($ in millions—FY17)



Note: No BU maintenance source available for other defense-wide restoration and modernization and facilities sustainment as well as for DLA direct non-WCF.

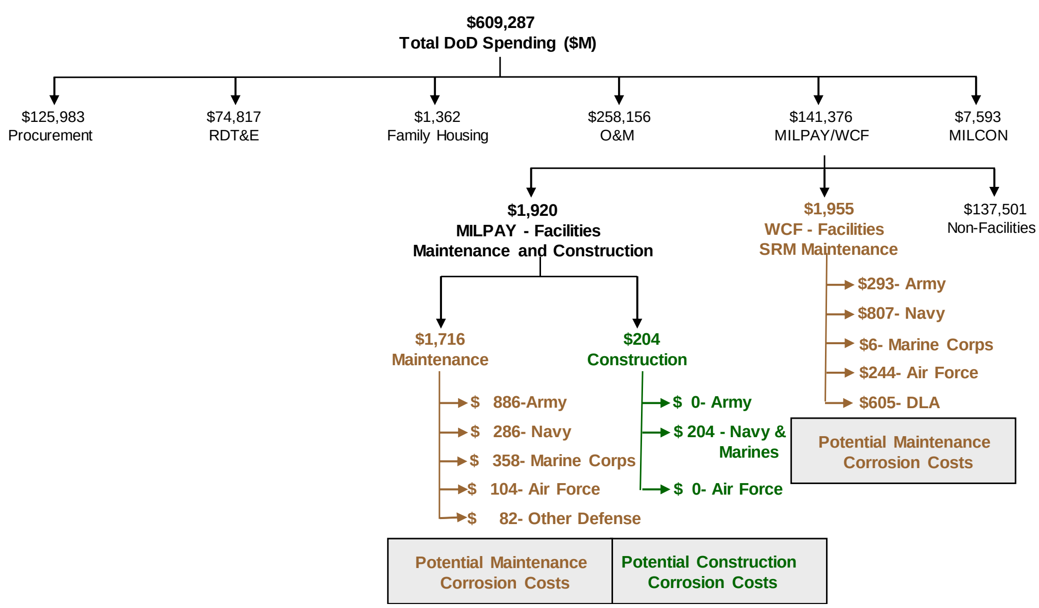
Next, we provide the FH and MILCON cost tree.

Figure B-2. FH and MILCON Appropriation Mapping ($ in millions—FY17)



Finally, we depict the MILPAY and WCF cost tree.

Figure B-3. MILPAY/WCF Appropriation Mapping ($ in millions—FY17)



Appendix C

Military Pay Contribution to Facilities Maintenance and Construction Expenditures

To calculate the TD labor cost for MILPAY that is potentially associated with corrosion, we first identified the number of service members assigned to facility management, facility maintenance and repair, and MILCON in the Army Corps of Engineers, Air Force, and Navy.

We used data from the Defense Manpower Data Center to determine the numbers of personnel from each service that work in facilities maintenance and construction. We obtained a listing of all maintenance personnel, their skill title and military occupation specialty. Based on the skill title which is the most descriptive classification of their job content, we were able to identify those personnel who worked in a facility maintenance or construction capacity.

To convert the TD personnel count into a labor cost, we multiplied the count of maintainers by the average salary they were paid. This salary, which includes all benefits and indirect costs, was specific for each service. We show these rates and calculations in Table C-1. We omit the labor costs for “Other defense” as this was not included.

This yielded a total labor cost for each service, as shown in Table C-1.

Table C-1. Facilities Maintenance and Construction Labor Cost of Military Personnel Combined (FY17)

Service	Number of active duty personnel	Active duty labor rate	Number of guard/reserve personnel	Guard/reserve labor rate	Number of civilian personnel	Civilian labor rate	Total yearly labor cost (in millions)
Army	6,848	$75,049	8,485	$29,081	1,312	$95,514	$886
Navy	2,835	$80,987	1,998	$45,098	1,716	$99,311	$490
Air Force	0	$79,648	0	$32,902	1090	$95,631	$104
Marine Corps	3,647	$69,983	596	$25,677	911	$95,681	$358
Other defense	—	—	—	—	719	$114,078	$82
Total	13,330	$74,926	11,079	$31,786	5,748	$99,018	$1,920

We can split the personnel into the maintenance and construction classifications based on their skill title. We show this breakout by service in Table C-2.

