

ANALYSIS OF MAINTENANCE OF CRITICAL UTILITY SYSTEMS ON U.S. NAVY
INSTALLATIONS TO DETERMINE OPTIMUM TIMING FOR RECAPITALIZATION

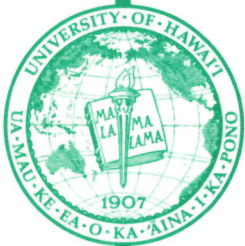
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EXECUTIVE SUMMARY

The Naval Facilities Engineering Systems Command (NAVFAC) is responsible for providing Facility Management and Sustainment (FM&S) services for all U.S. Navy installations worldwide. A critical element of this service is maintaining critical utility infrastructure that is key to operating these installations. Currently, most of the critical utility infrastructure systems – electrical, potable water, and wastewater – on U.S. Navy installations are near or past their useful life. When infrastructure start to degrade, the U.S. Navy allocate funds for recapitalization, but budget constraints have made it difficult to predict the timing of this investment and so facility managers must determine how to best extend the life of their utility infrastructure.

The purpose of this report is to conduct an analysis of NAVFAC’s preventive maintenance (PM) strategy, performance, and U.S. Navy’s utility infrastructure investment by:

- Analyzing the PM strategies NAVFAC uses for facility maintenance on U.S. Navy installations.
- Researching PM strategies used in the facility management industry.
- Analyzing the PM completion rates for utility systems on U.S. Navy Installations.
- Analyzing the level of investment that the U.S. Navy’s provides for maintenance of utility systems.
- Determine the optimum time for investing in the recapitalization of critical utility systems at U.S. Navy installations.

The methodology used for this report analyzed different processes and reviewed data for the items associated with the report’s objective. The methods include:

- Interviewing facility management teams within NAVFAC to determine the PM strategies used at their installations.
- Interviewing facility managers outside the Department of Defense to determine their organization’s maintenance strategy and use it as a point of comparison.
- Reviewing data on the condition of critical utility systems on U.S. Navy installations.
- Reviewing data of PM completion across the NAVFAC enterprise to determine if NAVFAC is meeting its 100% PM completion goal.
- Reviewing data on the historical level of U.S. Navy’s investment for critical utility systems, to determine if it is adequate to maintain the systems.

The analysis used data obtained from NAVFAC's electronic facility management systems, and the notes from interviews conducted with facility managers at various U.S. Navy installations. Based on this analysis, the key findings of this report are:

- NAVFAC-managed critical utility systems are old; with some past their useful life.
- NAVFAC uses a combination of maintenance strategies to maintain its utility systems.
- NAVFAC does not meet its PM completion goals.
- Maintenance investment from the U.S. Navy is not adequate to maintain the systems.
- The timing to receive funding for recapitalization is unpredictable, and utility systems do not compete well for funding during the project prioritization process.

Based on these findings, some recommendations for prolonging the life of critical infrastructure and receiving funding for recapitalization include:

- Incorporating elements of different maintenance strategies into NAVFAC's PM strategy.
- Addressing staffing issues to increase PM completion.
- Advocating for increase in sustainment funding.
- Advocating for increase in weighted priorities in the decision lens model, to increase the chances of utility infrastructure projects being selected for funding.
- Advocating for targeted funding for recapitalization of utility infrastructure Navy-wide.

The optimum time to invest in recapitalization for critical utility infrastructure is when systems are at the most significant risk of failure – as determined by the facility condition assessment tools used by NAVFAC. However, the reality of funding unpredictability means that NAVFAC must implement a well-disciplined PM program to help extend the life of critical infrastructure and mitigate the risks associated with projects not being selected for funding during the project prioritization process.

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CHAPTER 1. INTRODUCTION

Properly maintaining facilities and systems is crucial in ensuring they perform to the expected standards throughout their useful life. An important aspect of facilities lifecycle management is sustainment and recapitalization. The generally accepted method of ensuring that facilities and systems maintain the expected performance standards over their useful life, or in some cases extend their useful life, is by having facility sustainment practices that enable optimum management of facilities. A robust Preventative Maintenance (PM) program is an excellent way to keep facility performance consistent. As facilities approach the end of their service life, the requirement for replacing them comes into focus, and the planning process for replacing them takes shape depending on the organization. The time of this investment is critical to ensure there is no interruption in the service the facility is providing.

Within the United States Department of Defense, the nature of its mission demands an approach that ensures continuity of service for its critical infrastructure. However, resource constraints and infrastructure funding processes have made it necessary for facility management teams to become agile in responding to the uncertainties of funding availability at the required time and the reality of constantly evolving mission requirements.

1.1 Objective

The objectives of this report are:

- Analyze the current Preventive Maintenance (PM) approach PWDs use on U.S. Navy installations worldwide.
- Analyze the PM completion rates for Utilities Infrastructure on U.S. Navy Installations.
- Research different PM structures and strategies used in the facility management industry.
- Analyze the U.S. Navy's facility investment process to determine the level of investment required for utility systems and the level of investment provided by the U.S. Navy.
- Determine the optimum time for investing in the recapitalization of critical utility infrastructure at U.S. Navy installations.

1.2 Methodology

The methodology used for this report analyzed different processes and reviewed data for the items associated with the report's objective. The methods used include:

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- Interviews with facility management teams within NAVFAC to determine the PM strategies used at their installations, and also determine if the strategies are consistent across the NAVFAC enterprise.
 - Interview a facility manager outside the Department of Defense to determine their organization's maintenance strategy, to make a comparison between the strategies and determine if there are processes that can be implemented to improve the NAVFAC's PM processes.
 - Review data on the condition of critical utility systems on U.S. Navy installations to determine if they are able to adequately perform their intended function.
 - Review data of PM completion across NAVFAC and to determine if NAVFAC is meeting its 100% PM completion goal.
 - Review data on the historical level of U.S. Navy investment for critical utility systems to determine if the investment is sufficient.

1.3 Scope

The scope of this report is limited to the Facilities Management and Sustainment (FM&S) services provided by NAVFAC on U.S. Navy installations. Additionally, although NAVFAC manages all facilities on U.S. Navy installations, this report focuses on critical utility facilities.

Most of the data reviewed for this report were located on U.S. Navy's asset management systems. Due to the sensitive nature of military systems and information, only percentages were used to analyze the data, and the exact names and locations of utility systems components were not disclosed.

The data reviewed was used to determine the effectiveness of NAVFAC's utilities system management and the trends in the Navy's facilities sustainment model. These analyses were used to determine the best strategy for adequately maintaining critical utility systems and keeping them performing as intended.

CHAPTER 2. BACKGROUND OF NAVFAC FACILITY MANAGEMENT

The mission, functions, and tasks of the Naval Facilities Engineering Systems Command (NAVFAC) are encompassed within ten capabilities that outline its roles and the services it provides to the United States Navy. One of these capabilities is maintenance and facilities operations – providing reliable and resilient infrastructure – for all United States Navy and United States Marine Corps facilities. This capability supports all the facility requirements for the 71 U.S. Navy and 24 U.S. Marine Corps installations worldwide. Each of these installations is similar to a small or medium-sized city and functions as such. Figure 1 shows the laydown of NAVFAC-supported installations across the globe.

2.1 NAVFAC Products and Services

NAVFAC is organized by business lines that deliver specific products and services to its customers worldwide. The Public Works (PW) business line delivers the following products and services (NAVFAC, 2023):

1. **Facilities Management and Sustainment.** This service encompasses all aspects of building and specialized infrastructure maintenance, energy management and sustainability, condition-based maintenance management, and workforce efficiency initiatives and metrics.
2. **Utilities and Energy Management.** This service includes the management of utility commodities and infrastructure, energy management and conservation, and industrial control systems operations and maintenance.
3. **Facility Support Contract Management and Facility Services.** This service includes base operations contracting, base planning, and developing standard contract templates for services.
4. **Base Support Vehicles and Equipment.** Provides lifecycle management of non-tactical automotive vehicles, construction, railway, and weight handling equipment, and the management of alternative fuel vehicle programs.
5. **Utility and Energy Systems.** Monitoring the Capabilities Development Document (CDD) for Smart Grid. The CDD establishes the requirements that guide the capabilities of the Smart Grid.



Figure 2.1: NAVFAC Laydown

This report focuses on the Facility Management and Sustainment (FM&S) aspect of NAVFAC's responsibility. The ability of NAVFAC to successfully deliver FM&S services to its customers ensures that NAVFAC is performing its mandated role within the DoD to support customers on Navy and Marine Corps installations with facilities that enable them to focus on and meet their mission.

The Public Works Department (PWD) at each installation performs the daily tasks of maintaining the facilities at that installation. These PWDs function like a city's Department of Public Works (DPW). The PWD is responsible for a wide range of programs requiring constant coordination and planning, including the operation and maintenance of the facilities.

2.2 Lifecycle Management of Facilities

Lifecycle management is the business activity of managing, most effectively, a company's products across their lifecycle, from inception until they are retired or disposed of (Stark, 2022). In this case, NAVFAC's business is the management of facilities and infrastructure on installations. FM&S encompasses all the requirements for managing facilities over their entire lifecycle. Therefore, an essential aspect of NAVFAC's role is ensuring the reliability and availability of the critical infrastructure required to operate these installations. An example of a typical facility lifecycle is shown in Figure 2.2 (Roper, 2014).

Depending on their mission and the resources available to dedicate to their physical infrastructure, organizations use a version of this process to manage their facilities. In many organizations, facilities are a significant component of their administrative costs. Therefore, careful management of each phase in the process is essential to ensure continued availability of the service and reduction in the overall cost of operations over the life of their facilities.

2.3 Critical Commodities

NAVFAC is responsible for all aspects of facility management on all U.S. Navy installations, and it provides many services to support its customers' operational missions. The utility management branch within the Public Works Department (PWD) at each installation is responsible for delivering utility services for the installation.

The utility systems and infrastructure used to deliver these commodities are therefore critical to the uninterrupted operation of all installations. These common utility systems that are discussed in this report are:

1. Electrical Utility System
2. Potable Water Utility System
3. Wastewater Utility System

Maintaining and investing in these systems' recapitalization – at the appropriate time – is crucial to ensuring their reliability and availability to support the operational requirements of installation customers.

2.4 Sustainment and Recapitalization

The operation and maintenance of a system are essential in how reliable they are in meeting its intended function. In the lifecycle of a system, this is the area where the most effort is required. Sustainment and recapitalization combined help prevent interruption of service to installation customers.

2.4.1 Sustainment

One way to ensure critical systems operate as intended is to sustain them adequately. Sustainment encompasses all the maintenance and repair activities needed to keep a system functioning as designed. These activities include performing regularly scheduled inspections, performing periodic maintenance tasks, responding to unplanned outages, and performing minor repairs if necessary.

The facility management teams at the PWDs on each installation are responsible for operating and maintaining these systems. NAVFAC provides a Utilities Infrastructure Management Manual that helps guide each team on properly maintaining and assessing the system's functionality.

2.4.2 Recapitalization

When a system is approaching the end of its useful life or has degraded to a condition where a significant repair or replacement is necessary, the facility management team must begin to determine the recapitalization strategy to ensure there is no interruption in service for critical commodities.

The most common avenues to recapitalize facilities within the DoD are the Military Construction (MILCON) and the Facilities Sustainment, Restoration, and Modernization (FSRM) Special Projects processes. MILCON (5 years) and Special Projects (4 years) are multi-year planning processes that require early identification of requirements to submit projects for consideration for funding. Due to DoD funding constraints, projects have to compete for funding, with no guarantees that a project will be funded at a specific time. Therefore, facility management teams responsible for providing services to customers must account for this unpredictability and take the necessary steps to ensure minimal interruptions in service.

CHAPTER 3. MEASURING AND ANALYSING SYSTEM PERFORMANCE

Measuring performance is an essential aspect of a system's lifecycle for any type of process, product, or system. The measurement used to evaluate a system's performance is often based on the specific output expected from the system. This evaluation helps to determine whether or not a system is performing to its maximum potential, and it helps inform decisions on actions needed to keep it performing (maintenance), analyze reasons why it is not (failure analysis), and the corrective actions necessary to bring it back to working condition (repair/replacement).

To this end, several factors must be considered when evaluating a system's effectiveness. In many cases, the most common evaluation criteria to determine the effectiveness of a system is by looking at its reliability and availability.

3.1 Reliability

The reliability of a system is the probability that it will perform as specified, under specified conditions, for a specified period of time (Blank, 2004). Due to different systems' complexities and specific requirements, no single index applies to most processes, products, or systems. Some of the common indices used for measuring utility reliability include (IEEE, 2022):

- **System Average Interruption Frequency Index (SAIFI):** An indication of how often the average customer experiences an interruption over a period of time.
- **System Average Interruption Duration Index (SAIDI):** An indication of the total duration of interruption for the average customer during a period of time.
- **Customer Average Interruption Duration Index (CAIDI):** an indication of the average time needed to restore service.

This way, reliability can be characterized as the probability that a system will meet its intended specification. Mathematically, reliability can be expressed as a percentage value that describes the chance of a system performing its intended function. Reliability can be calculated using Equation (1) (Gryna, 2001).

$$P_s = R = e^{-t/\mu} = e^{-\lambda t} \quad (1)$$

where $P_s = R =$ probability of failure-free operation for a time period equal to or greater than t
 $e = 2.718$
 $t =$ specified period of failure-free operation
 $\mu =$ mean time between failures
 $\lambda =$ failure rate (reciprocal of μ)

Example 3.1. A component of an electric system has a specified MTBF of 2000 hrs. What is the component's reliability if it has to support a mission for 75 hrs.?

$$R = e^{-t/\mu} = e^{-75/2000} = 0.963$$

This means that the component has a 96.3% chance of supporting the mission without failure.

For complex systems – such as utility systems – with numerous components that can fail independently, the assumption is that the system's reliability is the product of the individual reliabilities of the number of components within the system. In this case, it is assumed that the failure of any of the components will cause a failure of the system. Mathematically, it can be expressed as:

$$P_s = P_1P_2\dots P_n \quad (2)$$

Example 3.2. An electric system has three components with reliabilities of 0.963, 0.987, and 0.997. What is the system's reliability?

$$P_s = P_1P_2\dots P_n = (0.963)(0.987)(0.997) = 0.948$$

Therefore, the reliability of the overall system is 0.948.

The inference that can be made from this assumption is that the overall reliability of a system is affected by the number of components that can fail. The larger the number of components in a system, the higher the probability that the entire system will be less reliable.

