2019-06

OPTIMIZING MARINE CORPS INSTALLATION READINESS

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Monterey, CA; Naval Postgraduate School

https://hdl.handle.net/10945/62858

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

OPTIMIZING MARINE CORPS INSTALLATION READINESS

by

Alyssa Renosto

June 2019

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2019	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE OPTIMIZING MARINE CORPS INSTALLATION READINESS	**5. FUNDING NUMBERS**
6. AUTHOR(S) Alyssa Renosto	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) MCICOM, Washington, D.C., MD 20301	**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Marine Corps Installations Command (MCICOM) (enacted in 2012) exercises command and control over United States Marine Corps (USMC) installations through regional commanders. The department manages over 27,000 buildings and structures across 25 installations. In November 2016, the commandant of the Marine Corps (CMC), signed the Infrastructure Reset (IR) strategy to fundamentally alter the USMC's infrastructure lifecycle management. The intent of this strategy is to optimize the USMC's assets in order to maximize support to operational readiness at minimal lifecycle costs. In this thesis, we develop a quantitative analysis and decision support tool in the form of a Mixed Integer Linear Program (MILP) to enable data-driven and informed decisions that best support the operating forces in line with the CMC's IR strategy. The IR multivariate decision tool uses a quantitative framework to summarize, describe, and optimize the USMC's infrastructure portfolio. The tool provides quantitative justification for funding, informs the Program Objective Memorandum (POM), and establishes readiness goals for MCICOM and the subordinate regions and installations. Results show that under the current budgetary constraints, MCICOM has little ability to improve installation readiness by manipulating its four levers of investment. We find MCICOM requires a budget of roughly one and half times its current annual limit to achieve installation readiness levels set forth by the IR strategy.

14. SUBJECT TERMS optimization, MCICOM, MILP, installation, capital planning, budget	**15. NUMBER OF PAGES** 77
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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OPTIMIZING MARINE CORPS INSTALLATION READINESS

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2019

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ABSTRACT

Marine Corps Installations Command (MCICOM) (enacted in 2012) exercises command and control over United States Marine Corps (USMC) installations through regional commanders. The department manages over 27,000 buildings and structures across 25 installations. In November 2016, the commandant of the Marine Corps (CMC), signed the Infrastructure Reset (IR) strategy to fundamentally alter the USMC's infrastructure lifecycle management. The intent of this strategy is to optimize the USMC's assets in order to maximize support to operational readiness at minimal lifecycle costs. In this thesis, we develop a quantitative analysis and decision support tool in the form of a Mixed Integer Linear Program (MILP) to enable data-driven and informed decisions that best support the operating forces in line with the CMC's IR strategy. The IR multivariate decision tool uses a quantitative framework to summarize, describe, and optimize the USMC's infrastructure portfolio. The tool provides quantitative justification for funding, informs the Program Objective Memorandum (POM), and establishes readiness goals for MCICOM and the subordinate regions and installations. Results show that under the current budgetary constraints, MCICOM has little ability to improve installation readiness by manipulating its four levers of investment. We find MCICOM requires a budget of roughly one and half times its current annual limit to achieve installation readiness levels set forth by the IR strategy.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACF	Average Cost Factor
BOS	Base Operating Support
BRAC	Base Realignment and Closure
BRACAS	Base Realignment and Closure Action Schedule
CATC	Combined Arms Training Center
CIPA	Capital Investment Planning Aid
CIWG	Capital Investment Working Group
CMC	Commandant of the Marine Corps
COBRA	Cost of Base Realignment Actions
CONUS	Continental United States
DC	Deputy Commandant
DoD	Department of Defense
EPA	Extended Planning Annex
FCI	Facility Condition Index
FS	Facility Sustainment
FSM	Facility Sustainment Model
FSRM	Facility Sustainment, Recapitalization, and Modernization
GAO	Government Accountability Office
HQMC	Headquarters Marine Corps
I&L	Installations and Logistics
IR	Infrastructure Reset
IROM	Installation Readiness Optimization Model
ISR-I	Installations Status Report for Infrastructure
LOE	Lines of Effort
MCAGCC	Marine Corps Air Ground Combat Center
MCAS	Marine Corps Air Station
MCB	Marine Corps Base
MCICOM	Marine Corps Installations Command
MCIEAST	Marine Corps Installations East
MCINCR	Marine Corps Installations National Capital Region

MCIPAC	Marine Corps Installations Pacific
MCIWEST	Marine Corps Installations West
MCLB	Marine Corps Logistics Base
MCMWTC	Marine Corps Mountain Warfare Training Center
MCRD	Marine Corps Recruit Depot
MCSF	Marine Corps Support Facility
MDI	Mission Dependency Index
MILCON	Military Construction
MILP	Mixed-Integer Linear Program
MSF	Million Square Feet
NAVFAC	Naval Facilities Engineering Command
O&M	Operations and Maintenance
OSAF	Optimal Stationing Army Forces
OSD	Office of the Secretary of Defense
POM	Program Objective Memorandum
PRV	Plant Replacement Value
SCOUT	Space Command Optimizer of Utility Toolkit
TOA	Total Obligated Authority
UFC	Unified Facilities Criteria
USAF	United States Air Force
USMC	United States Marine Corps

EXECUTIVE SUMMARY

Marine Corps Installations Command (MCICOM) (enacted in 2012) is responsible for the management, guidance, and organization of services on United State Marine Corps (USMC) installations. Its mission is to enhance operating forces' readiness and support base residents and activities. MCICOM manages over 27,000 buildings and structures across 25 installations. In November 2016, the Commandant of the Marine Corps (CMC) signed the Infrastructure Reset (IR) strategy to fundamentally alter the Marine Corps' infrastructure life-cycle management. The intent of the CMC's strategy is to optimize the USMC's assets in order to maximize support to operational readiness at minimal life-cycle costs. In this thesis, we develop a quantitative analysis and decision support tool in the form of a Mixed Integer Linear Program (MILP) to enable data-driven and informed decisions that best support the operating forces in line with the Commandant's IR strategy. The Installation Readiness Optimization Model (IROM) uses a quantitative framework to summarize, describe, and optimize the Marine Corps' infrastructure portfolio and provides quantitative justification to inform the Program Objective Memorandum and establish readiness goals for MCICOM, subordinate regions, and installations. The MILP objective is to maximize readiness subject to budget constraints, where readiness is defined by the Facility Condition Index (FCI) and Mission Dependency Index (MDI).

The FCI is a numerical rating from 0 to 100 that describes a building's state. MCICOM divides facilities into four FCI category ratings based on sustainment and condition levels: Q1 = Good, Q2 = Fair, Q3 = Poor, and Q4 = Failing. The IR strategy outlined a net total demolition requirement of 31 million square feet (MSF) across all installations by 2028, with a target of 11MSF by 2023. The 2016 Q3 and Q4 populations formed the initial demolition selections. The level of sustainment funding over the life cycle of a facility is directly related to the rate in which it degrades. MDI is also a numerical rating from 0 to 100 that distinguishes a facility's mission significance. This value enables facility prioritization for funding based on the scope of missions it supports. IROM prescribes sustainment, demolition, and recapitalization funding to maximize the sum of each building's FCI times its MDI.