Table C-2. Facilities Maintenance and Construction Labor Cost of Military Personnel Separated (FY17)

Service	Number of maintenance personnel	Facility maintenance labor cost	Number of construction personnel	Facility construction labor cost
Army	16,645	$886	0	$0
Navy	4,030	$286	2,519	$204
Air Force	1,090	$104	0	$0
Marine Corps	5,154	$358	0	$0
Other defense	719	$82	—	—
Total	27,638	$1,716	2,519	$204

We needed to attribute the Navy construction totals to either FH construction or MILCON. In Table C-3 we indicate the spending within these two construction categories.

Table C-3. Construction Spending ($ in millions—FY17)

Spending category	Amount
FH construction (post acquisition $73; new $246)	$319
MILCON	$7,593
Total Navy facilities construction	$7,912

The ratio of spending for FH construction is $319 ÷ $7,912, or roughly 4.0 percent. The ratio of MILCON spending is $7,593 ÷ $7,912, or 96.0 percent.

To attribute the Navy construction labor total (from Table C-2) of $204 million into FH construction and MILCON, we applied these ratios of FH construction spending to MILCON spending. We show this calculation and the final breakout in Table C-4.

Table C-4. Attribution of Navy Construction Labor Costs into FH Construction and MILCON (FY17)

Service	Total yearly labor construction cost ($ in millions)	FH construction percentage	MILCON percentage	FH construction attribution ($ in millions)	MILCON attribution ($ in millions)
Navy	$204	4.0	96.0	$8.1	$195.9

Appendix D
Facilities Databases

Table D-1 lists the data sources we used to determine the annual cost of corrosion for DoD facilities.

Table D-1. List of Service/Agency Databases Used in Corrosion Study

Database name	Owning service/agency	Use
Real Property Asset Database	OSD	Maintenance bottom-up
Fiscal Year Defense Program	OSD	Top-down
Integrated Facilities System	Army	Maintenance bottom-up
DD Form 1391 submissions	Army	Construction bottom-up
General Fund Business Enterprise System	Army	Maintenance bottom-up
Maximo	Navy	Maintenance bottom-up
DD Form 1391 submissions	Navy	Construction bottom-up
Standard Procurement System	Navy	Maintenance bottom-up
Maximo	Marine Corps	Maintenance bottom-up
Interim Work Information Management System	Air Force	Maintenance bottom-up
Automated Civil Engineer System—Project Management	Air Force	Maintenance bottom-up Construction bottom-up
DD Form 1391 submissions	Air Force	Construction bottom-up
TRIRIGA	Air Force	Maintenance bottom-up
Defense Medical Logistics Support System	Defense Health Agency	Maintenance bottom-up

Appendix E
LMI Shop Codes

Table E-1 shows the shop codes we used and their descriptions.

Table E-1. LMI Shop Codes and Descriptions

Shop code	Description
AL	Alarm
BO	Boiler
CE	Civil engineer
CP	Carpentry
CT	Contractor
DM	Demolish
DS	Data systems
EE	Exterior electric
EL	Electric
EN	Environmental
EQ	Equipment
FA	Facilities
FL	Flooring
FP	Fire protection
FU	Fuels
GEN	Generator
GL	Glass
GR	Grounds
HO	Housing
HVAC	HVAC
HZ	Hazmat
IE	Interior electric
LK	Lock
LT	Lighting
MD	Medical
ME	Maintenance engineer
MECH	Mechanic
MW	Metalwork
OP	Operations
PEST	Pest control
PL	Plumbing
PN	Pneumatics

Table E-1. LMI Shop Codes and Descriptions

Shop code	Description
PT	Paint
PVMNT	Pavement
ROOF	Roofing
SG	Signage
SH	Self help
ST	Structures
UTIL	Utilities
WASTE	Waste
WT	Water treatment

Appendix F
Corrosion Search Algorithm

The facilities maintenance corrosion search algorithm is a sequence of steps to exclude non-corrosion records from the database, then isolate and include corrosion records. We detail the sequence of steps below:

- *Step 1*: Search through combined database with exclusionary words. Flag these records and set aside. (We provide a list of exclusionary words in Appendix G.)
- *Step 2*: Search through combined database with definite corrosion words. Flag these records and set aside. (We provide a list of definite corrosion words in Appendix H.)
- *Step 3*: Search through combined database looking for records which contain all three possible corrosion words (noun, adjective, and verb). Flag these records and set aside. (We provide a list of possible corrosion words in Appendix I.)
- *Step 4*: Search through combined database looking for records which contain one or two of the possible corrosion words (noun, adjective, and verb).
- *Step 5:* Consolidate these records by craft and ESI zone. Apply the roundtable craft corrosion percentage by ESI zone to the corresponding flagged ESI zone and craft records. We show an example in Table F-1.