3.2 Availability

Availability is the percentage of time a system is available to perform its required function. Simply put, it is expressed as a ratio of the expected system uptime to the expected system uptime and downtime (Maciel, 2022). To measure availability, an assumption is that the component can be repaired when it fails. This characteristic, which is also known as maintainability, can be measured quantitatively, using Mean Time to Repair (MTTR). MTTR is

the average time it takes to repair a broken component. Availability can be broken down into two categories based on how downtime is measured (Gryna, 2001)

1. Operational Availability (A_o): This is when total downtime is measured. This period accounts for the active repair time, PM time, and any logistic time. Operational Availability can be calculated using Equation (3) (Trivedi & Bobbio, 2017).

$$A_o = \frac{MTBF}{MTBF + MDT} \quad (3)$$

2. Intrinsic Availability (A_i): This is when the downtime is measured based only on the active repair time.

$$A_i = \frac{MTBF}{MTBF + MTTR} \quad (4)$$

where MTBF = mean time between failure; MTTR = mean time to repair; MDT = mean downtime

Example 3.3. The mean time between failure of an engine component in an antique car purchased at an auction is 200 hours. The repair time for the component is 10 hrs. It takes approximately six hrs. to deliver the parts to the repair shop. What is the operational and intrinsic availability of the car?

$$A_o = \frac{MTBF}{MTBF + MDT} = \frac{200}{200 + 16} = 0.93$$

$$A_i = \frac{MTBF}{MTBF + MTTR} = \frac{200}{200 + 10} = 0.95$$

Therefore, the Operational availability of the car is 93%, and the Intrinsic availability is 95%.

The availability value can be used as a data point to make a decision on the operational effectiveness of a component or system. A specific availability value may be established for a component depending on the required function. If the component's availability falls below the established value, it can be inferred that the component is not meeting its intended function and is therefore not reliable. A corrective action would need to be determined, which can be additional repair or a complete replacement of the failing component.

3.3 Failure Mode and Effect Analysis

In any operational system, failure of a component is a reasonable expectation for facility managers to consider as they operate and maintain their systems. When these failures occur, it is imperative to conduct an analysis to determine the cause of the failure. An essential technique used for this analysis is failure mode and effects analysis (FMEA), which identifies potential problems or failures in a system and the effect of those problems so they can be addressed before failure (Soares, 2021).

MIL-STD-721C (1981) describes FMEA as a procedure where each potential failure mode in a system is analyzed to determine the results or effect of the failure on the system and to classify potential failures by their severity. The risk of failure and its impact can be determined by three factors (McDermott *et al.*, 2009):

1. Severity (consequence of failure).
2. Occurrence (probability or frequency of failure occurring)
3. Detection (likelihood of failure being detected before impact of failure is realized).

These factors provide a baseline for evaluating and analyzing potential failures and their effects on a system, which can be used to develop plans to prevent failure or mitigate the risks associated with failure.

CHAPTER 4. CRITICAL UTILITY SYSTEMS ON U.S. NAVY INSTALLATIONS

There are 16 critical infrastructure sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof (CISA 2010). What is considered critical infrastructure depends on the unique characteristics of each sector and its intended mission.

On U.S. military installations, there are many assets and systems that are considered critical for national defense reasons. A subset of these critical systems are the utility systems – and corresponding infrastructure – that support the operational needs of the organizations located at each installation. The loss or incapacitation of these systems can cause severe impacts on an organization's mission. For U.S. Navy installations, NAVFAC as the service provider is ultimately responsible for ensuring these critical systems' reliability, resilience, and availability.

4.1 Electrical Utility System

The electrical grid is an interconnected network that delivers electricity from a generation source to customers on the installation (NAVFAC P-603). The electrical grid consists of three major subsystems: the generation subsystem, the transmission subsystem, and the distribution subsystem (Murty, 2017).

Within the system, many essential components help the system function as required. The critical components designated as UKOI in electric systems include the primary and secondary switch stations (substations) and other support equipment like transformers, cables, fuses, relays, and breakers.

Electrical systems can be quite complex because they have a lot of interconnected components that are usually spread over large areas. In addition, electricity is typically the most essential commodity in operating an installation because it supports every other utility and non-utility system. Therefore, maintenance of all the components in the system is necessary for ensuring continued operations on any installation. Electrical outages have had the most negative impact on operations in many instances.

4.1.1 Electrical Utility at NAVFAC Managed Installations

The PWDs at each Navy and Marine Corps installation operate and maintain the electrical infrastructure. The electricity used on the installation is typically sourced from the local electricity utility provider. In most cases, NAVFAC manages the electric infrastructure and ensures service delivery to installation customers. A summary of NAVFAC-managed electrical infrastructure on U.S. Navy installations is shown in Table 4.1.

Table 4.1: NAVFAC-Managed Electric Infrastructure

NAVFAC-Managed Electric Infrastructure		
FEC	Facility Build Date	PRV (\$M)
Europe Africa Central (EURAFCENT)	1948	\$34
Far East (FE)	1986	\$310
Hawaii (HI)	1940	\$1,142
Marianas (MAR)	1976	\$53
Mid-Atlantic (ML)	1940	\$2,406
Northwest (NW)	1984	\$396
Southeast (SE)	1940	\$1,394
Southwest (SW)	1940	\$972
Washington (WASH)	1940	\$438
TOTAL		\$7,145

The table shows the approximate value of the electrical infrastructure for which NAVFAC is responsible. The Plant Replacement Value (PRV) is the aggregate of the critical components, the build date is the approximate age of the oldest critical component, and components within the system may have been replaced or repaired after the build date.

Analyzing the table shows that the average age of these equipment put them past their generally rated service life. While extending the service life of some components through maintenance is possible, the large number of components that need to be maintained makes it a difficult proposition. This leads to decreased performance of the system as a whole.

NAVFAC uses a couple of consumer-based indices, System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) to measure the reliability of its electrical system.

SAIDI is a measure of the average number of interruption hours a customer experiences over a period of time – daily, monthly or yearly. It can be calculated using Equation (4) (Brown, 2002).

$$SAIDI = \frac{\sum \text{Customer Interruption Duration}}{\text{Total Number of Customer Served}} \quad (4)$$

Example 4.1. An installation with 10,000 customers experienced an electrical outage for 28 minutes on a windy day in August. If the outage affected 120 customers, what is the SAIDI?

$$SAIDI = \frac{120 \times 28}{10,000} = 0.336 \text{ minutes}$$

This means that the average customer on the installation experienced an outage for 0.336 minutes that day. If this remains constant throughout the year, an average customer will experience outages totaling 121 minutes for the year.

SAIFI is a measure of the total duration of how often the average customer experiences a sustained interruption over a period of time. It can be calculated using Equation (5) (IEEE, 2022).

$$SAIFI = \frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customer Served}} \quad (5)$$

Example 4.2. An installation with a total of 1,000 customers experienced a power outage when a tree fell on a power line on the installation. 750 customers were affected by the outage. What is SAIFI?

$$SAIFI = \frac{750}{1,000} = 0.75$$

This means that the average customer on the installation experiences an interruption 0.75 times that day.

The SAIDI industry standard for power outage duration is 120 minutes a year; for NAVFAC, the average power outage duration from 2018 to 2022 has been about 430 minutes a year (NAVFAC, 2022). This higher interruption duration can be attributed to the condition of the

UKOI components, the downtime experienced due to the availability of parts, and the time to repair any failed component.

The SAIFI industry standard is two outages per year. For NAVFAC, the average power outage frequency from 2018 to 2022 is 1.4 outages per year, which indicates that the average customer experiences less frequent power outages than the industry standard.

4.2 Potable Water Utility System

A potable (drinking) water system connects water sources to customers using a network of storage facilities, pipes, pumps, and valves. This distribution system can also supply water for other applications, including fire protection and agricultural and commercial uses (EPA, 2023). The system also includes water treatment facilities where necessary to make the water safe for drinking. Potable water is essential because it directly affects the health and safety of consumers. Therefore, regulations from the Environmental Protection Agency (EPA) and other state agencies set legal limits on contaminants in drinking water delivered through public water systems.

The critical components that NAVFAC designates as UKOI in a potable water system can be divided into two different categories:

1. **Facilities:** Water source wells/shafts, water treatment facilities (if needed), pumping or booster stations, and storage tanks.
2. **Transmission Mains:** Sub-surface pipelines – usually 18 inches in diameter or larger.

These components are considered critical because their failure generally causes an interruption in service delivery to the customer, which can severely impact the health and safety of residents or workers on an installation and the customers' critical missions.

4.2.1 Potable Water Utility at NAVFAC Managed Installations

At installations where NAVFAC owns the potable water distribution system, the PWD is responsible for operating the system and maintaining all the critical components. In most cases, depending on the location of the installation, the distribution system can span thousands of miles. The distribution system may also be located in different terrains: below the surface (ground, water) or up and down mountains.

These factors make operating and maintaining this type of system challenging. Therefore, serious consideration must be given to the type of material used in the pipe system because the performance and maintenance of each pipe type can vary considerably due to technical and maintenance reasons (Singh & Adachi, 2011). A summary of NAVFAC-managed potable water infrastructure on U.S. Navy installations is shown in Table 4.2.

Table 4.2: NAVFAC-Managed Water Infrastructure

NAVFAC-Managed Water Infrastructure		
FEC	Facility Build Date	PRV (\$M)
Europe Africa Central (EURAFCENT)	1987	\$10
Far East (FE)	1986	\$19
Hawaii (HI)	1942	\$86
Marianas (MAR)	1956	\$334
Mid-Atlantic (ML)	1947	\$164
Northwest (NW)	1946	\$57
Southeast (SE)	1909	\$284
Southwest (SW)	1977	\$338
Washington (WASH)	1943	\$76
TOTAL		\$1,368

The table shows the approximate value of the electrical infrastructure for which NAVFAC is responsible. The Plant Replacement Value (PRV) is the aggregate of the critical components, the build date is the approximate age of the oldest critical component, and components within the system may have been replaced or repaired after the build date.

This shows that the components of water systems are very old. Because of the characteristics of a water system – distribution systems in different terrains and covering a considerable distance – it is difficult to assess the condition of the entire system routinely. Due to this, the most common failure seen in the system has been pipe failures. Pipe failures occur due to many reasons. Factors that affect pipe failure include age, size, pipe material, and soil type (Singh, 2011).

Using available GIS and as-built data, it was determined that the pipes in the system are over 50 years of age, which is considered over their useful life. The prevalent pipe materials used when the system was installed over 50 years ago were cast-iron (CI) and asbestos concrete (AC) pipes. A Bayesian analysis for causes of failure at a water utility conducted by Singh (2011)

shows that CI pipes over 40 years of age have the highest probability of failure, and it also shows that AC pipes also have a high probability of failure at that age.

The takeaway from this reality is that a significant amount of resources must be dedicated to maintaining these pipes, and the maintenance of pipes made of these materials may need to be prioritized over those of other materials.

4.3 Wastewater Utility System

Wastewater from various sources – homes, businesses, industrial, and storm water runoff – must be collected and conveyed to a designated treatment facility to remove the pollutants in the water before the facility can discharge into a natural body of water (Drinan & Spellman, 2012). Wastewater treatment removes pollutants – solids, dissolved organics, nutrients, and pathogenic organisms – that can cause damage to natural ecosystems and negatively impact human health (YSI Inc.).

Several federal and state regulations establish the standards for the treatment necessary before wastewater can be discharged into a natural body of water. The Clean Water Act (CWA) of 1972 established the National Pollutant Discharge Elimination System (NPDES) program that issues discharge permits “by either the U.S. Environmental Protection Agency or an authorized state/tribe contain industry-specific, technology-based, water quality-based limits, and establish pollutant monitoring and reporting requirements” (Boucher *et al.*, 2011).

When discharged, the wastewater utility system that collects the water from different sources consists of two main parts.

1. **Collection System.** The collection system carries the wastewater from the user to the WWTP. The collection system has various components, including (Drinan & Spellman, 2012):
 - a. Building services carrying waste from the generation point to the mains (pipeline)
 - b. Mains (force or gravity) that carry waste to collection sewers.
 - c. Collectors or sub-collectors carrying waste to trunk lines.
 - d. Trunk lines carrying waste to interceptors.
 - e. Interceptors carrying waste to the treatment plant.
 - f. Other components include lift stations, manholes, junction boxes, vents, and cleanout points.

-
2. **WWTP.** This is where the wastewater is treated before being discharged. The treatment consists of several processes, including:
 - a. Preliminary treatment to remove specific materials.
 - b. Primary clarification to remove solids remaining from the preliminary treatment.
 - c. Biological treatment to convert suspended or dissolved organic wastes to more stable solids that can be removed by settling.
 - d. Secondary clarification to separate solids from treated wastewater and concentrate or thicken the return sludge.
 - e. Advance treatment for specific discharge parameters or to meet reuse criteria.
 - f. Disinfection to reduce harmful organisms to low levels to protect public health.

4.3.1 Wastewater Utility at NAVFAC Managed Installations

As discussed above, the wastewater utility system comprises many complex components and processes that must be adhered to meet stringent NPDES permitting requirements before wastewater can be discharged into bodies of water. The system has many critical components that must remain functioning to achieve the standards required for operating a WWTP.

On installations with a WWTP, NAVFAC is responsible for ensuring the WWTP meets all the federal and state regulations associated with operating a WWTP. Failure to meet the required standards can lead to fines or a loss of operating or discharge permits. Losing a permit can lead to significant health and safety issues for customers on the installation. An inventory of NAVFAC-managed wastewater infrastructure on U.S. Navy installations is shown in Table 4.3.

The table shows the approximate value of the wastewater infrastructure for which NAVFAC is responsible. The Plant Replacement Value (PRV) is the aggregate of the critical components, the build date is the approximate age of the oldest critical component, and components within the system may have been replaced or repaired after the build date.

Similar to the electric and potable water systems, the wastewater utility system comprises system components past their useful life. The pipes and pump stations in the collection system have an average age of 50 years, which makes them highly susceptible to failure. Most of the critical equipment at the WWTP – clarifiers, aeration tanks, sand filters, disinfection systems, effluent pump stations – are past their useful life. At some locations, some of these components are inoperable, resulting in the WWTP operating at reduced capacity and being unable to adequately provide the required services to the installation they support.

Table 4.3: NAVFAC-Managed Wastewater Infrastructure

NAVFAC-Managed Wastewater Infrastructure		
FEC	Facility Build Date	PRV (\$M)
Europe Africa Central (EURAFCENT)	1998	\$33
Far East (FE)	1983	\$479
Hawaii (HI)	1976	\$784
Marianas (MAR)	1975	\$817
Mid-Atlantic (ML)	1971	\$496
Northwest (NW)	1978	\$44
Southeast (SE)	1990	\$754
Southwest (SW)	1961	\$794
Washington (WASH)	1940	\$172
TOTAL		\$4,373

CHAPTER 5. MAINTENANCE CLASSIFICATION AND STRATEGIES

Maintenance is defined as a combination of technical and administrative actions required to keep an asset in or restore it to a state where it can perform its required function (Velmurugan & Dhingra, 2015). The main objective of maintenance is to reduce the adverse effects of asset failure and increase its availability in order to improve asset performance (Simeu-Abazi & Sassine, 2001).

Maintenance encompasses all the tasks necessary to keep the asset from failing or restoring it to its original condition in the event of failure. Many organizations – companies, government agencies, schools, hospitals, etc. – invest a lot of money in their facilities and keeping them in good working condition is essential to their organization's mission. Organizations realize the need to invest in maintaining their facilities, but because facility maintenance outcomes are subtle, gradual, and often intangible, there is a reticence from decision-makers to dedicate the needed resources to maintenance due to other priorities that they may deem more important (Ottoman, 1999).

5.1 Maintenance Classifications

The importance of maintaining assets cannot be understated. Studies have shown that adequately investing in the maintenance of assets owned by an organization generally has long-term benefits – better reliability and availability of equipment and sometimes an extension of the asset's useful life.