Our results show that under the current budgetary constraints, MCICOM has little ability to improve installation readiness by manipulating its four levers of investment. Facility conditions across all three mission dependency tiers can only be improved by a maximum of 5.3%, given the current fixed budget. Under these conditions, the IROM optimal solution falls short of its demolition goals by 4.4MSF. MCICOM requires a significantly greater budget (an increase of $230 million annually) to improve installation readiness to the target levels of 80 for Tier I, 70 for Tier II, and 60 for Tier III, and meet all demolition goals. These numbers ensure that all facilities are above a failing quality rating, but still fall below the CMC's target of all facilities in Q1 and Q2 ratings. The increased budget allows for the elimination of Q4 facilities across all MDI tiers and elimination of Q3 Tier I facilities. Demolishing Q3 and Q4 facilities is more economical in many cases than trying to restore these facilities to the target levels. Given the current state of USMC facilities, the two most impactful levers of investment are demolition and recapitalization funding. Several facilities are currently degraded to the point where sustainment is not favorable. MCICOM faces a hefty task of improving USMC installations readiness. IROM is able to prioritize investments and provide justification for future budget requests.

ACKNOWLEDGMENTS

I would like to thank my advisors, Dr. Robert Dell and Mr. Jack Templeton, for their guidance and support throughout this thesis process. I have learned a tremendous amount over the past year, and I cannot thank you enough for the time and energy you spent helping me with the creation of this model and the writing of this thesis.

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I. INTRODUCTION

Marine Corps Installations Command (MCICOM) (enacted in 2012) is responsible for the management, guidance, and organization of services on United State Marine Corps (USMC) installations. Its mission is to enhance operating forces readiness and support base residents and activities (United States Marine Corps [USMC] 2018a). In November 2016, the commandant of the Marine Corps (CMC), General Robert B. Neller, signed the Infrastructure Reset (IR) strategy to recapitalize and reduce the USMC's infrastructure footprint to support its mission without excess. A key goal of the CMC's IR strategy is to maintain all retained critical facility capabilities at the lowest possible total life-cycle cost. The intent of this strategy is to "sustain infrastructure and installations as capable, resilient, right-sized platforms that generate force readiness and project combat power across the range of military operations" (Neller 2016). To meet this strategy, MCICOM seeks the ability to maximize facility condition by allocating funding across four levers of investment. This thesis develops a quantitative analysis and decision support tool in the form of a Mixed Integer Linear Program (MILP) to enable data-driven and informed decisions that best support the operating forces in line with the CMC's IR strategy. The IR multivariate decision tool uses a quantitative framework to summarize, describe, and optimize the USMC's infrastructure portfolio and provides quantitative justification to inform the Program Objective Memorandum (POM) process and establish readiness goals for MCICOM, subordinate regions, and installations.

A. MCICOM COMMAND STRUCTURE

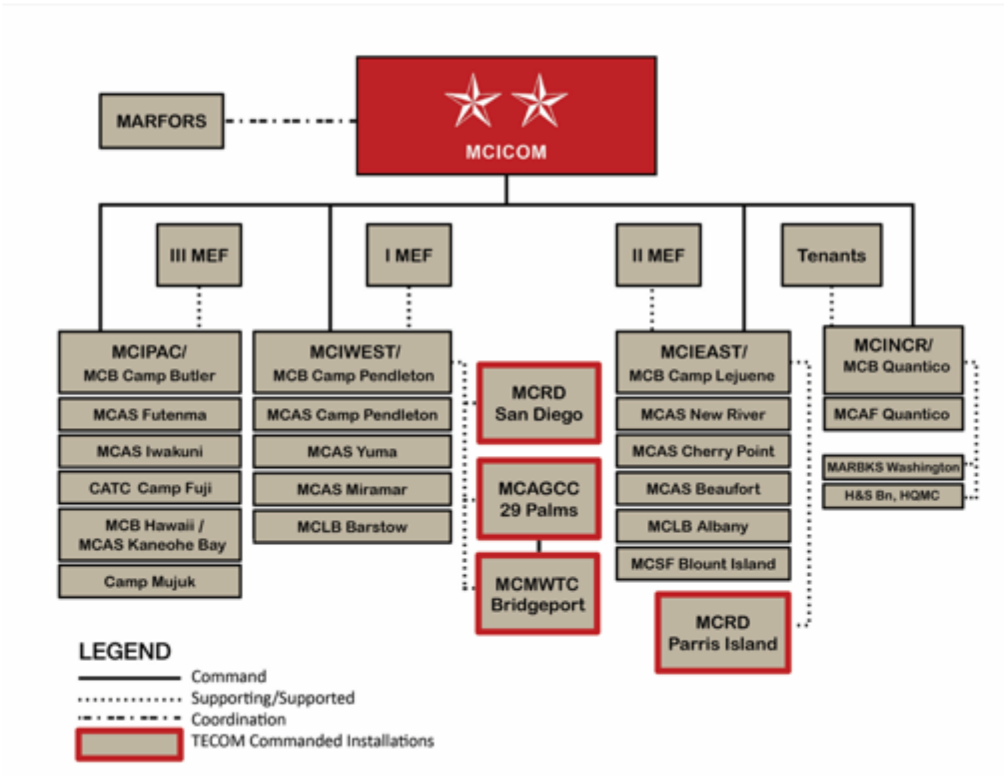
USMC installations encompass a wide array of ocean, coastal, riverine, land, and airspace used for military training. These areas are essential to defending our national security interests and directly support the combat readiness of our operating forces throughout all phases of deployment. Recent federal mandates require installations to manage changing requirements, such as the reduction of energy and water consumption, adherence to environmental protection requirements, and the improvement of sustainability and integration with surrounding developments aboard military installations (USMC

2018b). Because of these requirements, the CMC designated MCICOM as the single authority to exercises command and control over USMC installations through regional commanders, managing over 27,000 buildings and structures across 25 installations (MCICOM Staff 2018).

MCICOM is a subordinate command under the Deputy Commandant, Installations and Logistics (I&L), which "drives logistics plans, policies, and initiatives to increase the capability, endurance and reach of the Marine Air Ground Task Force. I&L provides ready and resilient bases that are exceptional training and force projection platforms, while also ensuring exemplary quality of life for Marines, Sailors and their families" (USMC 2018b). MCICOM is headquarters to four subordinate commands: Marine Corps Installations East (MCIEAST), Marine Corps Installations West (MCIWEST), Marine Corps Installations Pacific (MCIPAC), and Marine Corps Installations National Capital Region (MCINCR) (Figure 1). These four subordinate commands direct readiness, training, sustainment, mobilization, deployment, embarkation, redeployment, and reconstitution of USMC forces. They are an essential component of the U.S. defense strategy, theater security cooperation, and diplomatic security missions (USMC 2013). The only exceptions to this are installations under the command and control of the Commanding General of Marine Corps Training and Education Command: Marine Corps Recruit Depot (MCRD) San Diego, MCRD Parris Island, Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, and Marine Corps Mountain Warfare Training Center (MCMWTC) Bridgeport. In these cases, the installations receive MCICOM support, but do not collect all their resources from the same installation management chain of command. MCICOM does not have direct oversight on policy creation and coordination at these installations (USMC, 2018a).

Subordinate commands of MCIEAST are Marine Corps Air Station (MCAS) Beaufort, MCAS Cherry Point, MCAS New River, Marine Corps Base (MCB) Camp Lejeune, Marine Corps Logistics Base (MCLB) Albany, and Marine Corps Support Facility (MCSF) Blount Island. MCIWEST is in command of MCB Camp Pendleton, MCAS Camp Pendleton, MCAS Miramar, MCAS Yuma, and MCLB Barstow. Installations that fall under MCIPAC include, MCB Hawaii, MCB Camp Butler, MCAS

Futenma, MCAS Iwakuni, Combined Arms Training Center (CATC) Camp Fuji, and Camp Mujuk. Finally, MCINCR exercises command over MCB Quantico.