Table F-1. Example of Corrosion Factor Applied to Data Records Flagged with One or Two Corrosion Words (Algorithm Step 4)

Craft	ESI zone	Corrosion percentage	Flagged records	Maintenance cost of flagged records	Corrosion cost of flagged records
Exterior electric	5	15.0	65	$100,000	$14,000
Fuels	10	3.0	145	$75,000	$21,000
General building	14	25.0	50	$10,000	$1,500

Table F-2 is a summary of the craftsmen’s responses to corrosion severity by craft and ESI zone. The percentages depict the percentage of workload that is the result of corrosion by craft and ESI zone. ESI zone 20 does not contain corrosion percentages because that zone is assigned to Navy ships. Although Navy ships are viewed as installations from a logistics standpoint, facility maintainers do not maintain Navy ships.

Table F-2. Summary of Roundtable Corrosion Percentages by Craft and ESI Zone

	ESI zone									
	1		2		3		4		5	
Craft	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent
Interior plumbing	3%	0%	10%	20%	15%	5%	10%	0%	35%	10%
Exterior plumbing	5%	0%	50%	10%	20%	5%	2%	0%	12%	5%
Interior electric	1%	0%	8%	8%	20%	10%	10%	0%	2%	3%
Exterior electric	1%	0%	18%	18%	20%	10%	5%	43%	15%	15%
HVAC	1%	5%	3%	27%	25%	5%	15%	5%	10%	20%
Fuels	0%	0%	20%	20%	35%	5%	0%	5%	5%	5%
General building	2%	3%	15%	5%	40%	0%	40%	45%	15%	10%
Roads & grounds	10%	0%	3%	3%	30%	10%	45%	30%	10%	40%

	ESI zone									
	6		7		8		9		10	
Craft	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent
Interior plumbing	30%	8%	28%	6%	40%	30%	12%	0%	10%	10%
Exterior plumbing	14%	8%	15%	10%	20%	80%	13%	0%	13%	6%
Interior electric	3%	3%	3%	3%	6%	9%	0%	0%	8%	2%
Exterior electric	13%	13%	11%	10%	40%	10%	0%	0%	3%	10%
HVAC	11%	17%	11%	14%	60%	40%	1%	0%	30%	30%
Fuels	15%	5%	26%	5%	1%	4%	2%	3%	3%	3%
General building	10%	15%	7%	21%	70%	0%	24%	0%	25%	25%
Roads & grounds	18%	25%	26%	8%	15%	35%	15%	0%	2%	1%

	ESI zone									
	11		12		13		14		15	
Craft	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent	Correct	Prevent
Interior plumbing	5%	5%	50%	30%	35%	20%	20%	10%	12%	3%
Exterior plumbing	13%	13%	50%	10%	50%	5%	50%	0%	8%	13%
Interior electric	1%	1%	15%	5%	22%	5%	30%	5%	12%	3%
Exterior electric	5%	20%	2%	3%	2%	3%	3%	4%	5%	5%
HVAC	10%	15%	25%	15%	27%	15%	30%	15%	5%	10%
Fuels	10%	40%	1%	4%	3%	7%	4%	8%	5%	10%
General building	25%	5%	85%	10%	50%	17%	25%	25%	7%	5%
Roads & grounds	2%	0%	75%	5%	67%	3%	60%	0%	19%	0%

Table F-2. Summary of Roundtable Corrosion Percentages by Craft and ESI Zone

	ESI zone									
	16		*17*		*18*		*19*		*20*	
Craft	**Correct**	**Prevent**	**Correct**	**Prevent**	**Correct**	**Prevent**	**Correct**	**Prevent**	**Correct**	**Prevent**
Interior plumbing	25%	50%	10%	0%	0%	0%	1%	0%	—	—
Exterior plumbing	25%	50%	35%	35%	10%	10%	1%	4%	—	—
Interior electric	10%	0%	85%	5%	9%	1%	40%	10%	—	—
Exterior electric	10%	15%	76%	4%	60%	20%	25%	5%	—	—
HVAC	25%	25%	30%	40%	50%	25%	30%	0%	—	—
Fuels	1%	4%	5%	15%	3%	10%	1%	1%	—	—
General building	40%	0%	20%	40%	20%	40%	10%	10%	—	—
Roads & grounds	10%	0%	18%	4%	40%	10%	1%	0%	—	—

Appendix G
List of Exclusionary Corrosion Words

The following is a list of exclusionary corrosion words we use for step one of the search algorithm:

- animal
- ant
- ATFP
- bee
- bird
- bug
- change of occupant
- clog
- custod
- deer
- entomology
- exterminate
- fabricate
- freeze
- froze
- frige
- garden
- grass
- grounds maint* or ground maint*
- HAZMAT
- insects
- land
- lock (but not locker)
- mice
- pest
- plants
- reefer
- refuse collection
- roach
- rodent
- seed
- snow
- species
- spray for
- stopped
- stopped-up
- termite
- tree
- unplug
- un-plug
- un-stop
- unstop
- wasp
- weed.