To that end, maintenance is a business decision. Decision makers must understand how the decision to provide or not provide resources for asset maintenance can impact their organizations. The level of investment plays a crucial role in determining the maintenance approach. There are several maintenance practices that an organization can undertake depending on how they like to operate.

5.1.1 Maintenance Classification A

Maintenance can generally be classified into two categories: Preventive Maintenance (PM) and Corrective Maintenance (CM). PM are actions taken to prevent failure, and CM are actions taken after failure to restore an asset's function (Duffuaa *et al.*, 2021). A basic representation of this classification is shown in Figure 5.1 (Gulati, 2021).

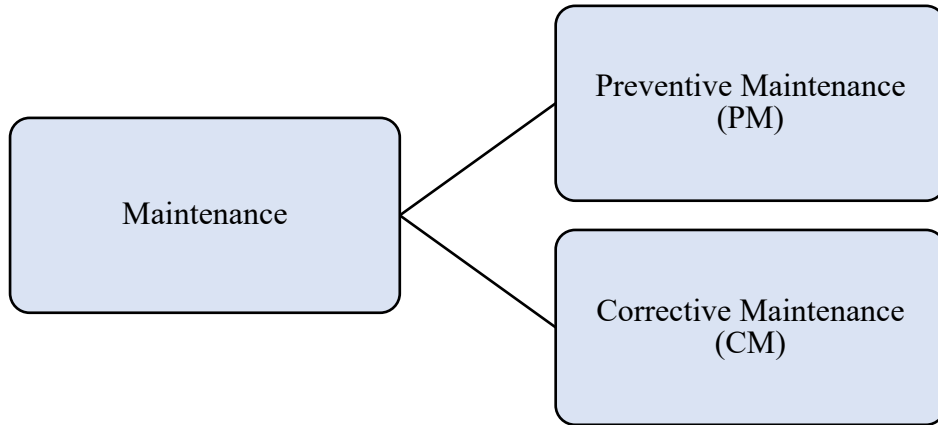


Figure 5.1: Maintenance Practices – Classification A
(Modified from: *Maintenance and Reliability Best Practices* (3rd ed.), Gulati (2021))

In each of these categories, their effectiveness is dependent on how the required tasks are executed. It is more effective to have these tasks planned and scheduled. The operator may complete additional tasks if necessary during planned PM to reduce the chances of asset failure. If an asset fails, conducting timely repair can help bring it back to operation earlier to minimize any impact.

5.1.2 Maintenance Classification B

This classification breaks down the required maintenance tasks into additional categories of PM. Time-Based Maintenance (TBM) and Run-Based Maintenance (RBM)), Condition-Based Maintenance (CBM), Operator-Based Maintenance (OBM), Total Productive Maintenance (TPM), planned CM as a result of PM, CBM, or OBM, and Breakdowns; a basic representation of this classification is shown in Figure 5.2 (Gulati, 2021).

As in Classification A, the effectiveness of these practices depends on how well the required tasks are conducted. This classification provides additional structure to the way maintenance is performed.

5.1.1 Maintenance Classification C

This classification expounds on earlier classifications and introduces some additional maintenance. Each element gives facilities and asset owners other options on how they plan to approach maintenance within their organizations. A basic representation of this classification is shown in Figure 5.3 (Gulati, 2021).

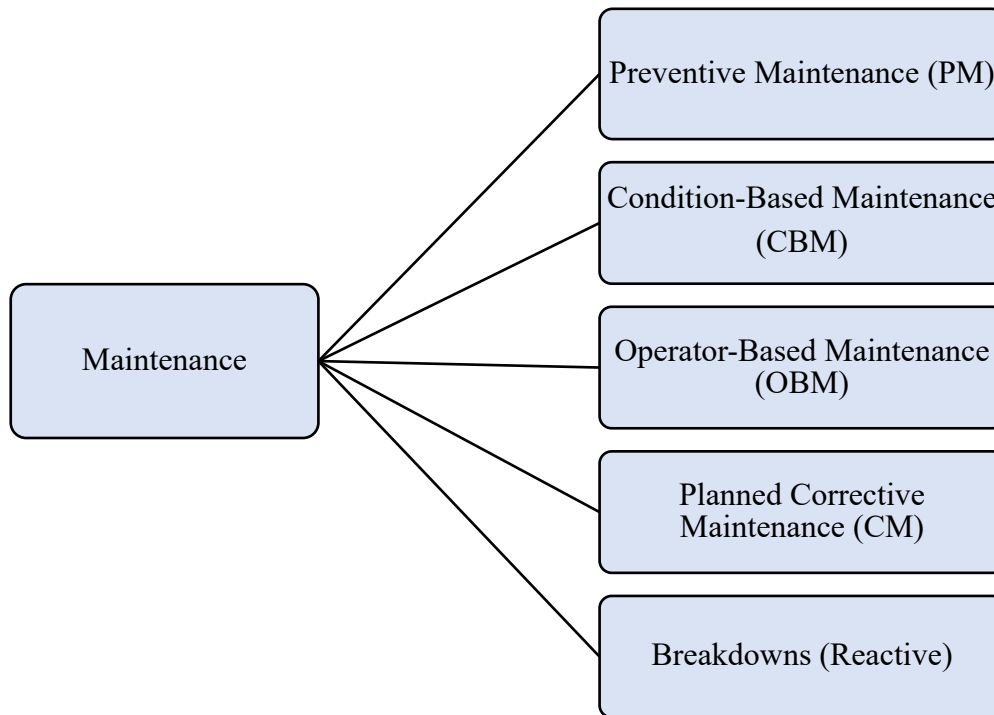


Figure 5.2: Maintenance Practices – Classification B
(Modified from: *Maintenance and Reliability Best Practices* (3rd ed.), Gulati (2021))

In this classification, all tasks are planned or scheduled except when the asset breaks down unexpectedly. In some situations, a decision is made to allow an asset to run to failure, especially if that component is not crucial or can be easily repaired. Even in cases like this, there is a repair plan after the component fails.

5.2 Maintenance Strategies

Properly maintaining an organization’s facilities or assets is essential to helping the organization meet its operational requirements. The level of investment and the structure of the maintenance program may differ, but the end goal is the same for all organizations. How an organization approaches how they maintain their facilities or assets can depend on several factors: the type of prevalent facilities in their inventory, their mission, the location of the facilities, the age of their facilities, and so on. For example, a school with mostly classroom facilities may approach maintenance using a simple PM/CM strategy. In contrast, a military base that supports national defense-type missions may use a combination of PM, CBM, or RBM to maintain their facilities.

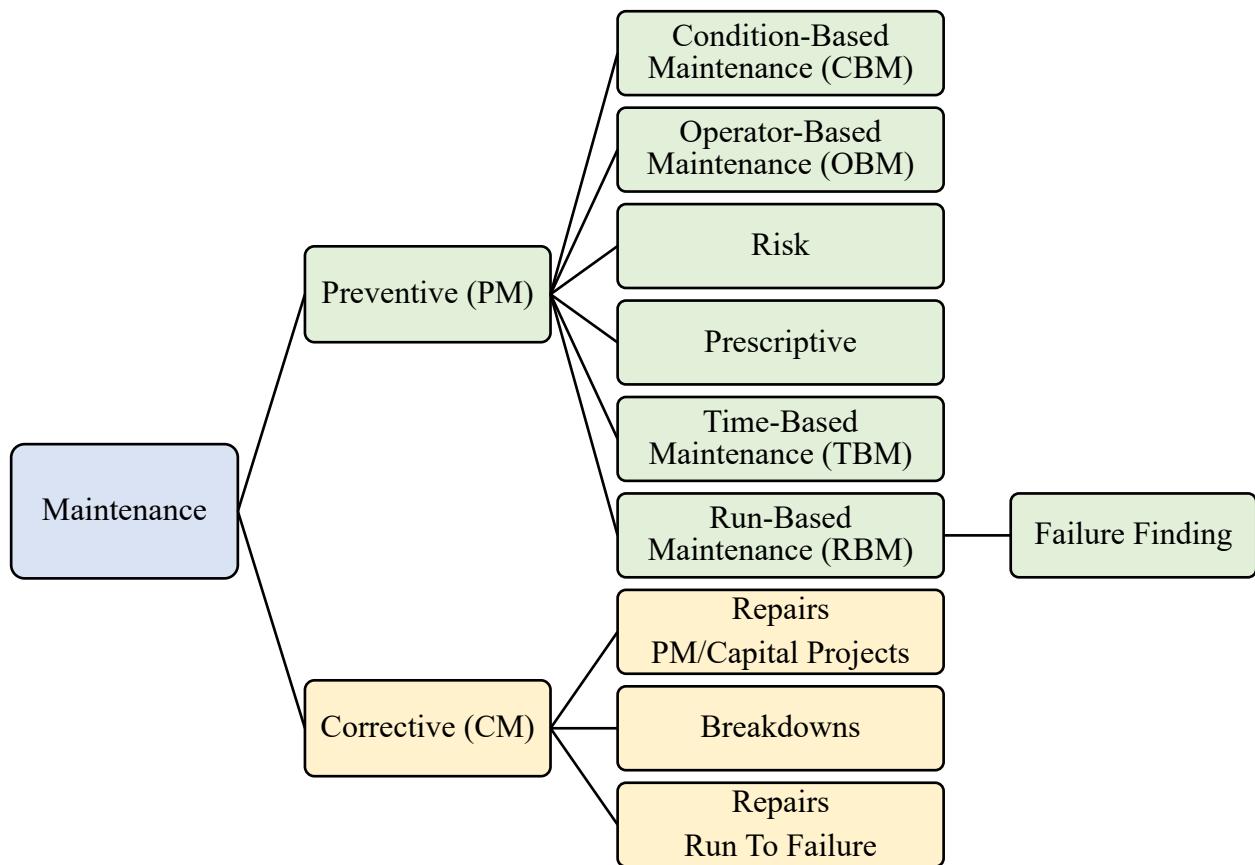


Figure 5.3: Maintenance Practices – Classification C
 (Modified from: *Maintenance and Reliability Best Practices* (3rd ed.), Gulati (2021))

Maintenance strategies have evolved based on new technology and experience gained from hands-on efforts in maintaining different types of systems. The evolution of maintenance strategies over a period of time is shown in Figure 5.4 (Arunraj & Maiti, 2007).

This evolution stems mainly from the need to maintain equipment that is becoming more complex and the realization that maximizing the reliability and availability of a system helps reduce long-term costs.

Based on this evolution, several strategies are available for organizations to structure their maintenance approach. Some of the common strategies are discussed below.

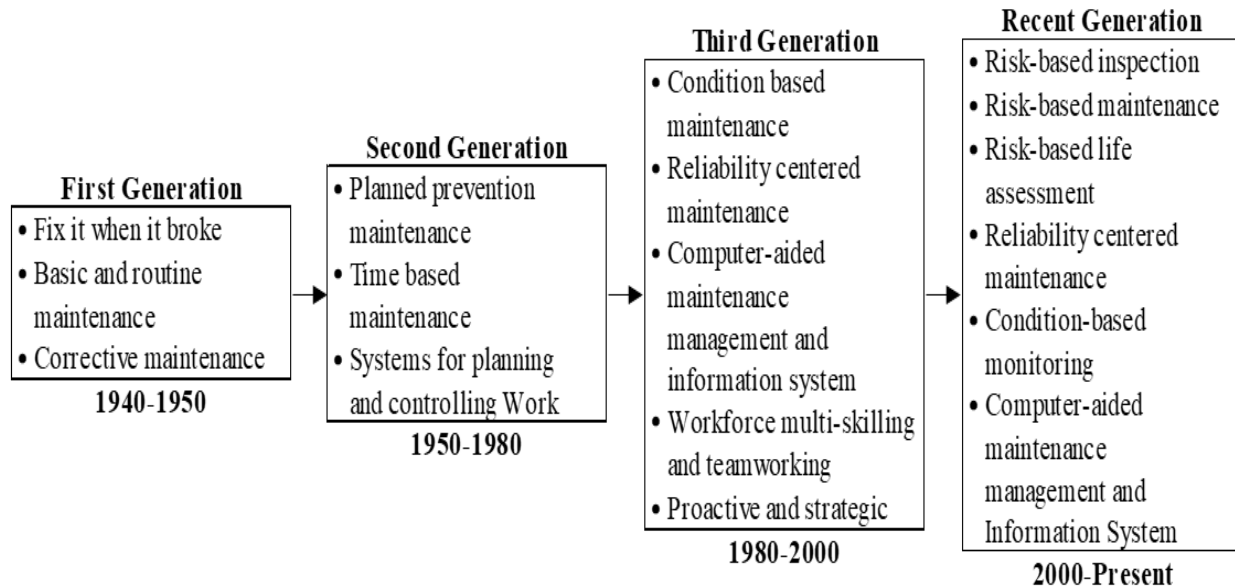


Figure 5.4: Development of Maintenance Philosophies
(Modified from: Risk-Based Maintenance – Techniques and Applications. *Journal of Hazardous Materials*. (Arunraj & Maiti, 2007)).

5.2.1 Condition-Based Maintenance (CBM)

Condition-based maintenance, also called predictive maintenance, is an approach that periodically assesses an asset's condition based on data collected from the system through monitoring or inspections. This approach aims to help determine any required maintenance actions to prevent predictable failure (Neelamkavil, 2011).

This strategy is predicated on having a way to continually monitor an asset, which can be completed by visual inspections or technology. This strategy bases the maintenance need on the actual condition of an asset, as opposed to a preset schedule.

The key advantage of this strategy is that since a large percentage of equipment failures are preceded by indications that a failure is likely to occur, it allows for a real-time assessment of the equipment condition, which enables the ability to make maintenance decisions (Ahmad & Kamaruddin, 2012)

5.2.2 Preventive Maintenance (PM)

Preventive maintenance is a strategy whereby maintenance is planned and performed after a specified period, or when an asset has been used for a certain period, to reduce the asset's probability of failure (Kimura, 1997). PM often requires regular visits to monitor an asset's

condition and determine if there are signs of failure or imminent failure. In most cases, an asset manufacturer typically provides a checklist or procedures detailing what an inspector should observe to determine the asset's condition.

PM can be based on either calendar time or asset runtime, which is valuable because it allows for the maintenance of assets to keep them in satisfactory operating condition by enabling inspection, detection, and correction of minor failures before they can develop into major failures. Additionally, the data obtained from the monitoring and observations can be used to analyze the asset and develop needed corrective tasks.

5.2.3 Reliability-Centered Maintenance (RCM)

Reliability-centered maintenance is a process whereby asset maintenance is carried out at the component level, and the maintenance tasks for the component are a function of its reliability and its consequence of failure under normal operations (Murthy, 2002). RCM is based on the hypothesis that an efficient lifecycle maintenance program can be developed using a disciplined logic analysis process that focuses on the consequences of failure and actual preventive maintenance tasks. This logic process considers three maintenance tasks (Anderson & Neri, 1990).

1. Hard-Time Replacement (HTR), where degradation due to age can be prevented by replacing the component at a predetermined fixed interval before failure.
2. On-Condition Maintenance (OCM), where degradation can be detected using periodic inspections.
3. Condition Monitoring (CM), where degradation can be detected by using instrumentation to monitor the asset's condition.