Training commands and recruit depots do not fall under MCICOM Operational Control, but do receive installation support from MCICOM.

Figure 1. MCICOM Command Structure. Source: USMC (2018a).

B. IR STRATEGY LINES OF EFFORT

MCICOM and the regional commands are responsible for the four lines of effort (LOE) outlined in the IR strategy, including "a) Optimizing Infrastructure Footprint, b) Ensuring Investment Decisions Enable Lowest Total Life cycle Costs, c) Implementation of Best Practices and Process Efficiencies, and d) Alignment of Installation Management and Establishment of Enterprise Governance" (Neller 2016).

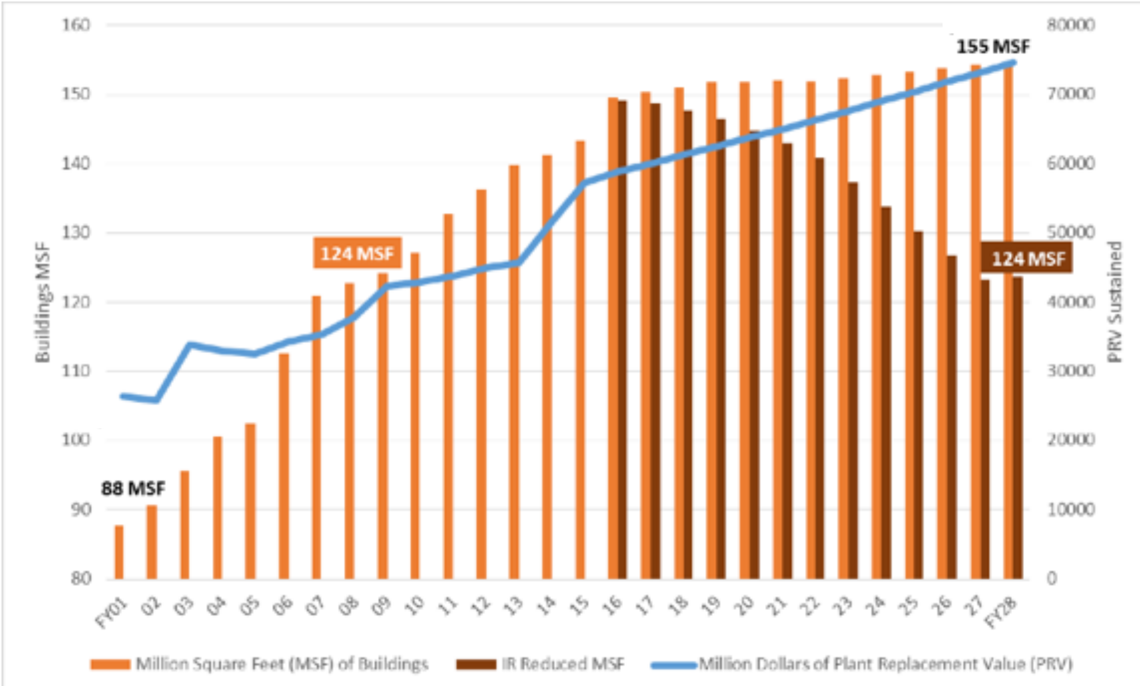
The first LOE, "Optimizing Infrastructure Footprint," has a focus on reducing and optimizing the current infrastructure footprint through consolidation, the maximal use of available spaces, and purging of excess and failing facilities that require long-term financial resources that could be used for higher priority needs across the USMC. These decisions are subject to Basic Facility Requirements, which are the minimum constrained infrastructure footprint requirements for validated missions (Neller 2016). Additionally, the CMC emphasizes that regional and installation commanders must develop long-range global infrastructure plans that identify operational force and supporting establishment infrastructure divestiture, including the potential for relocation of units to best use existing facilities. FY2027 is the target year for complete divestment of underused facilities and consolidation to enhance force protection and total force support requirements (Neller 2016).

The second LOE, "Ensuring Investment Decisions Enable Lowest Total Life cycle Costs," develops a balanced facility investment plan supporting facility and unit requirements at the lowest life-cycle cost. This five-year portfolio plan requires each installation to assess facilities regularly for condition, configuration, capacity, resilience, and mission reliance. Based on the CMC's IR guidance (Neller 2016), portfolios should prioritize demolition of excess and failing facilities and recapitalization of poor facilities. This reduction offsets new MILCON projects approved after regional commanders establish total life-cycle costs and determine projects that are cost/energy saving investments (Neller 2016).

LOE three, "Implementation of Best Practices and Process Efficiencies," pursues efficiency through streamlining processes, standardizing levels of services, and implementing best practices in support of Marine Corps installation priorities. These efforts allow commanders to monitor performance metrics and adjust best practices to reduce installation portfolio management costs across the Marine Corps (Neller 2016).

Unifying efforts across regions through common installation management practices and governance is the fourth and final LOE, "Alignment of Installation Management and Establishment of Enterprise Governance." The CMC tasks executive leadership with institutionalizing the IR strategy with operational force input (Neller 2016). He emphasizes that the management and oversight of this program through all phases of the Planning, Programming, Budgeting, and Execution process is the responsibility of dedicated leadership at MCICOM and the installations (Neller 2016).

In a fiscally constrained environment, MCICOM seeks to provide relevant installation support to maintain the readiness and security of USMC deployable forces. The changing security environment and increased operational requirements over the past two decades caused significant changes to installation support. This is in large part due to the total force size surge and subsequent reduction from 182,000 to 280,000 and back down to 184,000 throughout the years of multi-front operations (Figure 2). A key element of these changes is the restructuring of the USMC infrastructure footprint as a result of the pivot to the Pacific. The IR strategy lays out guidelines to modernize the USMC's obsolete and costly infrastructure and close the gap between available resources and facilities maintenance costs. Additionally, the IR strategy seeks to balance the four levers of facility investment in order to maximize readiness while minimizing installation life-cycle costs. These four levers are New Military Construction (MILCON), Current Facility Sustainment (FS), Recapitalization and Modernization (FSRM), and Demolition. "The end-state of this effort is to close the gap between requirements and resources to ensure that Marine Corps installations are enduring, efficient, and elude a long-term readiness impact. Closing the funding gap by reducing the excess and failing infrastructure footprint on bases and stations will ensure installations can support warfighting readiness, quality of life for Marines, and recapitalize the necessary facilities to meet mission requirements" (USMC 2013).



The IR strategy assumes the Marine Corps should be able to support 184K troops with the infrastructure that supported 202K during the troop surge in 2009 (Brinkman 2018). Without the IR strategy reduction in facility square footage, the real property value of the Marine Corps will continue to increase towards $80 billion. The reduction plan will bring the estimated 155 Million Square Feet (MSF) down to 124 MSF by FY28. The square foot growth from FY01-FY20 without IR is estimated at 76%, with IR the expectation is nearly half at 41%.

Figure 2. Plant Replacement Value (PRV) Increase in Relation to Force Size. Adapted from Brinkman (2018).