Appendix H
List of Definite Corrosion Words

The following is the list of definite corrosion words we use in step two of the search algorithm:

- anode
- bilge
- blast to brighten metal
- broken main
- broken line
- busted main
- busted line
- cathod
- corro
- crumb
- deterior
- EOPS
- fade
- inspect
- mildew
- mold
- osmotic
- oxid
- paint
- preserve
- re-caulk
- recaulk
- re-grout
- regrout
- reseal
- re-seal
- rust
- seal (plumbing only)
- spall
- water damage.

Appendix I

Search Algorithm Verbs, Adjectives, and Nouns

The following are verb, adjective, and noun combinations we used to flag corrosion records.

Table I-1. List of Algorithm Verbs, Adjectives, and Nouns

Facility classification	No. of FACs	General area	Verb	Adjective	Noun
Buildings	309	Interior	paint, prepare, prepare surface, repair, replace, R/R, rpl, rpr, fix, retube, maintain, rplc	leak*, water damag*, corrod*, rust*, crack*, bulg*, ruptur*, mildew, dehumidify	roof, water heater, pipe, valve*, wir*, water heater, heater, radiator, duct*, tank, tube nest, tube, boiler, mainten*, A/C*, Heat*, water*
		Exterior	paint, prepare surface, repair, replace, fix, *point*, patch, maintain, R/R, rpr, rpl	deteriorat*, rust*, fad*, chalk*, leak*, drip*, discolor*, crack*, bulg*, mildew	roof, leak*, gutter, downspout, leader, window, door, light, fixture, wall, brick*, siding, metal, mortar, stucco, steam coil, cooling tower, condenser, circ pump, circulating pump, mainten*, water*
Land	42	Exterior	repair, fill, backfill, maintain, R/R, rpr, rpl, rplc	sink*, hole, erod*, sluff*, fall*, wash*	
Marine facility	16	Interior	paint, prepare surface, repair, replace, fix, retube, blast to bright metal, maintain, rpr, R/R, rpl, rplc	leak*, water damag*, corrod*, rust*, brok*, crack*, bulg*, ruptur*, dehumidify	roof, water heater, pipe, valve*, wir*, water heater, heater, radiator, duct*, crane, rail, window, door, tube, tube nest, boiler, steam coil, cooling tower, condenser, circ pump, circulating pump, tube nest, fire side tube, water side tube, mainten*, water*, A/C*, heat*
		Exterior	paint, prepare surface, repair, replace, descale, scrape, blast to bright metal, maintain	deteriorat*, rust*, crack*, bulg*	roof, leak*, gutter, downspout, leader, window, door, light, fixture, bollard, cleat, rail, buoy, pile, hanger, support, panel, antenna, lamp, tower, mainten*, water*
Pavement	42	Exterior	patch, resurface, fix, reseal, overlay, maintain	deteriorat*, crack*, brok*, spall*	mainten*