This strategy is useful as a proactive approach to identify potential failures that can occur in specific components, which can then be used to plan and prioritize maintenance actions to reduce the chances of failure.

5.2.4 Risk-Based Maintenance (RBM)

Risk-based maintenance is a strategy where possible modes of failure are identified, risks associated with those failures are determined, and a maintenance plan is developed to minimize the probability of high-risk system failures occurring (Arunraj & Maiti, 2007)

This strategy uses risk analysis techniques to identify and evaluate the risk of an asset failure. A risk level is determined from the analysis, which is then used to prioritize maintenance actions (Dickerson & Ackerman, 2016). With this approach, assets with higher risk or consequence of failure can be prioritized for maintenance.

This strategy is especially valuable for organizations where maintenance resources are limited. High-risk assets with a more significant consequence of failure are monitored and maintained more frequently, while the maintenance of assets with lower risks is less stringent.

5.2.5 Corrective Maintenance (CM)

Corrective maintenance is a strategy where maintenance actions such as repair or replacement are carried out on a system to restore it to its required functionality after failure. This strategy often leads to a high level of system breakdown and high replacement costs because of sudden and unexpected occurrences of failure (Paz and Leigh, 1994).

CM tasks can be classified into three categories:

1. Scheduled tasks, where the repairs are planned ahead of time. This can be tasks identified through CBM and PM monitoring outcomes.
2. Major repairs or projects which are also planned and scheduled.
3. Reactive tasks, which are unplanned and have to be completed in case of breakdowns.

This strategy carries many risks and is only useful for assets with low consequences of failure or inexpensive to repair or replace.

CHAPTER 6. NAVFAC UTILITY MANAGEMENT AND MAINTENANCE STRATEGY

NAVFAC is responsible for facility management at 95 installations worldwide. The nature of NAVFAC's business demands that they manage a considerable number of assets across the enterprise. Each system discussed in Chapter 2 presents its unique challenges in managing it – the systems are complex and critical. To meet this challenge, careful attention must be paid to each facility's lifecycle management to ensure they meet their intended function and perform at an acceptable standard to support customers' mission across all NAVFAC-managed installations.

NAVFAC, like all other organizations, invests heavily in its facilities and has to manage the facility's lifecycle model, which can be simplified into the following elements:



Figure 6.1: NAVFAC Facilities Lifecycle Model

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1. **Planning.** Identifying facility requirements for specific missions, evaluating acceptable options, developing strategies for obtaining funding, and determining cost estimates and schedules.
 2. **Design and Construction.** Developing plans and specifications based on the facility requirement and all activities and efforts that directly support the implementation of the design and the physical construction of the facility.
 3. **Sustainment and Recapitalization.** Conducting required maintenance to keep the facility operating at an acceptable level and then reinvesting in a replacement facility when facility performance has become degraded.
 4. **Divestiture.** Disposal of the facility. It can refer to the demolition of a facility once it is at the end of its useful life and can no longer perform its intended function or transfer to another party that can use the facility for other purposes.
 5. **Environmental, Cybersecurity, and Energy.** Other necessary factors depend on prescribed standards by law, the location of the building, and the intended use of the facility.

In facility lifecycle management, sustainment and recapitalization is often the most protracted and most expensive phase of a facility or asset's lifecycle, accounting for up to 60% of the lifecycle costs (Gallaher *et al.*, 2004). In many cases, this phase is 15-25 times longer than all the other phases in the life of a facility (Roper, 2014). This phase encompasses all the maintenance actions required to keep an asset functioning as intended and the replacement of the asset in the case of failure or at the end of its useful life.

6.1 Facility Maintenance on NAVFAC-Managed Installations

To properly support these installations, NAVFAC is divided into Facilities Engineering Commands (FEC) that manage the facilities in their respective regions. Across the NAVFAC enterprise, standardized concepts of operations are promulgated by NAVFAC Headquarters to all FECs in managing their facilities. This information is contained in the Utilities Infrastructure Management Manual for utility systems, commonly referred to as NAVFAC P-603.

PWD personnel at each installation perform all the maintenance tasks for all the assets in their respective locations. As they perform these maintenance tasks, they record the actions

performed and the asset's condition as observed. The actions and observations are then entered into the appropriate EAM system so the asset's condition can be monitored and updated to plan appropriately for future maintenance or replacement requirements.

6.1.1 NAVFAC Preventive Maintenance Strategy

NAVFAC, as mandated by the Office of the Secretary of Defense (OSD), currently uses a CBM strategy to maintain the facilities on NAVFAC-managed installations. This approach allows for maintenance based on the asset's actual condition as observed by an installation's PWD maintenance personnel. The asset evaluation is then recorded in an Enterprise Asset Management (EAM) system – NAVFAC uses IBM's Maximo. The condition, as observed, is recorded in Maximo as a Direct Condition Rating (DCR), which is subsequently used to determine the sustainment requirements for the asset (NAVPAC P-503).

Generally, for this approach, the PWD personnel use a combination of site visits and technology to monitor and conduct system maintenance. The personnel use the SCADA control system – especially at larger installations – to monitor the systems. PWD personnel visit an asset to perform scheduled PM tasks and evaluate the asset. Any CM task generated from the site visit or discovered through monitoring is planned and scheduled for completion. Every time an asset is touched, the technician records it in Maximo so that the asset can be tracked, analyzed, and the information can be used to determine when the asset is degrading. The planning for a replacement can begin.

An interview of facilities management personnel at three of NAVFAC's FECs was conducted to determine if this strategy is consistent across the NAVFAC enterprise. Some of the observations noted from the interview are discussed below:

1. There were no significant differences between strategies at the FECs; some of the minor differences were due to factors such as the location and size of installations within the FEC and the mission of the majority of the installation's customers – which determines the predominant type of assets they have to monitor and maintain.
2. The CBM strategy is the prevalent strategy used across the FECs. Other strategies – RBM, RCM, PM, or CM – are in use, depending mainly on the criticality of the asset being maintained. High-risk assets with greater consequences of failure are monitored and maintained more closely than low-risk assets.

-
3. The use of monitoring systems (SCADA) is common at larger installations. The information received from the system is used to adjust the timing and frequency of PMs. Additionally, the system's automation level is based on the location, especially in cases where the asset is located in a hard-to-reach area – for example, a transmission main located underground or a transformer located in a mountain.
 4. Resource constraints (maintenance funding, qualified personnel) have made PM completion fall below mandated standards. Some of these constraints and their effects are discussed later in this chapter.

6.1.2 NAVFAC Utility Management

As previously discussed, NAVFAC is responsible for operating and maintaining the utilities infrastructure on U.S. Navy installations. To be consistent across the enterprise, NAVFAC has adopted maintenance strategies based on a Utilities Infrastructure and Condition Assessment Program (UICAP).

The UICAP is a combination of tools and processes that helps understand utilities systems' maintenance, repair, and replacement needs. The tools and processes also help to analyze risks of failure and help prioritize investment resources for assets requiring replacement. The UICAP is divided into four phases (NAVFAC P-603).

1. Phase 1: Baseline Inventory/Condition Assessment

In this phase, the initial condition is determined through inspection and recorded. A Degradation Index (DI) rating is then assigned to the asset based on the condition. The DI rating is a score from 1 to 5 that describes the asset's condition from best to worst. The components of the DI rating are shown in Table 6.1 (NAVFAC P-603).

The rating highlights the current condition of the asset, whether it is fully functional or if the function is affected. This information is necessary to assess the risk to the asset and is a data point as part of the project prioritization process.

2. Phase 2: Risk Assessment and Risk-Based Investment Planning

This phase takes information from Phase 1 and uses it to assess the asset's risk of failure. The assessment is based on the DI rating. The rating is then used to determine maintenance requirements and, if necessary, the need to start planning for major repair or replacement of the asset.

Table 6.1 UICAP Degradation Index
(Modified from: NAVFAC P-603, *Utilities Infrastructure Management Manual*, 2018)

	Likelihood Category	Degradation Index
Fully Functional	Negligible = 1	No noticeable defects. Some aging or wear may be visible. Fully functional
	Not Likely = 2	Only minor deterioration or defects are evident. Noticeable wear or aging is visible. Fully functional. Minor maintenance may be required.
	Possible = 3	Deterioration or defects are evident. Function is not significantly affected. Minor repairs are required.
Function Affected	Likely = 4	Serious deterioration or defects in at least some portion of the asset. function is significantly affected. Extensive repairs or replacement are required.
	Very Likely = 5	Extensive deterioration or defects in the asset. Not functional, barely functional or beyond repair.

Risk assessment is part of the calculation when deciding where to allocate resources for investment. The risk rating developed from the assessment is used to prioritize projects developed to maintain or repair assets with a high probability of risk of failure.

3. Phase 3: OSD Real Property Inventory Requirements

This phase deals with validating assets in the NAVFAC inventory and associating asset records across the multiple management and inventory systems that NAVFAC uses to track the facilities they manage.

This phase is essential because having reliable records of assets in the inventory and their actual condition ensures that the proper assessments can be made and that resources are allocated to the right assets. The authoritative databases (with the ability to interact with each other) for Navy use assets include (NAVFAC P-603):

1. **Maximo:** NAVFAC’s enterprise asset management and maintenance system. It consists of application modules that contain service requests, work orders, outage records, and condition ratings for all Navy assets.
2. **Internet Naval Facilities Assets Data Store (iNFADS):** The official record of the Navy’s real property assets. The database is an electronic file storage system of data on each facility.

3. Geographic Information System (GIS): Electronic map application for planning, operating, and maintaining installations. GIS can be used to link work orders to facility footprints.

4. Phase 4: Standard PM Program

The efforts from Phases 1 through 3 form the baseline to develop the standard PM program for an asset. The asset's current condition is used to identify the PM needs for an asset. From this, the tasks required to repair the asset can be planned, scheduled, and prioritized depending on the asset's importance.

Once the PM tasks are completed, the DI scores for each touched asset can be updated across the required enterprise systems. This gives a clear picture of where utility risks are across the enterprise and enables decision-makers to decide where best to allocate resources.

6.1.3 Utility Risk Assessment Tools

A Utilities Risk Tool (URT) is used to help complete the assessment described in phase 2 of the UICAP process. The URT considers the asset's likelihood of failure and its consequence of failure. The result of this assessment is then used to develop a risk matrix that drives actions that have to be undertaken depending on the risk category of an asset. The URT cycle is shown in Appendix A.

6.1.3.1 Likelihood of Failure

The Likelihood of Failure (LoF) is a numeric score from 1 to 5 based on the DI of the asset, and it represents the probability that the asset will fail to perform its intended function. The score is the weighted average of four categories: Degradation Index, Performance Capability, O&M/PM Procedures, and Reliability.

The score generated from these categories gives facility managers an indicator of the expected performance of an asset. A score of 1 indicates that the asset is fully functional and has a low probability of failure, while a score of 5 indicates that the asset has a high probability of failure. This information is used to determine if there are any steps they need to take to ensure that the asset is available to perform its required function when it is called upon. A detailed LoF matrix is shown in Appendix A.

6.1.3.2 Consequence of Failure (CoF)

The CoF is a numeric score from 1 to 5 based on mission importance and redundancy. It represents the most severe probable outcome if the asset cannot perform its intended function. The score is the weighted average of six categories: Mission Disrupted, Disruption Severity, Number of Facilities, Health and Safety/Regulatory Compliance, Financial Impact, and Asset Restoration Time.

The score generated from these categories gives facility managers an indicator of the impact of the failure of an asset. A score of 1 shows no disruption to a mission, while a score of 5 indicates a significant disruption to a customer's mission. This can be useful in determining what they can do to mitigate the impact of the failure. A detailed CoF matrix is shown in Appendix A.

6.1.3.3 Risk Matrix

The combination of the LoF and the CoF is a relative rating used to determine the risk rating of an asset. The rating is on a 1 to 5 scale. The score is then used to determine a risk category and provides a recommendation on the actions to take to mitigate the risks in each category. Table 6.2 (NAVFAC P-603) shows the risk rating matrix.

Mitigations are identified for each risk category based on the risk rating score. The rating is important for facility managers because the risk rating score is critical to how projects are evaluated and prioritized for funding.

6.2 NAVFAC PM Assessment

Based on the respective mission on various installations, there are varying degrees of tolerance for utility downtime, and planned periodic maintenance is fundamental to the continued operation of critical utilities (NAVFAC P-603). The PM completion goal for NAVFAC PWDs is 100 percent. A review of the PM execution rates across the enterprise shows that there has been inconsistent PM performance across the NAVFAC enterprise.

6.2.1 PM Completion Rate

The PM completion rates at each FEC across the NAVFAC enterprise is shown in Figures 6.3 and 6.4. They show the completion rates for all infrastructure on an installation and the rates for Utility infrastructure, respectively.

Table 6.2: Risk Rating Matrix
 (Modified from: NAVFAC P-603, *Utilities Infrastructure Management Manual*, 2018)

Risk Rating	Risk Category	Recommended Action
1.0 - 2.4	Low Risk	No repairs or projects are needed to mitigate risk.
2.5 - 3.4	Moderate Risk	Mitigation should be identified. Implement low-cost options or operational changes. CoF and LoF scores should be used to determine if projects should be funded.
3.5 - 4.4	Significant Risk	Mitigations must be identified, and a project developed.
4.5 - 5.0	Considerable Risk	Mitigations must be identified, and immediate funding of a project should be considered.

The completion rates account for all the facilities for an installation; there is no distinction on the importance of an asset. At each FEC and across the NAVFAC enterprise, the completion rates for all facilities are higher than the completion rate for utilities' infrastructure. One of the reasons for this could be the complexity and nature of the utilities infrastructure, as each system covers a lot of ground and has many components.

Even though the completion rates for utilities' infrastructure are lower than for the overall infrastructure, discussions with facility management personnel at some of the FECs indicate that they adopt an RBM approach for utilities and prioritize critical components for maintenance and repair. Even though the completion rate for the critical components is much higher, they are still unable to achieve the 100 percent PM completion goal. Some of the reasons for this are discussed in the next section.