Federal regulations make environmental considerations one of the largest financial factors contributing to the POM and capital budgeting planning. All four levers of investment must comply with state and federal environmental laws as Marine Corps installations account for 2.5 million acres of diverse land—home to 65 federally listed threatened and endangered plant and animal species. Protecting the local wildlife and preserving the historical and cultural sites of the Nation's military falls under the National Environmental Policy Act and Executive Order 12114 for overseas installations (USMC 2018a). Land is a finite resource and compliance with federal environmental laws ensures the Marine Corps can preserve the air, land, and water necessary to maintain force readiness. Balancing modernization and resilience with environmental restrictions is a key effort for MCICOM. As the USMC transitions from sustained land/desert operations, "the next generation Marine Air Ground Task Force requires next generation installations" (USMC 2018a). These "next generation installations" center on leveraging the intellect and insights of private industry, academia, and other government agencies. While the environment is highly regulated, for the purposes of this thesis we only consider structural costs and do not incorporate costs associated with ecological impact.

C. FACILITY SUSTAINMENT MODEL

To support a force of 184,000 Marines stationed aboard 25 installations, the USMC uses the Office of the Secretary of Defense's (OSD) Facility Sustainment Model (FSM) to establish funding benchmarks. The tool, implemented in 2003, estimates the annual sustainment cost for the entirety of facilities managed by the Department of Defense (DoD) (roughly 577,000 structures worldwide, with a value of $712 billion [GAO 2008]). This program calculates the annual sustainment requirement through the current budget and also includes the Fiscal Year Development Plan, ensuring facilities "remain in good working order throughout their service lives" (Office of the Assistant Secretary of Defense for Sustainment [OASDS] 2018). Based on the Unified Facilities Criteria replacement unit costs, (DoD 2018b), the FSM generates a 100% sustainment requirement using industry standards to sustain facilities at their current condition. Funding at less than the 100% requirement results in facility degradation. Due to internal budget constraints, the USMC funds to the OSD minimum facilities sustainment requirement for the Marine Corps, which is 70–75% of the 100% requirement. Although FS is a MCICOM centrally managed program, 55% of the 100% sustainment requirement generated from the FSM is decentralized to the regions' and individual installations' discretion of where to best allocate the FS resources to individual projects.

The FSM uses averaged facilities unit costs to calculate the FS requirement for Marine Corps installations. The unit costs are average unit costs for new construction estimated at no less than three project awards of the same building type since September 2014 for Army, Navy, Air Force, Defense Education Activities, and Defense Health Agency facilities (DoD 2018b). With the exception of family housing and schools, FSM bases all project estimates on the continental U.S. (CONUS), Hawaii, and Alaska locations.

Additionally, calculations exclude projects with extreme variation from the mean (more than 50%). The FSM normalizes data by location to the National Average Area Cost Factor (ACF=1), the number of bidders, then-year dollars (October 2017), and size of the facility (DoD 2018b). Facility unit costs include minimum antiterrorism design features (in accordance with the DoD Minimum Antiterrorism Standards for Building Unified Facilities Criteria [UFC] 4–010-01), sales tax on building materials, information system costs (such as conduits, racks, trays, etc.), furnishings funded with MILCON dollars, and energy management control system connections. The cost calculations do not include gross taxes, "Acts of God" or unusual market conditions, supporting facility costs, cybersecurity costs, supervision, inspection, overhead, or design costs (DoD 2018b).

In 2008, the U.S. Government Accountability Office (GAO) conducted a report on the FSM and found concerns with two vital inputs affecting the model's reliability. The first is the assumption that services verify every facility listed in their inventory at least every five years as required by the DoD. Lacking verification, there is a probability that the model uses inaccurate inventory quantities (which was confirmed during GAO's investigation where they identified discrepancies in quantities). The second issue GAO found was the sustainment cost factor. An unnamed independent contractor hired by the DoD found that "only 13 of the 45 factors evaluated were deemed reasonably accurate and adequately supported" (GAO 2008). Since GAO released the study results, the DoD issued additional guidance to the services regarding inventory tracking; however, GAO has not published any follow-on studies specific to this topic. Lacking a more robust model, the DoD continues to use the FSM as its baseline sustainment calculator.

The FSM associates facilities unit costs with Facility Analysis Categories that factor into the DoD Real Property Categorization System, which identifies, categorizes, and models the DoD's inventory of land and facilities (DoD 2018a). Table 3 of the UFC Facilities Pricing Guide shows the breakdown of unit costs used in DoD facilities cost models and metrics. These values are used in PRV calculations:

PRV = Q x RUC x ACF x HF x PD x SIOH x CF

where

Q	=	facility quantity [in the same unit of measure as the RUC]
RUC	=	replacement unit cost (found in Table 3 of UFC FPG) [$FY]
ACF	=	area cost factor, which accounts for geographical labor, materials, and equipment costs differences (Table 4 of UFC FPG)
HF	=	adjustment of 1.05 for increased costs of replacement of historical facilities or for construction in a historic district
PD	=	accounts for planning and design of a facility; currently 1.09 for all non-medical facilities, 1.13 for medical facilities
SIOH	=	supervision, inspection, and overhead factor; currently 1.057 for CONUS, 1.065 USACE or 1.062 NAVFAC for OCONUS.
CF	=	construction contingencies factor of 1.05. (DoD 2018b)

The FSM uses sustainment calculations as outlined in UFC 3–701-01 to calculate the 100% sustainment requirement of facilities. This calculation accounts for regularly scheduled adjustments and inspections (fire sprinklers, heating, ventilation, and air conditioning systems, elevators, bridges, etc.), preventative maintenance, emergency response and service calls for minor repairs, and major replacement of facility components (DoD 2018b). Sustainment costs include cosmetic and minor structural construction, such as regular roof replacement, refinishing wall surfaces, repairing and replacing electrical, heating and cooling systems, and replacing tile and carpeting. Not included are costs associated with repairing or replacing non-attached equipment or furniture, building components that typically last more than 50 years, or facilities operations such as custodial services, grass cutting, landscaping, and waste disposal (DoD 2018b). The sustainment cost formula calculates the annual average sustainment cost for each Facility Analysis Category:

SR = Q x SUC x SACF x I

where

SR	=	sustainment requirement

Q = facility quantity [in the same unit of measure as the SUC]

SUC = sustainment unit cost (Table 3 of UFC FPG) [$FY]

SACF = sustainment area cost factor (Table 4 of UFC FPG)

I = value(s) representing future-year escalation for operation and maintenance accounts (Table 4–4 of UFC FPC). (DoD 2018b).

MILCON uses a similar cost estimation guidance as provided by the UFC Programming Cost Estimates for Military Construction (DoD 2011). The adjustment factors used in the new construction cost estimation formula explained in the UFC guidance includes size, location, cost escalation, technological updating, design contingency, historical requirements, site sensitivity, and technical specialty competition. Unlike sustainment cost calculations, supporting facility and design costs are included in MILCON calculations:

$A = $GUC x S x ACF x CE x TU x DC

where

$A = adjusted guidance unit cost

$GUC = guidance unit cost

S = size adjustment factor

ACF = area cost factor

CE = cost escalation adjustment due to inflation factors

TU = technological updating adjustment factors

DC = design contingency adjustment factors. (DoD 2011)

Finally, there is the estimation of alteration projects—"a change to interior of exterior facility arrangements to improve or change its current purpose"(DoD 2011). One of the critical decisions is whether to demo and rebuild or recapitalize an existing structure. The removal/demolition cost and new work cost for the project are calculated using the formulas:

RDC = \$GUC x S x ACF x CE x RDF

and

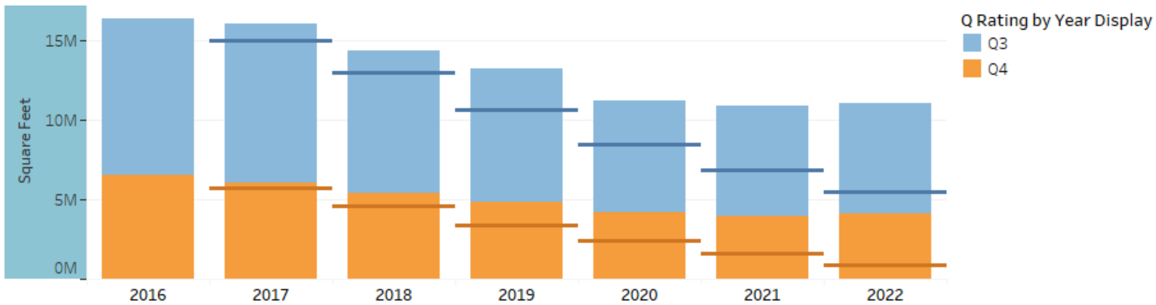
NWC = \$GUC x S x ACF x CE x RNF

where

\$GUC	=	guidance unit cost
S	=	size adjustment factor
ACF	=	area cost factor
CE	=	cost escalation adjustment due to inflation factors
RDF	=	removal/demolition factor
RNF	=	replacement new factor. (DoD 2011)

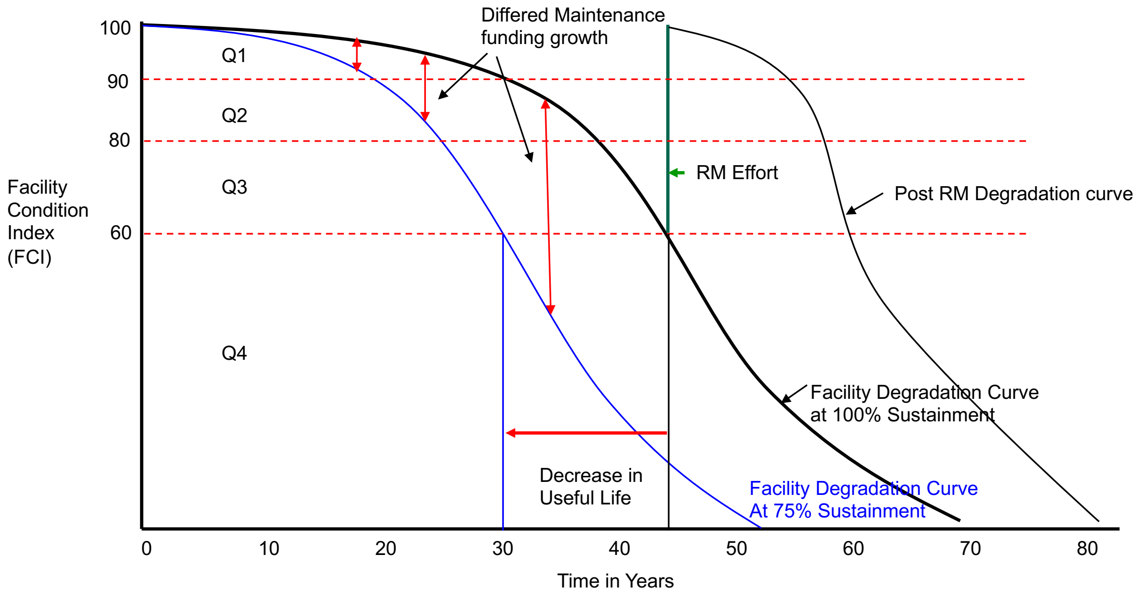
D. FACILITY CONDITION INDEX

"The Marine Corps' continual increase in the facilities footprint without divestiture of old facilities, while operating in a fiscally constrained environment and deferring maintenance as an accepted risk, has created a growing funding gap that if not addressed will result in deteriorating infrastructure" (Brinkman 2018). MCICOM divides facilities into four category ratings based on sustainment and condition levels: Q1 Good, Q2 Fair, Q3 Poor, and Q4 Failing. Facilities are inspected every three years and facilities categorization is then degraded at a calculated rate based on time. The IR strategy outlined a net total demolition requirement of 31 million square feet (MSF) across all installations by 2028, with a target of 11MSF by 2023. The 2016 Q4 population formed the initial demolition selections. Figure 3 shows how mitigating the growth of Q3 and Q4 facilities can taper the upward slope of the funding gap. The issue with differed maintenance is that, as time goes on, the lack of sustainment decreases the expected life span of the building and the cost to restore the facility to 100% increase exponentially compared to the initial cost of sustainment to maintain the building (Brinkman 2018). Thus, the cost of returning a Q4 building to a Q1 is much higher than doing so for a Q2 building. Level of sustainment funding over the life of a facility is directly related to the rate in which it degrades to Q3 or Q4. For example, 75% sustainment results in a 10% decrease in facility life span compared to 100% sustainment funding (Brinkman 2018). Figure 4 shows the decrease in facility life span and the increasing restoration costs as differed maintenance continues over time.



Mitigating Q3/Q4 growth eliminates the upward slope of the expanding funding gap. The target is to eliminate all Q4 facilities by FY2023 (Brinkman 2018). Reducing the overall square footage of real property owned by the Marine Corps is just part of the IR strategy. The goal is to modernize and restore all facilities to Q1 and Q2 ratings and sustain them at these levels.

Figure 3. Mitigate Q3/Q4 Structures through Demolition. Source: Brinkman (2018).



Differing maintenance on Q1 buildings may save money in the short term, however, the penalties for deferment increase exponentially as time increases. While recapitalization will restore the building to "like new conditions," it does not extend the life of the building at an equal rate. The industry standard is that a government facility is designed to last 67 years, one of the issues that arise however, is that capabilities typically only last 25 years before they become technologically obsolete. One of the Marine Corps' concerns involves constructing facilities that can be recapitalized to function and support new emerging technologies as the technology of the initial tenants becomes obsolete (Brinkman, 2018).

Figure 4. Effects of Differed Maintenance. Adapted from Brinkman (2018).

E. MISSION DEPENDENCY INDEX

In 2015, the USMC's Facilities Investment Campaign Plan issued a strategy to bridge the gap between facility condition and mission relativity (Dunford 2015). The plan acknowledges the need to establish a method to track the mission significance of a particular facility, using quantifiable metrics to assess the importance of the USMC's missions and the contributions provided by a facility to those missions. "The MDI will enable the prioritization of facilities based on scope of missions executed by both installation and tenant commands" (Dunford 2015). High MDI scores reflect facilities with substantial mission-related functions; lower scores are facilities with less significant or no mission-related functions.

While the campaign plan issued a goal of 30 September 2015 for calculation of all facility MDIs, there has yet to be strictly specified guidelines on how such calculations are determined. This thesis uses the MDIs provided to MCICOM by subject matter experts at the installations. The target for 2020 is to have all High MDI rated facilities at an average FCI of 85, Moderate MDIs at an average FCI of 80, and Low MDIs at an average FCI of 75 (Dunford 2015).