Table I-1. List of Algorithm Verbs, Adjectives, and Nouns

Facility classification	No. of FACs	General area	Verb	Adjective	Noun
Piping	17	Interior	paint, prepare, prepare surface, repair, replace, fix, retube, maintain, rpr, rpl, rplc, R/R	leak*, corrod*, rust, blocked, ruptur*, scaling	pipe, valve, hanger, connection, nipple, support, steam coil, tub*, water tube, fire tube, condenser, circ pump, circulating pump, tube nest, cooling tower, tank, mainten*, water*
		Exterior	paint, prepare, prepare surface, repair, replace, fix, maintain, rpr, rpl, rplc, R/R	leak*, corrod*, rust, blocked, scaling	pipe, valve, hanger, connection, nipple, support, steam trap, mainten*, water*
Ranges	40	Interior	paint, prepare, prepare surface, repair, replace, fix, maintain, R/R, plr, rpl, rplc	leak*, water damag*, corrod*, rust*, dehumidify	roof, water heater, pipe, valve*, wir*, water heater, heater, radiator, duct*, door, mainten*, heat*, A/C*, water*
		Exterior	paint, prepare surface, repair, replace, fix, fill, patch, maintain, R/R, rpl, rpr, rplc	rust*, corrod*,	sign, post, fence, gate, light, lamp, pole, mainten*, water*
Structures above ground	167	Interior	paint, prepare, prepare surface, repair, replace, fix, retube, maintain, R/R, rpl, rplc, rpr	leak*, water damag*, corrod*, rust*, crack*, bulg*, ruptur*, dehumidify	roof, water heater, pipe, valve*, wir*, water heater, heater, radiator, duct*, tank, steam coil, cooling tower, condenser, circ pump, circulating pump, tube, tube nest, water side tube, boiler, fire side tube, mainten*, water*
		Exterior	paint, prepare surface, repair, replace, fix, fill, patch, maintain, R/R, rpl, rpr, rplc	rust*, corrod*, crack*, bulg*, arcing, glowing, blue flame, crackling, sparks, noise on radio, scaling, plugged tubes	sign, post, fence, gate, light, lamp, pole, roof, door, lock, fence, gate, post, pole, lamp, luminaire, wall, antenna, lamp, tower, canopy, mainten*, water*
Structures under ground	23		paint, prepare surface, repair, replace, fix, fill, patch, maintain, R/R, rpl, rplc, rpr	leak*, broken, rust*, corrod*, deterior*	wall, access, plate, door, handle, hanger, wire, transformer, mounting plate, bolts, pump, motor, panel, wir*, plate, mainten*, water*
Interior components	2		repair, replace, fix, maintain, R/R, rpl, rpr, rplc	corrod*, rust*	wir*, cabinet, panel, motor, pump, duct*, pip*, mainten*

Note: * means match preceding letters only (allows for “ing,” “ed,” “s”); we also allowed for close, but not exact, matches to account for spelling errors.

Appendix J
Abbreviations

ACF	area cost factor
BU	bottom-up
CCF	corrosion cost factor
CPC IPT	Corrosion Prevention and Control Integrated Product Team
DHP	Defense Health Program
DLA	Defense Logistics Agency
DoD	Department of Defense
EF	escalation factor
ESI	environmental severity index
F&I	facilities and infrastructure
FAC	facility analysis category
FAD	Facilities Asset Database
FASAB	Federal Accounting Standards and Advisory Board
FH	family housing
FHM	family housing maintenance
FYDP	Future Years Defense Program
GAO	Government Accountability Office
GFEBS	General Fund Enterprise Business System
HVAC	heating, ventilation, and air-conditioning
IFS	Integrated Facilities System
ISO	International Organization for Standardization
KW	kilowatt
MADW	Maintenance and Availability Data Warehouse
MCB	Marine Corps Base
MILCON	military construction
MILPAY	military pay
NAVFAC	Naval Facilities Engineering Command
O&M	operations and maintenance
OSD	Office of the Secretary of Defense

PA&E	Program, Analysis, and Evaluation Office
PE	program element
POM	program objective memorandum
R&D	research and development
RDT&E	research, development, testing, and evaluation
RPAD	Real Property Asset Database
S	salinity
SCF	sustainment cost factor
SF	square feet
SRM	sustainment, restoration, and modernization
TD	top-down
TOA	total obligational authority
TOW	time of wetness
USACE	U.S. Army Corps of Engineers
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology and Logistics
WCF	Working Capital Fund

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In the 1990s, Congress became increasingly concerned about the high cost of corrosion in DoD. In 2002, it enacted legislation that gave the Under Secretary of Defense for Acquisition, Technology and Logistics, USD(AT&L), primary responsibility for mitigating or preventing the effects of corrosion on military equipment and infrastructure. USD(AT&L) established the Corrosion Prevention and Control Integrated Product Team (CPC IPT), a cross-functional team of personnel from the military departments and private industry, to help carry out that responsibility. In April 2006, the CPC IPT published the results of the first corrosion cost study, and it has periodically updated the studies since then. This report presents the results of the most recent corrosion impact study on cost and estimates the cost of corrosion for DoD infrastructure and facilities assets; identifies corrosion cost-reduction opportunities for these same assets; and analyzes trends and draw conclusions using the results of the initial and most recent DoD infrastructure and facilities studies.

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CONTACT
Eric F. Herzberg
LMI Fellow
+1.571.633.7732 *office*
eherzberg@lmi.org

LMI | 7940 Jones Branch Drive, Tysons, VA 22102

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