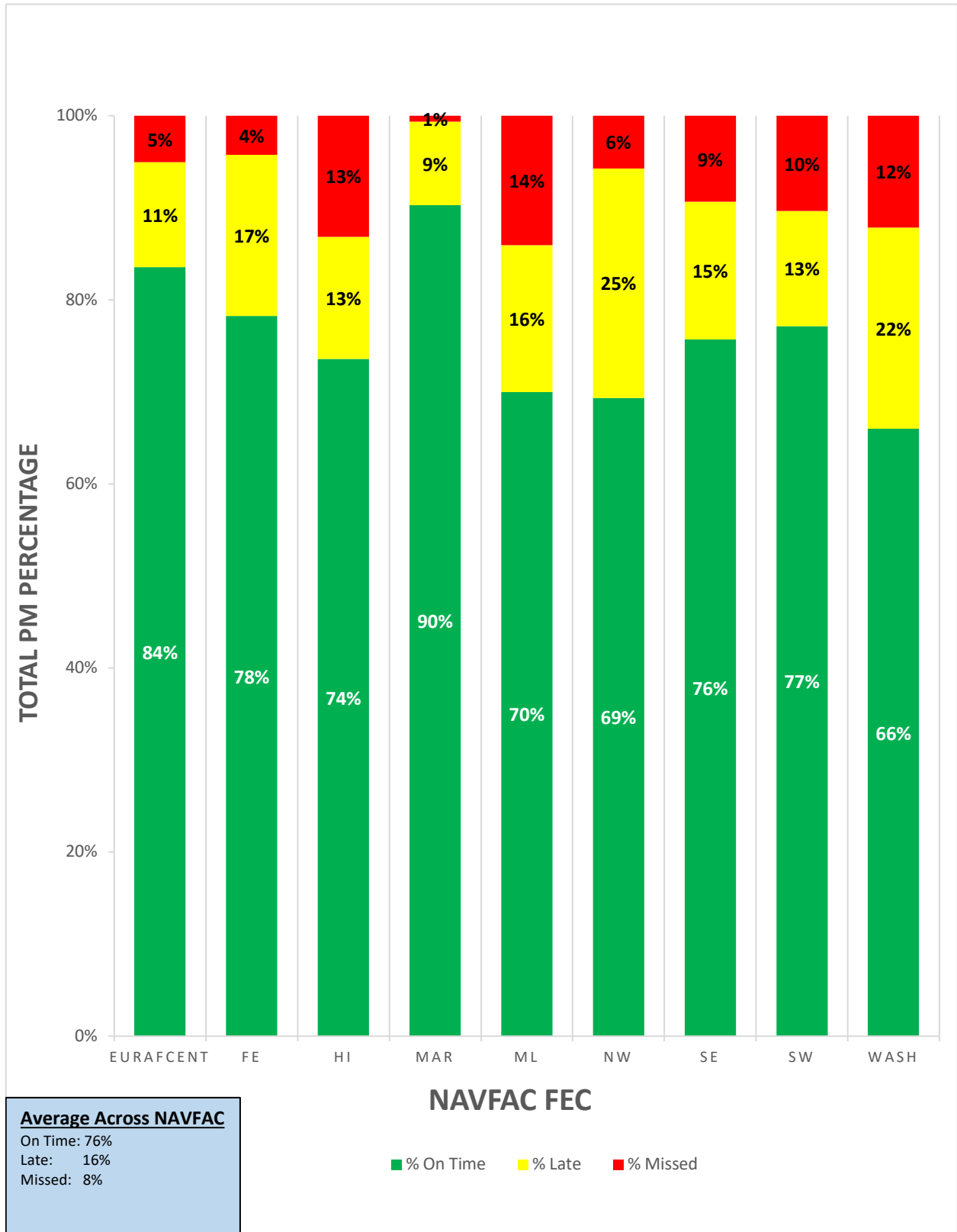


Figure 6.2: NAVFAC PM Execution (All Facilities)

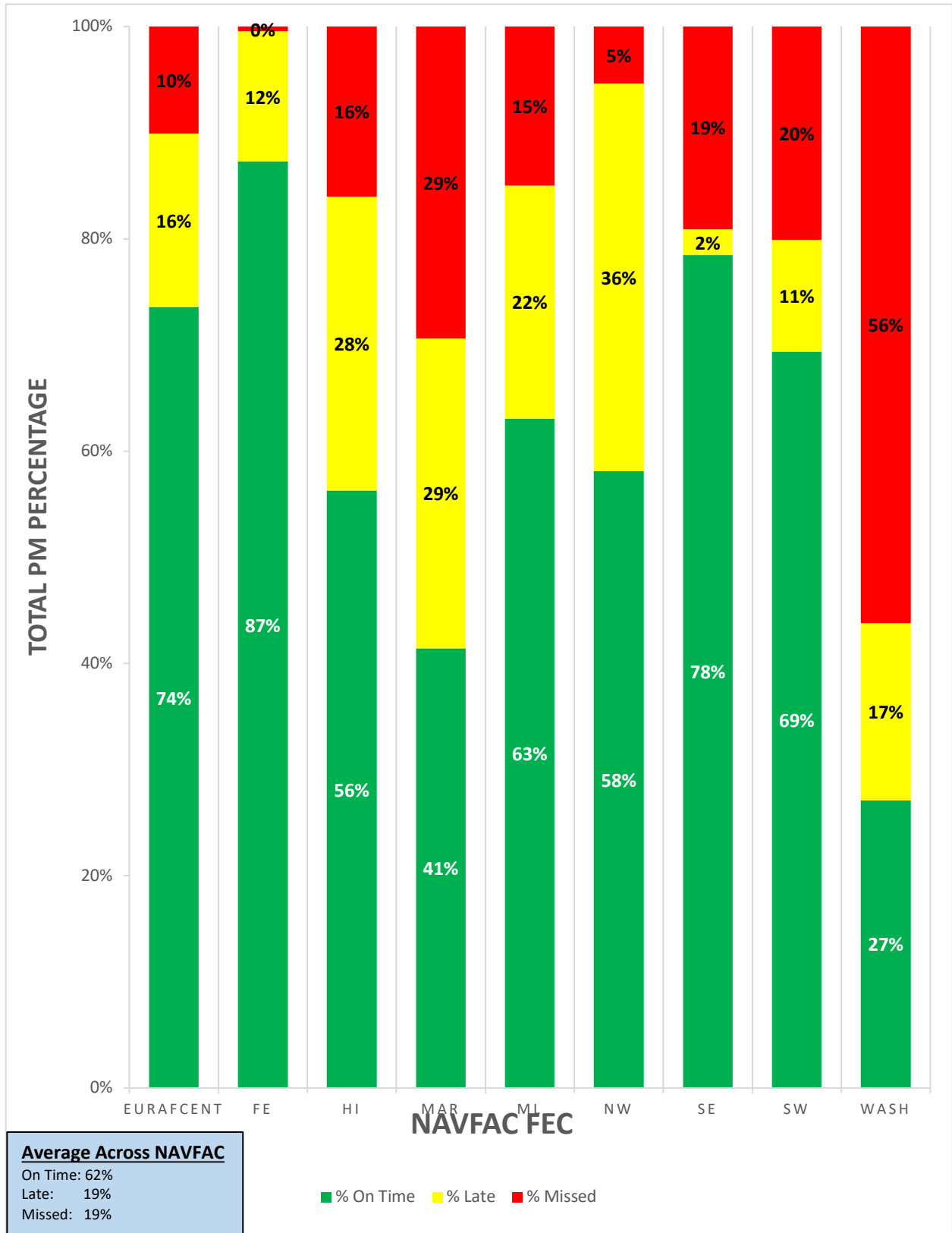


Figure 6.3: NAVFAC PM Execution (Utilities)

6.2.2 PM Completion Limitations

There are several reasons why PWDs cannot meet established PM goals, and most of them deal with the resources needed to complete PM on many assets across the NAVFAC enterprise. Some of these limitations are described below.

6.2.2.1 Facilities Sustainment Investment

The DoD uses a Facilities Sustainment Model (FSM) – published annually by the Office of the Secretary of Defense (OSD) – to fund the sustainment of facilities. The FSM is a lifecycle cost model designed to forecast funding requirements for DoD’s inventory of facilities. The model is used to determine the cost of sustaining all of DoD’s facilities, which is then used to generate an annual sustainment requirement (NRC, 2001). The FSM formula for determining sustainment requirements is shown in Figure 6.5 (OPNAV Instruction 11010.20J).

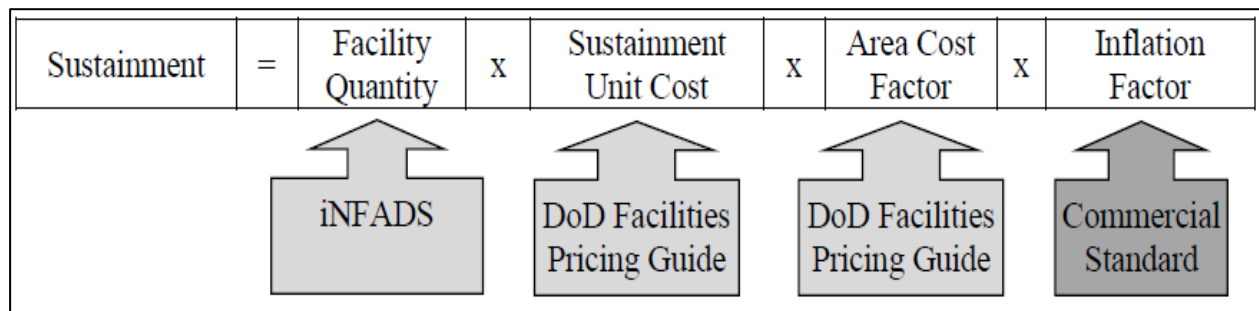


Figure 6.4: Facility Sustainment Requirement Formula
(Source: OPNAVINST 11010.20J, *Navy Facilities Project*, 2022)

The facility quantity is the facility size (measured in square feet). The sustainment unit cost is the average annual unit cost – in current year dollars (updated and published annually) – for sustaining the average size facility of a facility in the same facility analysis category. The area cost factor (ACF) provides an adjustment based on the location of a project; it considers the difference in the costs of construction, materials, labor, equipment, taxes, procurement, design, and project administration (Taam & Singh, 2010). The inflation factor is applied to the sustainment cost using the latest inflation indices (OPNAVINST 11010.20J).

Example 6.1. What is the sustainment requirement in 2023 for a 20,000-square-foot dining facility on Joint Base Pearl Harbor-Hickam, Hawaii. (Note: Obtain sustainment unit cost, ACF, and inflation factor from the DoD facilities pricing guide.)

$$\text{Sustainment Requirement} = 20,000 \text{ SF} \times \$7.26 \times 1.99 \times 1.035 = \$299,061.18$$

Therefore, the sustainment requirement for the facility will be approximately \$299,000.

By policy, DoD’s goal is to fund sustainment programs at 90 percent or higher of the FSM (USD AT&L). The sustainment requirement and funding received for Utilities infrastructure across the NAVFAC organization over the last five years is shown in Figure 6.6.

The reality – due to budget constraints – over the past four to five years is that annual investment goals for maintaining utilities infrastructure have not been met, and there is a continual decrease in the investment. This causes a cascading effect, where required maintenance is deferred, which ultimately reduces an asset's service life.

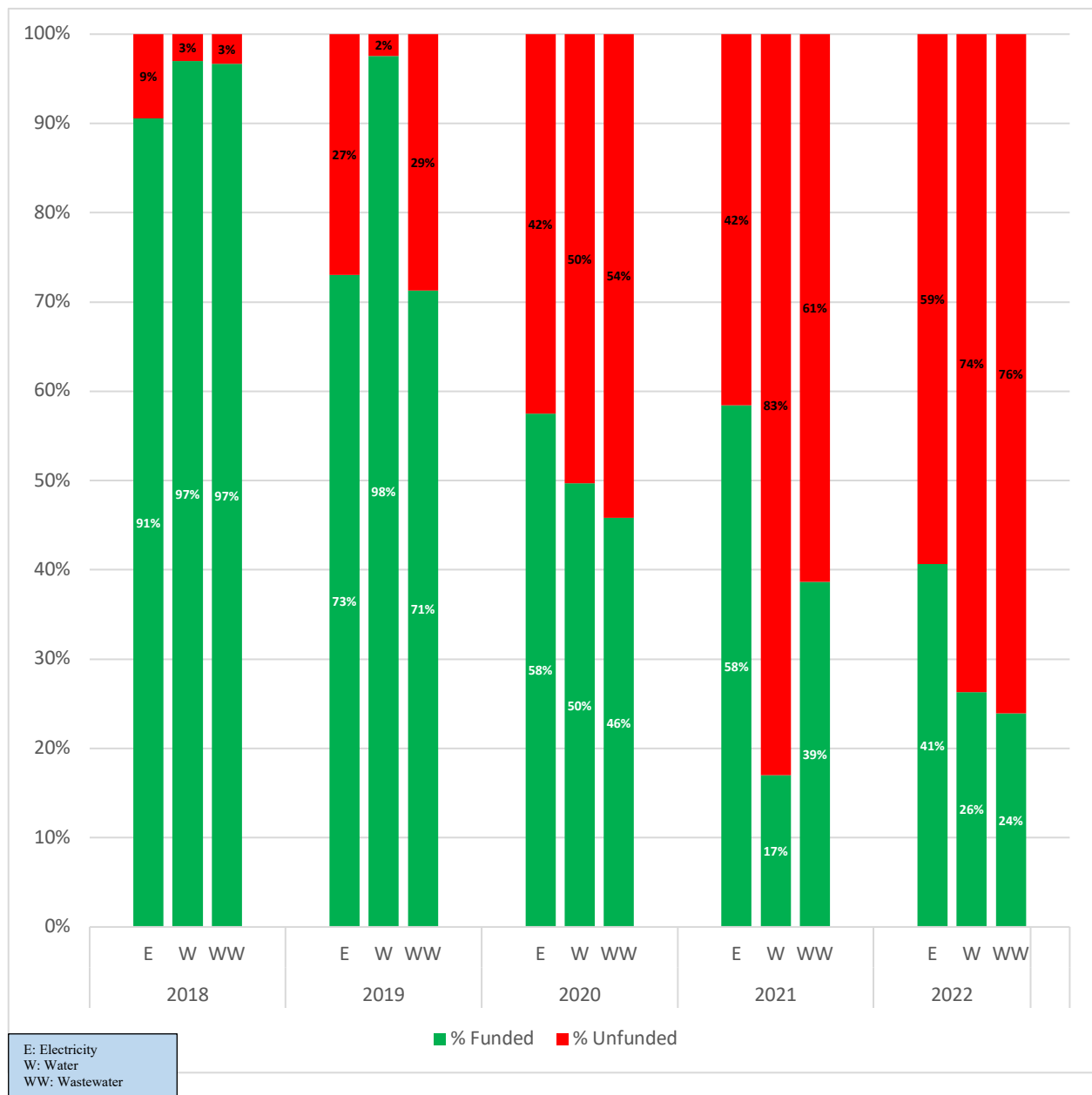


Figure 6.5: CBM Execution Investment (Utilities)

6.2.2.2 Staffing Vacancies

Another factor that affects PM completion is staffing vacancies at PWDs. Misalignment of skill sets is also a factor in this problem. Discussions with utility facility management personnel indicate that understaffing is a major concern. These vacancies imply that in addition to PMs not being completed on time, there is not enough personnel to update management systems, leading to data inconsistencies.

In addition, the complexity of most utility systems requires personnel specifically trained to conduct certain tasks to maintain the systems. At many PWDs, there are insufficient trained personnel to maintain the significant number of assets in the inventory. This also leads to required maintenance being deferred.

6.2.2.3 Workload Management and Parts Availability

Utility systems have many components, and having several systems on one installation or across multiple installations can create a situation with a considerable maintenance workload. Due to being understaffed, there can be issues managing the amount of work that needs to be completed.

Another factor that can affect PM completion is the availability of parts. Acquiring needed parts in specific locations (for example, in Hawaii) can lead to repair tasks taking longer than expected. Also, some systems in the inventory are so old that parts needed to repair them after failure are no longer available or hard to find.