F. MILITARY CONSTRUCTION

MILCON provides facilities used by the USMC for a minimum of 67 years. From planning to construction, the MILCON process takes approximately six to seven years. All projects must undergo a rigorous vetting process, including: a) USMC Installation Planning and Regional Prioritization Boards (nine months), b) Headquarters Marine Corps (HQMC) MILCON Prioritization Board and HQMC Planning/Programming (19 months), c) OSD/ Congressional Program Review (17-22 months), d) Construction (24-36 months). Projects costing in excess of $2 million fall under MILCON and are heavily scrutinized by installations, regions, HQMC, Department of the Navy, DoD, and finally, approved by Congress for location, cost, and scope. Table 1 provides an example of the types of projects submitted to the board and shows the breakdown of what Congress approved (sometimes with alterations). Installations work with their tenant units to ensure all project requirements are identified in DD Form 1391, which documents and registers requirements sent to the MILCON Prioritization meetings for regions to integrate base projects. Marine Corps Forces and Deputy Commandants (DC) then develop prioritization lists for the Capital Investment Working Group (CIWG) to vote on. The CIWG is a subset of the Installations Program Evaluation Board and the Marine Corps Installations Infrastructure and Investment Board. The CIWG has 13 voting members representing all facets of the Marine Air Ground Task Force. The Working Group Chair is the MILCON Head, Logistics Forces/MCICOM. Other voting members are representatives from DC Aviation, DC Combat Development and Integration, DC I&L, DC Information, DC Manpower, DC Plans Programs and Operations, DC Programs and Resources, Marine Forces Command, Marine Forces Cyber, Marine Forces Pacific, Marine Forces Reserves, and Training and Education Command. The 2019 Planning Board requested authorization and funding of $906 million for 16 construction projects (Sanders 2018).

Table 1. FY19 MILCON Program Budget Submissions

Installation	P #	Project Title	Budget Submit ($000)	NDAA Approved ($000)
CNI NWS Seal Beach, CA	160	Reserve Training Center	21,740	21,740
MCAS Miramar, CA	222	F-35 Vertical Landing Pads and Taxiway	20,480	20,480
MCAS Miramar, CA	238	Airfield Security Improvements	11,500	11,500
MCB Camp Pendleton, CA	79	Potable Water Distribution Improvements	47,230	47,230
MCB Camp Pendleton, CA	334	Supply Warehouse SOI-West (UPL PROJECT ADD)	0	16,600
MCB Camp Pendleton, CA	1901	AAV-ACV Maintenance & Warehouse Facility	49,410	49,410
MCLB Albany, GA	947	Welding and Body Repair Center Consolidation (UPL PROJECT ADD)	0	31,900
Panzer Kaserne, Germany	1	MARFOREUR HQ Modernization and Expansion	43,950	43,950
US NAVSUPACT Andersen, Guam	270	ACE Gym & Dining Facility	27,910	27,910
US NAVSUPACT Andersen, Guam	290	Earth Covered Magazines	52,270	52,270
US NAVSUPACT Andersen, Guam	295	Ordnance Ops	22,020	22,020
US NAVSUPACT Andersen, Guam	735	Machine Gun Range (CONGRESS INCREMENTALLY FUNDED)	141,287	70,000
MCB Hawaii, HI	946	Corrosion Control Hangar	66,100	66,100
MCAS Cherry Point, NC	199	Aircraft Maintenance Hangar (CONGRESS INCREMENTALLY FUNDED)	133,970	60,000
MCAS Cherry Point, NC	235	Flightline Utility Modernization (CONGRESS INCREMENTALLY FUNDED)	106,860	55,000
MCB Camp Lejeune, NC	1458	2nd Radio Bn Complex, Phase 2 (UPL PROJECT ADD)	0	51,300
MCAS Beaufort, SC	457	Cryogenics Facility (UPL PROJECT ADD)	0	6,300
MCAS Beaufort, SC	487	Recycling/Hazardous Waste Facility	9,517	9,517
MCRD Parris Island, SC	404	Range Improvements & Modernization, Phase 2	35,190	35,190
MCB Quantico, VA	542	TBS Fire Station (CONGRESS DELETED PROJECT - ADDED VIA FY18 UPL)	21,980	0

Installation	P #	Project Title	Budget Submit ($000)	NDAA Approved ($000)
MCB Quantico, VA	724	Ammunition Supply Point Upgrade, Phase 2 (UPL PROJECT ADD)	0	13,100
Various Locations		Enhancing Force Protection & Safety (PORTION OF DON CONGRESS ADD)	0	17,500
Planning and Design	101	USMC Planning and Design - Active Force	62,986	62,986
Planning and Design	103	USMC Planning and Design - DPRI Guam	20,780	20,780
Planning and Design	200	USMC Planning and Design - Reserve Force	2,401	2,401
Unspecified Minor Construction		USMC Unspecified Minor MILCON	8,589	8,589
		TOTAL	**906,170**	**823,773**

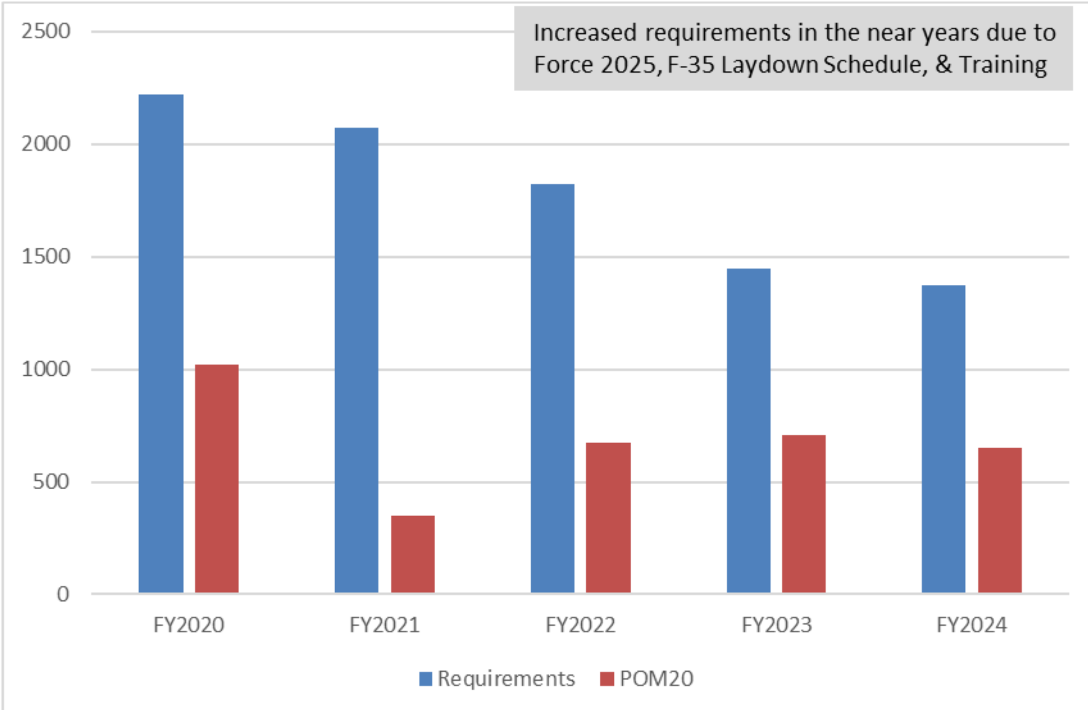
The FY19 MILCON program budget submission lists the requested projects, with those highlighted in yellow as Congressional reductions and those in green as Congressional action additions. The submitted proposal with Congressional input totaled over $906 million. The NDAA approved just over $823 million of the submissions. Source: Sanders 2018.

New security and safety projects are just a fraction of the $906 million proposed MILCON budget for FY2019. Long-term sustainment capitalized through this MILCON budget is primarily focused on supporting new platforms and capabilities such as the F-35 aircraft and the new amphibious combat vehicle, relocation of forces to Guam, replacement of inadequate facilities, and correcting environmental deficiencies (USMC 2018a).