6.2.2.4 Denial of Outage Request

There have been situations where utility outage requests to perform maintenance or minor repairs on utility infrastructure did not receive concurrence from mission owners – usually because taking the asset down for the period (typically multiple hours) required to perform the necessary tasks – will negatively affect their mission.

In these types of situations, assets that can affect missions in such a way are critical. Without the concurrence of the mission owner, the maintenance has to be deferred. Another factor that aids this is the lack of adequate redundancy to replace the function of the asset requiring maintenance.

CHAPTER 7. RECAPITALIZATION

Recapitalization is the complementary piece to sustainment in the O&M phase of the facility lifecycle. Recapitalization is the major renovation or reconstruction activities necessary to keep existing facilities modern and relevant. Recapitalization helps extend the service life of facilities or restores lost service, and it includes the restoration, modernization, or replacement of facilities but not the acquisition of new facilities (CNIC, 2023).

The avenues for obtaining funding for recapitalizing major systems within the DoD are the Military Construction (MILCON) or the Facility, Sustainment, Restoration, and Modernization (FSRM) centrally managed Special Project processes. These processes originate at each installation, where a list of projects is developed based on facility requirements.

7.1 Project Planning Process

The MILCON and Special Projects processes are multi-year planning processes used to develop, prioritize, and allocate funding for projects above the respective funding threshold. These processes involve many stakeholders to determine projects that can be funded based on the amount allocated and appropriated by law.

Both processes are initiated at the installation level. Projects are generated based on their specific installation facility requirement in support of their customers' mission. The requirement from each installation is combined, and working groups across different echelons evaluate each project to determine the final list of projects that will be funded. The evaluation of projects is subject to the guidance and criteria established by U.S. Navy leadership.

A detailed project timeline sequence and working group members across echelons for each process is shown in Appendix B.

7.2 Project Prioritization

As expected from these processes, a large number of requirements are generated every year. Within the DoD, facility maintenance and repair is a lower priority for funding than weapon systems, personnel, training, and quality of life objectives (Ottoman, 1999).

Budget constraints dictate that not every requirement can be funded. Therefore, prioritization of projects becomes essential. Guidance is provided by Navy leadership to help

streamline the groups' decisions and assist the working groups in evaluating projects and prioritizing them for funding. Based on this guidance, a Program Objective Memorandum (POM) is developed each year, which can change yearly depending on national security requirements.

The guidance provided is used to develop a decision lens model to prioritize projects for funding. The model comprises three weighted factors that are combined into a facilities investment model (CNIC, 2022). Table 7.1 shows an example of the combined model.

Table 7.1 Typical Combined Decision Lens Model
(Modified from: *Addendum 1 to the CNIC N4 Project Development and Assessment Guide* (CNIC, 2022))

Combined Decision Lens Model		
First Level	Second Level	Weight Within Level (%)
Strategic Alignment/Guiding Principle		62.42
	Mission Alignment	63.63
	Readiness Support	28.24
	Operational Cost	8.13
Installation Figure of Merit (IFOM)		8.49
	Capacity	48.51
	Condition	34.36
	Configuration	17.13
Risk Assessment		29.09
	Severity	100

Both the MILCON and Special Project processes use this model, albeit with different weights assigned to each category. A description of the weighted factors and the categories within each factor is provided below.

1. **Strategic Alliance and Guiding Principles.** This is to ensure that the projects in consideration are prioritized in accordance with national security requirements. Historically, this factor has had the highest weight and is a combination of the following categories.

-
- a. Mission Alignment.** Based on capability requirements to meet the current or future strategic intent of the Chief of Naval Operations (CNO). It includes infrastructure to support forward assigned forces, stand up of new missions or capabilities, and maintain force readiness.
 - b. Readiness Support.** Ensures the current and future readiness of the fleet. It includes projects that increase training capabilities, address life, safety, and health deficiencies, and improve utility services' quality and reliability.
 - c. Operational Cost.** Focuses on delivering projects at the lowest lifecycle cost. It includes projects that result in significant cost savings, reduce energy consumption, eliminate temporary facilities and lower than lease costs, and reduce footprint, resulting in sustainment savings.
 - 2. Installation Figure of Merit.** Used at the installation level to determine if the infrastructure is adequate to meet customers' mission needs. The weighted score is a combination of the following categories.
 - a. Capacity.** Used to determine if a customer has adequate facility space of a particular use category to meet their mission requirement.
 - b. Condition.** Based on the condition of installation infrastructure and whether or not they are adequate to meet mission requirements.
 - c. Configuration.** Used to determine if a facility is configured appropriately to meet customer requirements.
 - 3. Risk Assessment.** Based on the severity of the impact of an infrastructure failure if a project is not executed to address the issue. Severity can include gaps in capability that affect mission readiness, antiterrorism or force protection risks, and threats to life, safety, and health.

Typically, the weight applied to each factor changes annually to account for any changes in strategic intent or current events that necessitate a change in national security outlook. The implication is that specific types of projects may compete well for funding one year, but they become less competitive the following year and vice versa. Additionally, since the project lists developed cover multiple years, a project that was not funded in a particular year may get funding the following year if the impact of not funding it becomes severe enough to warrant immediate attention based on the abovementioned factors.

7.3 Utility Project Funding

As discussed in previous chapters, utilities' infrastructure across the Navy are old, degraded, or past their useful life. However, a review of funded projects shows that utilities projects do not usually compete well for funding. This can be attributed to the importance placed on specific types of projects as dictated by the guiding principles provided in the project prioritization process.

Figures 7.3 and 7.4 summarize the Navy's facility investment requirement plans for MILCONs and Special Projects.

These figures are for future years, but they show that Utilities projects face a daunting task of being selected for funding. The projects not selected for funding will roll over to the next year to compete again with other projects. One thing to note is that each installation typically submits an average of five Utilities projects for funding. Still, the trend shows that Navy-wide, an average of four MILCONs and ten Special Projects are selected for funding.

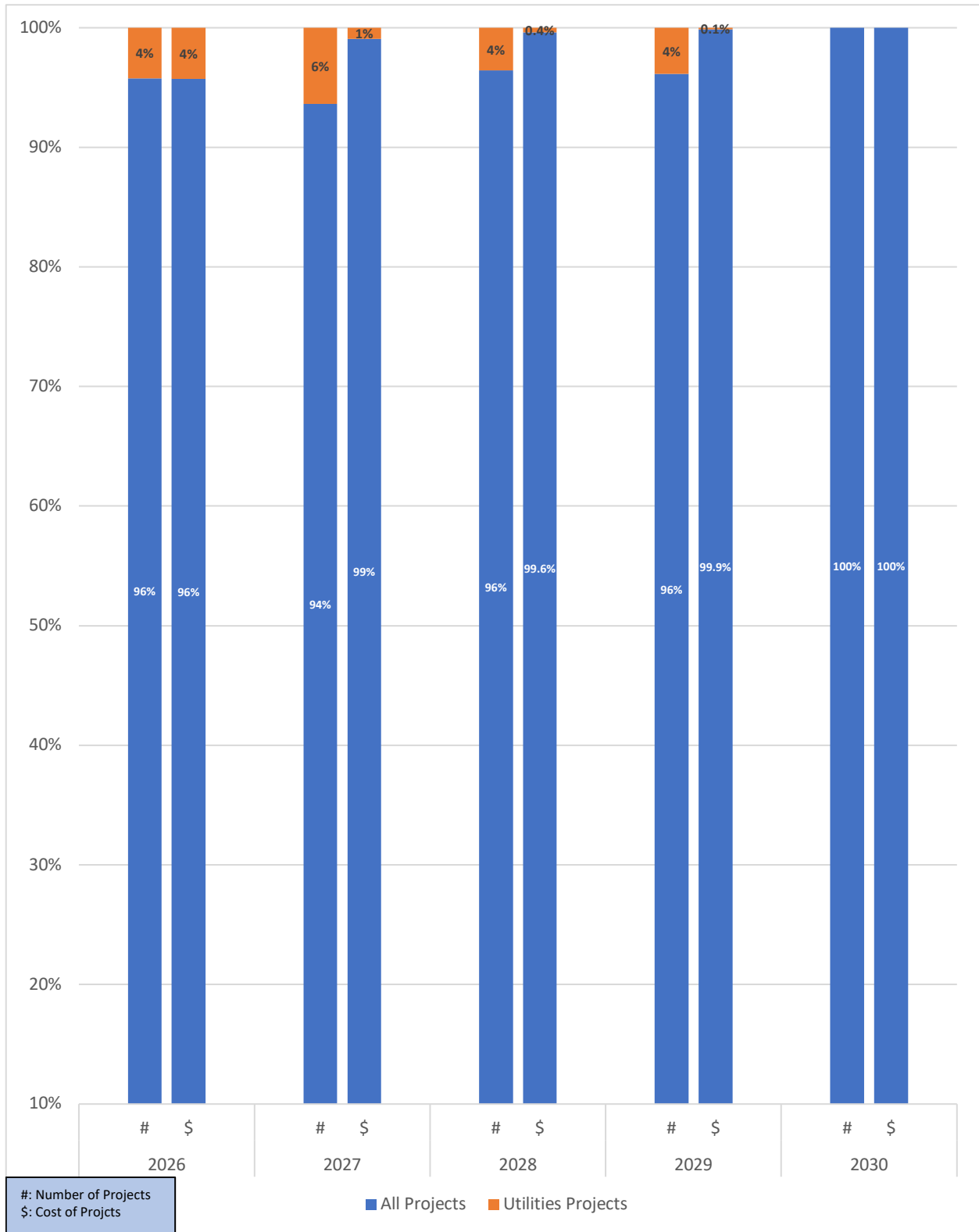


Figure 7.1: MILCON Facilities Investment Plan

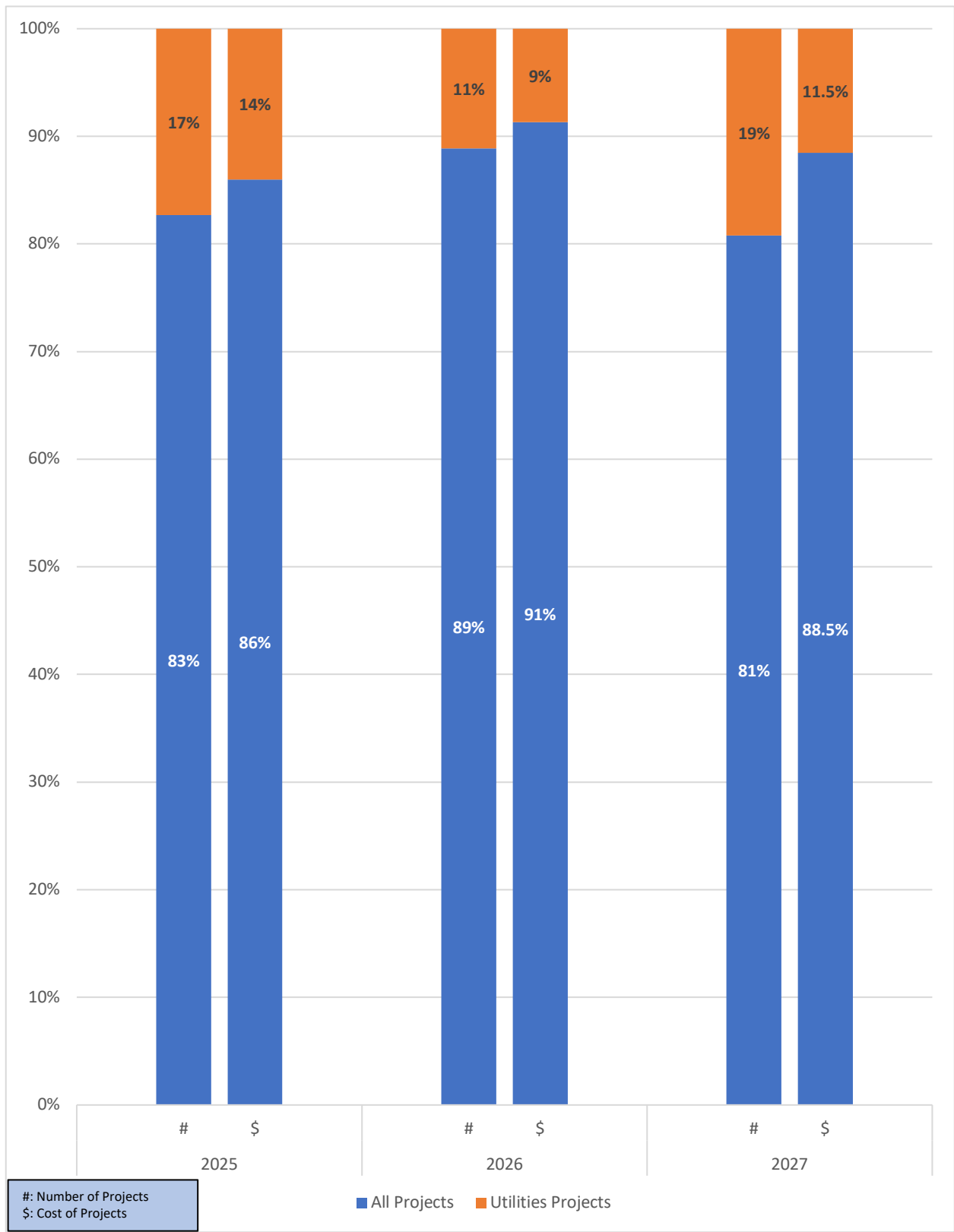


Figure 7.2: Special Projects Facilities Investment Plan

CHAPTER 8. SUMMARY, RECOMMENDATIONS, AND CONCLUSION

8.1 Summary

The discussions in the preceding chapters highlight the difficulties in adequately sustaining and recapitalizing the degrading critical utility infrastructure on U.S. Navy installations. The primary driver is the unpredictability of funding availability to properly invest in this critical infrastructure. Budgetary constraints and the relative priority of facilities within the DoD ecosystem mean that things are not likely to change soon. NAVFAC, as an organization, must embrace this reality and adopt its maintenance strategies to ensure the reliability and resilience of critical utility systems in support of mission owners.

8.2 Recommendations

The challenge for NAVFAC is how they operate in this environment and still deliver the services needed to support the DoD. Some recommended actions include:

1. Incorporate elements of CBM, RCM, and RBM strategies into the PM program for critical utility infrastructure. Using an RCM basis to determine where to apply CBM and RBM efforts will be the most effective use of scarce resources. A well-implemented maintenance plan will drive a reduction in maintenance costs and can help improve the reliability and resilience of these systems.
2. Address staffing issues, especially in areas with a shortage of personnel, to maintain critical utility systems properly. A vital element of this is having knowledgeable and trained personnel who can maintain these systems properly. Provide training opportunities as necessary so that the applicable personnel can continually improve their maintenance skills.
3. Advocate for an increase in sustainment funding. Reduction in sustainment funding over the years has accelerated the degradation of systems and reduced their useful life. Any additional funding can be used to address systems requiring immediate attention.
4. Advocate for increased weighted priorities for CBM and Recapitalization in the Facilities Investment Structural Model for Utilities infrastructure to increase the chances of utility projects being selected for funding.

-
5. Advocate for targeted funding for a comprehensive program to recapitalize critical utility infrastructure Navy-wide. The program should prioritize critical utility infrastructure that requires immediate upgrades, are in danger of failing, or are needed to support new and future mission requirements.

8.3 Conclusion

The optimum time to invest in recapitalization for critical utility infrastructure is when the systems are at the most significant risk of failure. Typically, this is when the infrastructure has a DI score greater than 3 or a risk rating greater than 4.4. However, the nature of the funding processes for recapitalization and their unpredictability require that the planning begins before the infrastructure is degraded to that point.

Based on these factors, the more effective means of sustaining the performance of critical utility systems over their useful life is to have a well-implemented PM program. The program can be structured dynamically to make it easily adaptable to changes in infrastructure priorities in situations where resources are inadequate to support all infrastructure maintenance requirements.

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APPENDIX A: UICAP PROCESSES AND TOOLS

Appendix A contains detailed information on UICAP process and tools. These tools are used to assess the condition of utility infrastructure to assist facility managers determine the actions that need to be taken to keep them performing as intended, and if not, provide avenues to provide input for maintenance, repair, or recapitalization requirements.

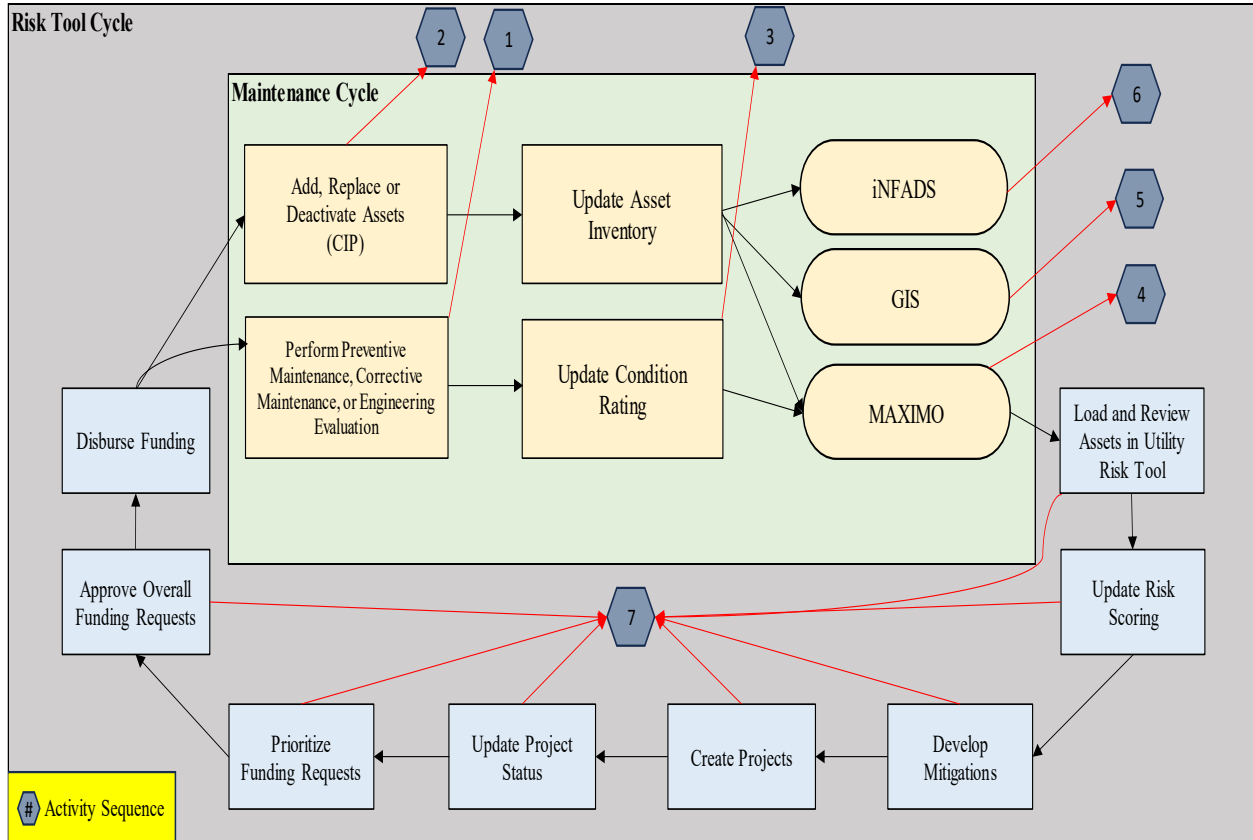


Figure A1. Utilities Risk Tool (URT Cycle)

Source: NAVFAC P-603, *Navy Facilities Project*. NAVFAC, 2022)

The URT cycle is used to help complete the assessment described in phase 2 of the UICAP process and is used to continuously assess and maintain the condition of utility assets. The figure shows the flow of activities, the various elements, and the relationship between all the elements involved in the process.

Table A1. Likelihood of Failure (LoF) Matrix
(Source: NAVFAC P-603, *Navy Facilities Project*. NAVFAC, 2022)

Likelihood of Failure: How probable is it that this utility asset will fail to perform its function?				
Score	Degradation Index	Performance Capabilities	O&M / PM Procedures	Reliability
	The condition of assets in this Failure Scenario. Imported from the most recent Direct Condition Ratings in Maximo.	The ability of assets in this Failure Scenario to meet demand and quality requirements, plus operate in compliance with applicable code and design specifications.	The quality of utility operation and preventive maintenance being performed on assets in this Failure Scenario.	The frequency of corrective maintenance performed on assets in this Failure Scenario.
1	No noticeable defects. Some aging or wear may be visible. Fully functional.	Equipment operates <u>within</u> design limits while meeting demand and quality requirements.	Employees are operating the equipment properly and 100% of the NAVFAC Standard Preventive Maintenance Program was completed during the last 12 months.	Run to Failure Asset or No Repair History
2	Only minor deterioration or defects are evident. Noticeable wear or aging is visible. Fully functional. Minor maintenance may be required.	Equipment <u>continuously</u> operates <u>near or at</u> design limits in order to meet demand and quality requirements.	Employees are operating the equipment properly and The most recent Critical Preventive Maintenance was completed on these assets.	Infrequent corrective maintenance. Typical or less frequent than expected for similar equipment.
3	Deterioration or defects are evident. Function is not significantly affected. Minor repairs are required.	Equipment <u>periodically</u> operates <u>outside</u> design limits in order to meet demand and quality requirements.	Employees are operating the equipment properly and Some of the most recent Critical Preventive Maintenance was not completed on these assets.	Some and/or accelerating corrective maintenance. More frequent than expected for similar equipment.
4	Serious deterioration or defects in at least some portion of the asset. Function is significantly affected. Extensive repairs or replacement are required.	Equipment <u>continuously</u> operates <u>outside</u> design limits in order to meet demand and quality requirements. Equipment has installation or design deficiencies that are <u>very likely</u> to create extended disruptions of service, loss of life, or regulatory non-compliance.	Employees are not operating the equipment properly or None of the most recent Critical Preventive Maintenance was completed on these assets.	Frequent rate of corrective maintenance. Significantly more frequent than expected for this classification of equipment.
5	Extensive deterioration or defects in the asset. Not functional, barely functional, or beyond repair.	Equipment <u>cannot meet</u> demand or quality requirements. Equipment has installation or design deficiencies that <u>have created</u> extended disruptions of service, loss of life, or enforceable regulatory non-compliance.	Employees are not equipped to operate the equipment or None of the NAVFAC Standard Preventive Maintenance Program is being performed.	Out of service.

This matrix provides a description of each of the four weighted categories that are combined to determine the LoF score for an asset. It also shows the detailed criteria for assigning a LoF score for an asset.

Table A2. Consequence of Failure (CoF) Matrix
(Source: NAVFAC P-603, *Navy Facilities Project*. NAVFAC, 2022)

Consequence of Failure: When an asset is called upon to perform its' function and does not, what is the most probable-serious outcome?						
Score	Mission Disrupted	Disruption Severity	Number of Facilities	Health & Safety / Regulatory Compliance	Financial Impact	Asset Restoration Time
	Most critical mission within all facilities that will be disrupted as a direct result of this Failure Scenario. May not be the most critical command served. Outage must disrupt customer mission, not simply affect customer facilities.	The time required to restore temporary service to the mission disrupted in the failure scenario. Outages include degradation in quality of service. Excludes time to make permanent repair.	The number of facilities with an MDI > 84 that will experience an outage or degradation in quality of service.	The effect of this Failure Scenario on the safety of likely bystanders, customers receiving service, and regulatory compliance. Excludes injuries resulting from loss of service to customer.	The cost to restore temporary and permanent service. Includes site restoration. Excludes consequential damage to non-UEM property.	The time to restore permanent service. Includes contracting, procurement, and repairs. Excludes: site restoration.
1	No mission disrupted or Community Support functions (e.g. MWR, NEX, Schools)	Electrical Outage: < 5 min Civil-Mechanical Outage: < 1 hr	0	<u>Safety:</u> No injuries and no potential hazard. <u>Health:</u> No effects on health. <u>Regulatory:</u> In compliance.	< \$25k	< 8 hr
2	Base Support functions (e.g. Personnel Support, Clinics, Housing) and General Warehousing , plus Data Centers supporting these missions.	Electrical Outage: 5 min to 1 hr Civil-Mechanical Outage: 1 hr to 4 hrs.	1 to 5	<u>Safety:</u> Creates potential hazard requiring preventive measures beyond SOPs, but no injuries likely. <u>Health:</u> No effects on health. <u>Regulatory:</u> In compliance.	\$25k-\$100k	8 hr to 24 hr
3	Operating Forces Training, RDT&E, Weapons and Fuels Storage, Public Works, Safety Dept, Command & Staff , plus Data Centers supporting these missions.	Electrical Outage: 1 to 4 hrs. Civil-Mechanical Outage: 4 hrs. to 8 hrs.	6 to 15	<u>Safety:</u> Creates hazard that is difficult to mitigate, injuries possible. <u>Health:</u> Possible health effects. <u>Regulatory:</u> Not in compliance.	\$100k-\$1M	1 day to 7 days
4	Operating Forces Support functions (e.g. Hospitals, Weapons Loading and Manufacturing, Fueling, Intermediate Maintenance Facilities, Operational Maintenance, Pre-Deployment Qualification Training), plus Data Centers supporting these missions.	Electrical Outage: 4 hrs. to 8 hrs. Civil-Mechanical Outage: 8 hrs. to 24 hrs.	16 to 50	<u>Safety:</u> Injuries requiring minor medical attention but no lost time injuries. <u>Health:</u> Long term exposure creates health hazard. <u>Regulatory:</u> Violation, no enforcement action likely.	\$1M-\$5M	7 to 30 days
5	Operating Forces functions (e.g. Air Ops, Port Ops, Operational Communication & Control) and Nuclear Activities , plus Data Centers supporting these missions.	Electrical Outage: more than 8 hrs. Civil-Mechanical Outage: more than 24 hrs.	> 50	<u>Safety:</u> Lost time injuries or Loss of life. <u>Health:</u> Short term exposure creates health hazard. <u>Regulatory:</u> Violation with written Notice of Violation requiring enforcement action or correction likely.	Cost >\$5M	>30 days

This matrix provides a description of each of the six weighted categories that are combined to determine the CoF score for an asset. It also shows the detailed criteria for assigning a CoF score for an asset.

APPENDIX B: PROJECT PRIORITIZATION PROCESS

Appendix B contains additional details on the project prioritization process, including the coordination required across multiple echelons, the project evaluation process, and the project time sequence for MILCON and Special Projects. This integrated effort results in a prioritized project list that lays out the investment plan across the FYDP for both programs.

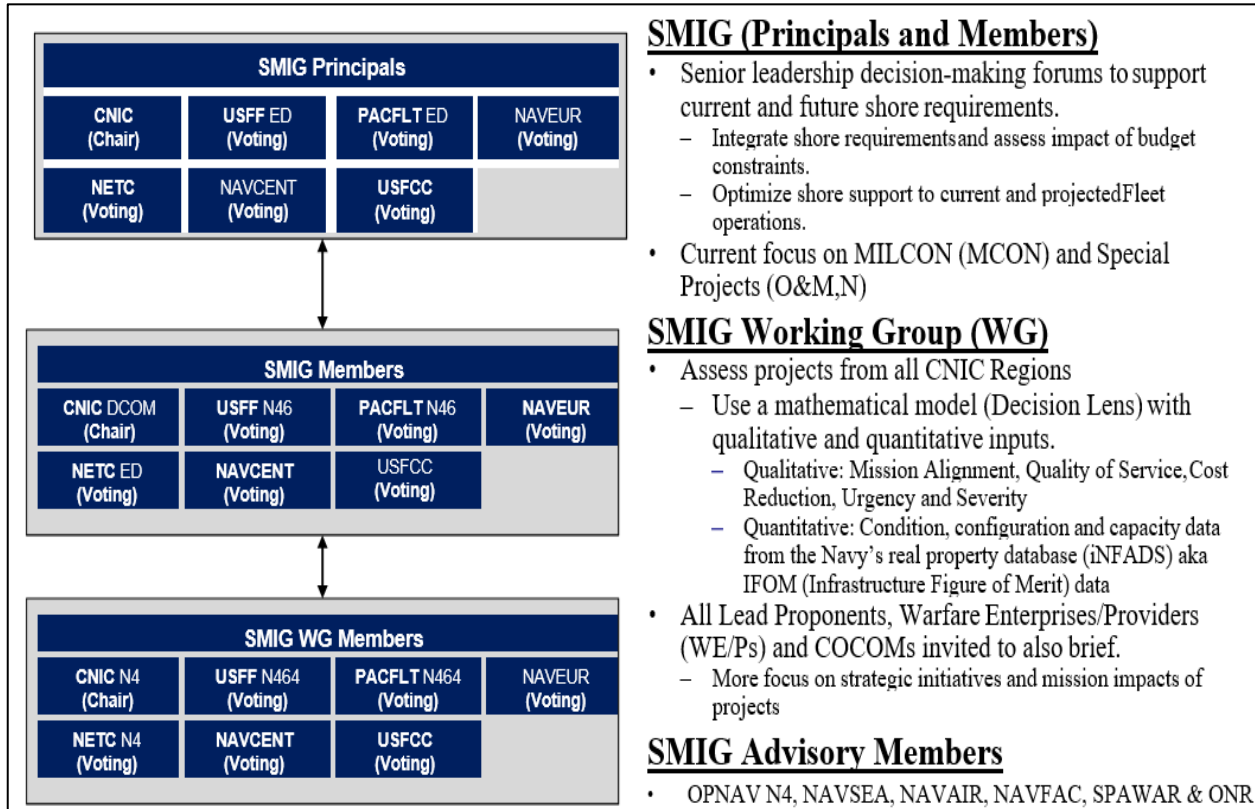


Figure B1. SMIG Membership and Working Group Process

(Source: *Addendum 5 to the CNIC N4 Project Development and Assessment Guide* (CNIC, 2022))

This figure shows the composition of the Shore Mission Integrated Group (SMIG). The SMIG receives the Integrated Project List (IPL) from all regions, combines the inputs, deliberate on the projects, and develops an enterprise-wide final IPL for funding based on the guidance received from Navy leadership.