> The need for Military Construction is driven by Operational Force and Marine Corps-wide mission requirements such as:
>
> - new platform or weapons introduction;
> - adjusted force structure requirements and/or relocating forces;
> - meeting a force protection or safety standard;
> - eliminating unacceptable conditions in the workplace or living facilities;
> - meeting new and improved training standards and improving training areas to include aerial/ground ranges;

- modernizing critical infrastructure;
- improving utilities reliability to support readiness;
- meeting environmental compliance regulations; and
- acquiring land as necessary for Operational Force use. (USMC 2018a)

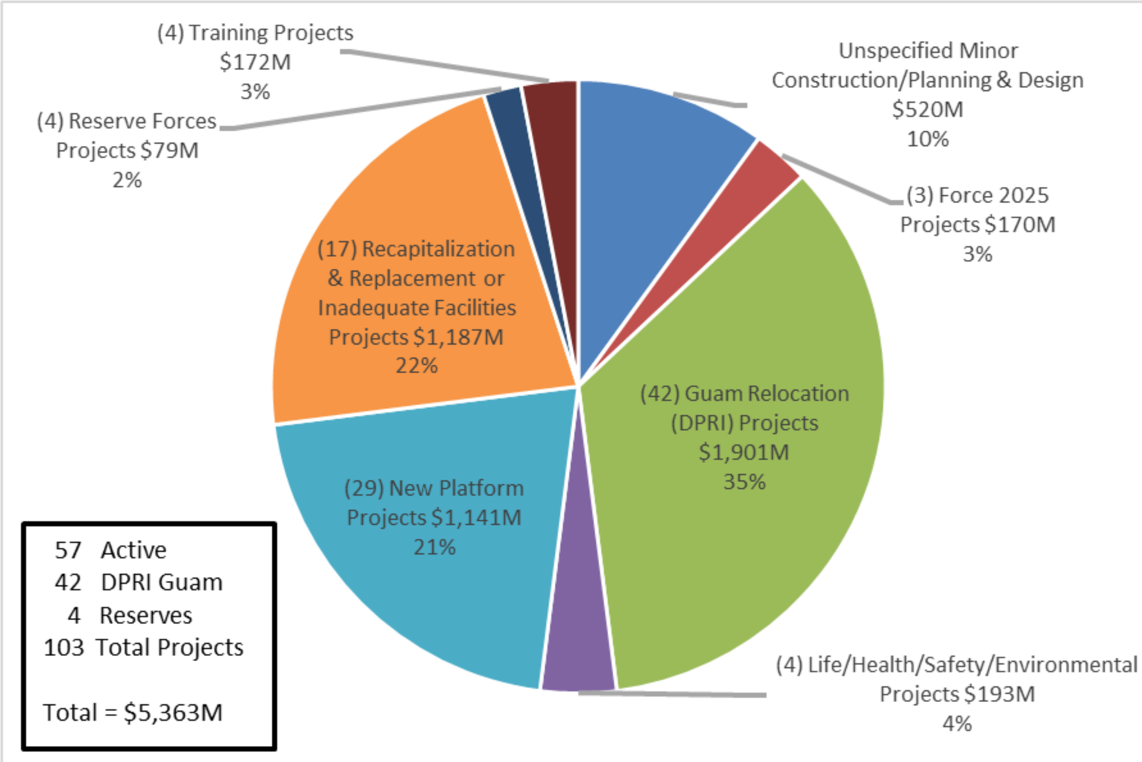
An increase in the NET square footage possessed by the Marine Corps increases the current sustainment and delayed restoration and modernization requirement. The multitude of MILCON requirements in contrast to the actual availability of resources is shown in Figure 5. As shown, there is a perpetual deficit in funding to requirements. There is a clear need for a decision support tool that helps optimize the scarce available resources against the plethora of requirements.



Shown in millions of dollars, the higher requirements in the next few years are due to new platforms (i.e., the F-35 joint strike fighter), IR strategy requirements, training area advancements, movement of the Marine Corps into the Force 2025 plan, and major upgrades to MCB Hawaii. This does not include DPRI Guam or MRF-Darwin requirements (Sanders 2018).

Figure 5. Active and Reserve POM20 MILCON Requirements versus Available Funding (in Millions). Source: Sanders (2018).

As the USMC enters a new phase of force draw-down and footprint reduction, new and increasingly stringent environmental requirements continue to tighten the MILCON budget. National Environmental Policy Act and Executive Order 12114 require the USMC to analyze any human or natural impacts its actions may have on the environment. Thus, all facilities action planning (MILCON, demolition, or FSRM) is integrated with environmental planning and resource management. For the scope of this thesis, we assume all environmental considerations and costs are factored into project proposals and decisions. Figure 6 shows the MILCON submissions breakdown by project type for POM20; cost assessments include the estimated environmental expenses.

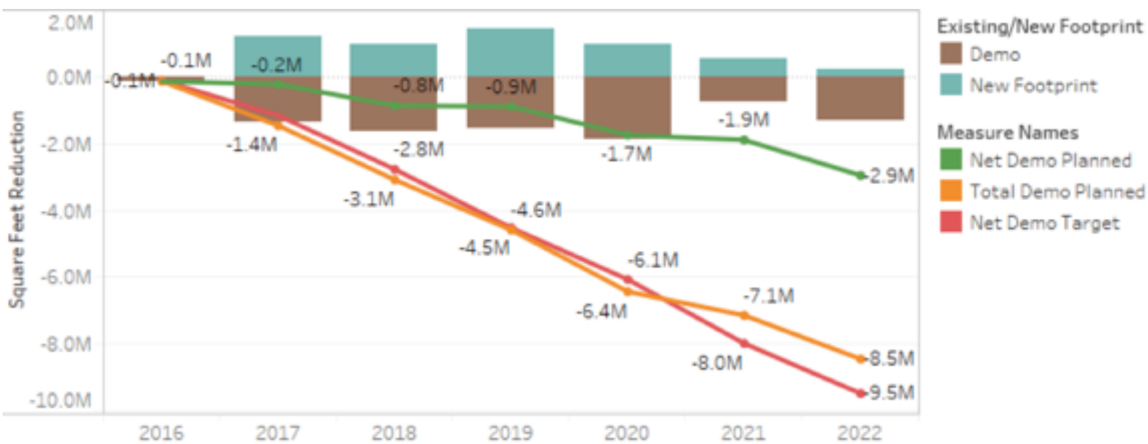


This breakdown supports the force reshaping initiative Force 2025, as well as new platform introduction at stateside and overseas locations. Additionally, it corrects environmental and safety deficiencies, supports relocation and consolidation of forces to Guam, and replaces inadequate and obsolete facilities and consolidates functions from multiple facilities (Sanders 2018).

Figure 6. POM20 MILCON Program Summary Based on Submissions to OSD in August 2018. Source: Sanders (2018).

G. DEMOLITION

Of note, the MILCON budget factors in demolition costs if a new facility is being built on top of where the current facility stands, otherwise, demolition falls under the Operations and Maintenance (O&M) budget. "Demolition and disposal of excess or obsolete facilities serves to reduce operating and maintenance costs, eliminate potential fire and safety hazards from installations, remove the potential for the unauthorized use of excess facilities, and eliminate degraded facilities that detract from the overall integrity of installations" (OASDS 2018). There are two options to consider when a building is slated for demolition. The first is continuing to sustain the building until it is actually demolished (i.e., providing utility services, such as power). The second is to "shutter" the building, in which case all power and utilities are turned off and the building is rendered inaccessible to unauthorized personnel. While shuttering the building is generally more cost effective, it can create an eye sore on the installation and provide additional fire and safety hazards. Additionally, some buildings slated for demolition must remain operational in order to support a unit that is transitioning to a new facility. It should be noted that just because a building is Q4 does not mean it is not mission critical; thus, demolition targets are established by the region and installation commanders. Figure 7 shows the new footprint (MILCON) versus demolition target goals for the next four years.