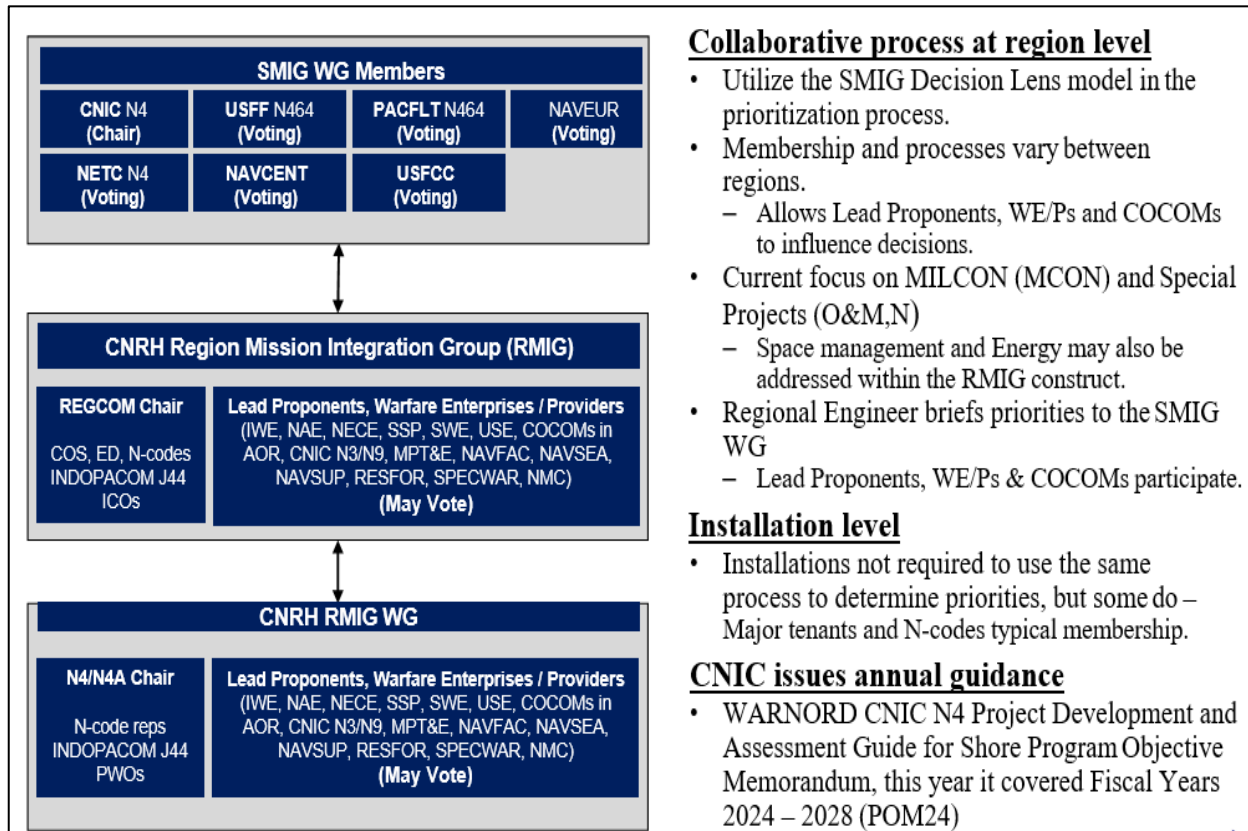


Figure B2. RMIG Membership and Relationship to SMIG

(Source: *Addendum 5 to the CNIC N4 Project Development and Assessment Guide (CNIC, 2022)*)

This figure shows the relationship between the Region Mission Integration Group (RMIG) and the SMIG. The prioritization process starts at the installation, where the Installation Mission Integration Group (IMIG) evaluates and prioritizes installation projects. The RMIG combines information from all the installations within their respective region and develops a prioritized Integrated Project List (IPL), which represent the region’s input to the SMIG.

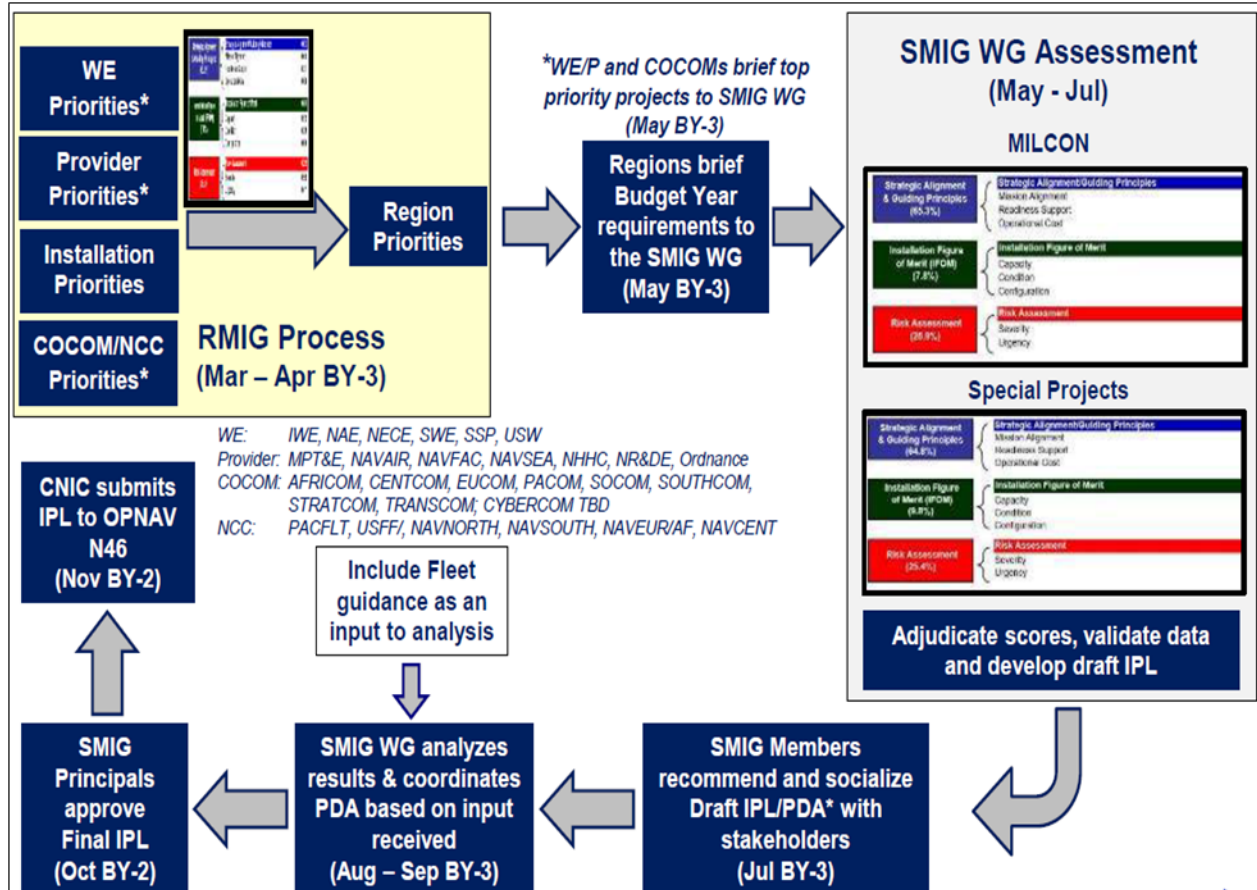


Figure B3. SMIG Evaluation and Prioritization Process
 (Source: CNIC N4 Project Development and Assessment Guide (CNIC, 2022))

This figure shows the timeline and flow of the SMIG evaluation and prioritization process. The process for each program covers multiple years, and planning to fund projects has to begin years in advance in order to have a project list ready by the time funding is allocated for the projects.

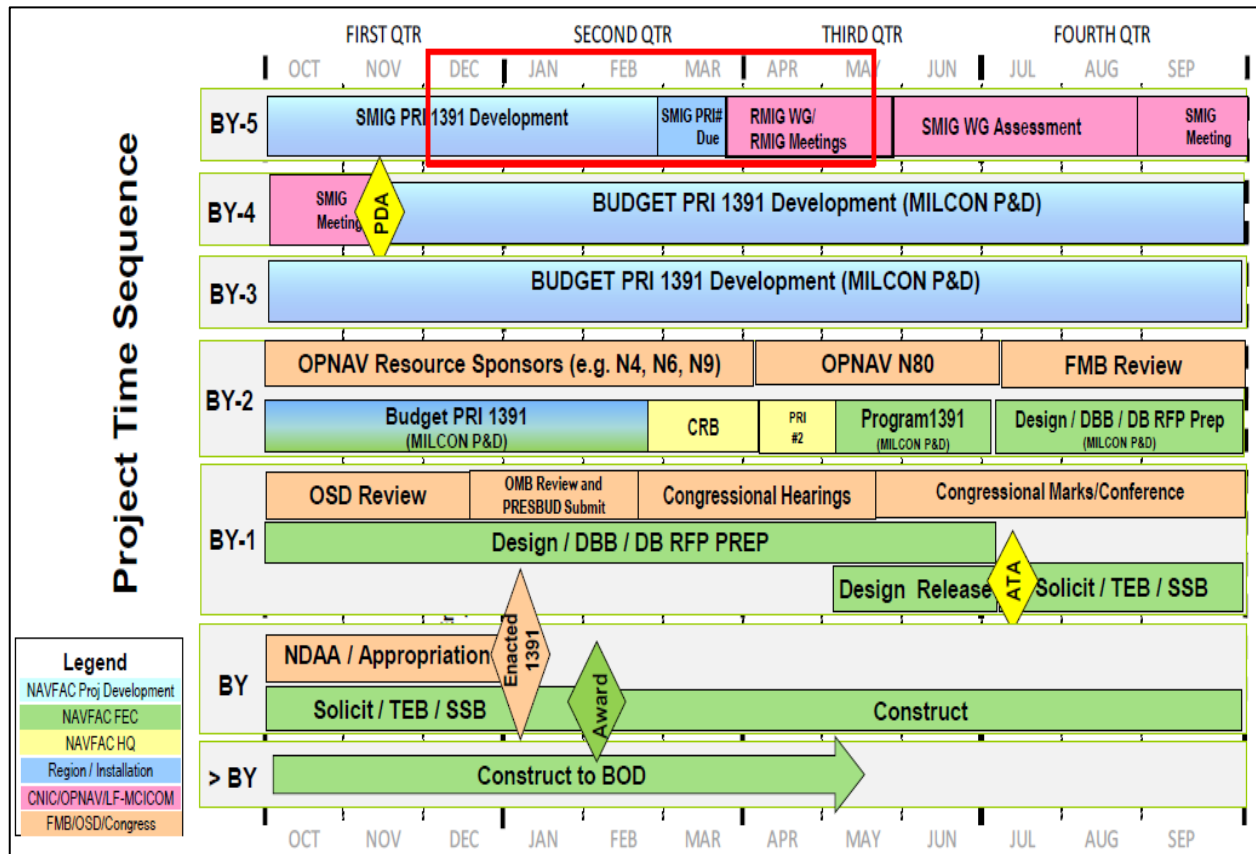


Figure B4. MILCON Project Assessment and Development Process
 (Source: *CNRH RMIG Working Group Brief*. CNRH N4, 2023)

This figure shows the entire project time sequence, actions required, and the responsible party for each action for the MILCON project assessment and development process. Each project submitted for consideration initially goes through the process and the planning can continue if it is on the list of projects selected for funding – an output from the SMIG meeting.

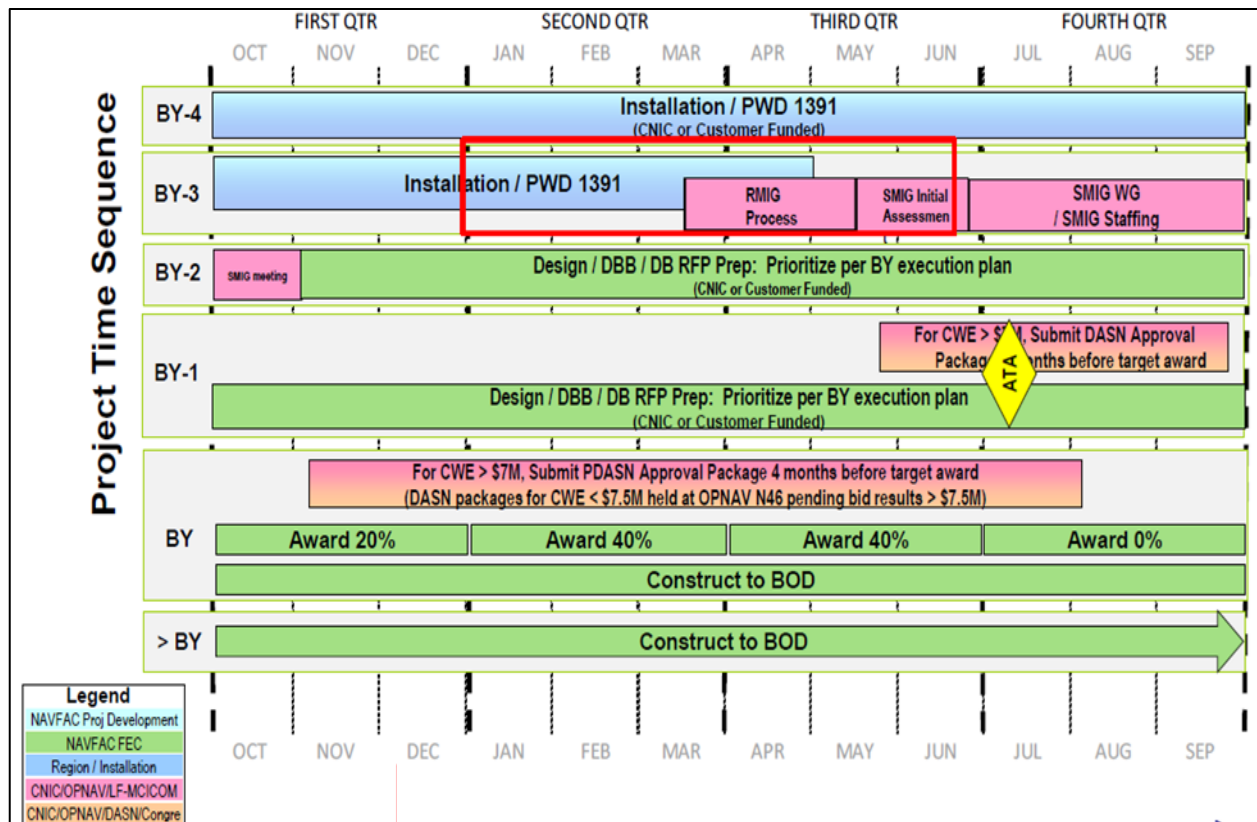


Figure B5. Special Projects Project Assessment and Development Process
 (Source: *CNRH RMIG Working Group Brief*. CNRH N4, 2023)

This figure shows the entire project time sequence, actions required, and the responsible party for each action for the Special Projects assessment and development process. Each project submitted for consideration initially goes through the process and the planning can continue if it is on the list of projects selected for funding – an output from the SMIG meeting.