The planned demolition projects fall short of the targeted requirement of 11 MSF, which was based on the Q4 facility population in 2016. In addition to demolition, new construction must be limited in order to reduce the net square footage of the Marine Corps (Brinkman 2018).

Figure 7. New Footprint (MILCON) and Demolition Targets. Source: Brinkman (2018).

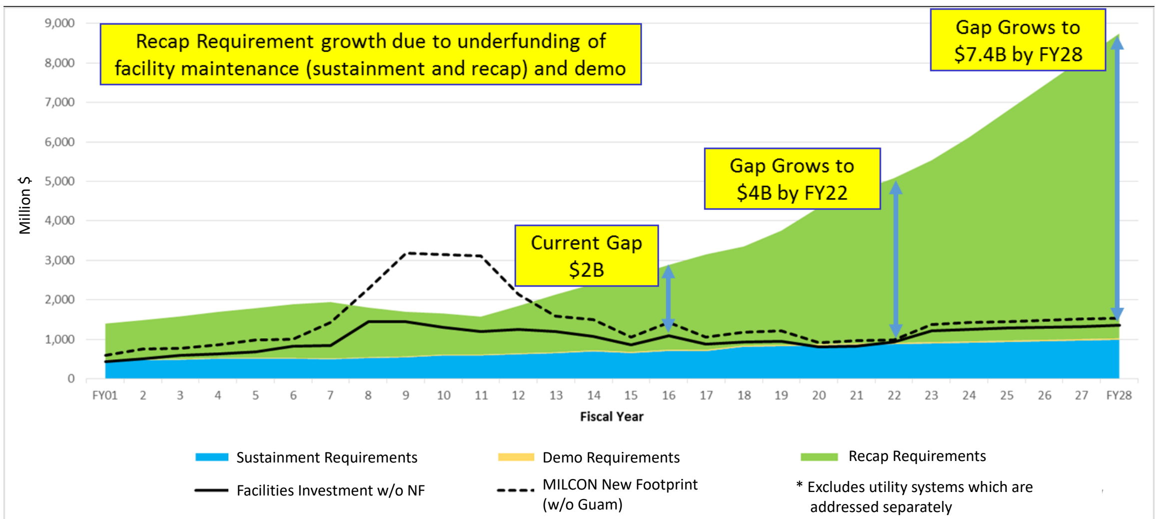
H. FACILITY SUSTAINMENT, RESTORATION, AND MODERNIZATION

Although facility sustainment, restoration, and modernization fall under the same lever of investment, restoration and modernization activities are tracked separately from sustainment investing. Sustainment ensures DoD facilities remain habitable and operational throughout their expected life cycles, and include repairs, inspections, and preventative maintenance (OASDS 2018). Conversely, restoration undertakings aim to restore facilities close to their original condition, and include projects that renovate facilities degraded by differed maintenance, age, natural disaster, fire, and accidents (OASDS 2018). Modernization covers activities that "alter or replace facilities solely to implement new or higher standards (including regulatory changes), to accommodate new functions, or to replace components that usually last more than 50 years like foundations and structural elements" (OASDS 2018). While sustainment is calculated using the FSM, restoration and modernization is not estimated through an OSD model, and is funded by O&M. The FSRM project life cycle, from validation to contract award, generally requires a minimum of two years, and projects are authorized based on their value to the Marine Corps. FSRM decisions remain at the institution level, however, any project costing in excess of $7.5 million must be reported to Congress. Project cost calculations include civilian labor, materials and supplies, and contracts.

Local FSRM (M1/R1)—repair projects under $300K (M1) and minor construction less than $100K (R1)—is allocated to installations for day-to-day maintenance, repairs, and minor construction. In total, 55% of the modeled FSRM requirement covers local M1/R1 contracts but limited to 4% of total M1/R1. The remaining 45% of FSRM funding pays for Centrally Managed Program (M2/R2)—repairs greater than $300K (M2) and minor construction between $100K and $1M (R2)—special projects. Installations/Regions submit prioritized lists of M2/R2 projects (e.g., demolition; energy investment; or large, non-recurring requirements) to the Facility Investments Web, where projects are nominated for validation. MCICOM controls the centrally managed assessment program, where facility conditions are assessed by contracted architect and engineer teams on scheduled cycles, based on facility type. The following is a list of facility type and schedule:

- buildings every 3 years
- bridges every 2 years
- dams and levees every 3–5 years
- rail annually
- airfield pavement every 3 years for condition and every 10 years for subsurface voids (eroded materials below the pavement) (Wagner 2018).

Figure 8 shows how the facilities maintenance gap continues to grow exponentially if maintenance remains underfunded as currently projected. The green in Figure 8 shows the exponential growth of recapitalization requirements if differed maintenance is left unchecked. By managing MILCON growth and the growth of Q3/Q4 facilities, the USMC can stabilize the maintenance funding requirements.



The recapitalization cost due to differed maintenance to return facilities to Q1/Q2 will grow exponentially if Q3/Q4 facility growth and MILCON are not mitigated. The current funding gap between facility sustainment and recapitalization is $2 billion. This gap is expected to double in the next six years and nearly quadruple by FY28 if left unchecked (Brinkman 2018).

Figure 8. Growth of Recapitalization Costs Due to Differed Maintenance. Source: Brinkman (2018).

II. LITERATURE REVIEW

Facility and installation optimization research are important topics throughout the DoD. Operating on a limited budget requires services to strictly limit excess facilities while maintaining mission capabilities. By tracking facility degradation, the DoD is able to better project its capital budgeting strategy. Past optimization research looked at the integration of readiness reporting metrics and capital budgeting constraints using various models. Some models were widely used throughout the DoD in the 1990s and early 2000s in support of Base Realignment and Closure (BRAC) rounds. Since then, several academics developed models that build off of the BRAC framework, adding constraints and characteristics that mimic the modern military. The authors designed several of these models to provide analytical justification for POM development and facilities investment decisions. Our research builds on this foundation, incorporating several characteristics of past models and adds restrictions and constraints unique to the Marine Corps' current investment goals and requirements.

A. DEGRADATION MODELS

The U.S. Army uses the Army Installations Status Report for Infrastructure (ISR-I) to assess the condition, performance, and readiness of its facilities. Grussing (2012) reports on integrating the Army Corps of Engineers' BUILDER Sustainment Management System (SMS) with condition assessment information provided by ISR-I. With this ISR-I condition assessment history for each component of a facility, BUILDER projects the facility's life-cycle and degradation over time using a Weibull probability distribution function and different industry estimates of service life for unique components (Grussing 2012), generating estimates on expected component and system failures. Grussing's (2012) integrated system produces work recommendations for each year based on given standards across all assets, supporting both installation-level forecasting and strategic-level planning. Standardizing facilities inspections and ratings across the branches of service using BUILDER SMS is one of the primary initiatives of the Facilities Investment & Management office under the Office of the Assistant Secretary of Defense for Energy, Installations, and Environment. Degradation rates are dependent on multiple variables (building type, current condition, geographic location, etc.); many of which are incorporated in statistically calculated degradation models. However, for simplicity, this thesis follows the DoD's benchmark deterioration rate of 1.5% of the PRV per year, assuming a reasonably well maintained facility.

B. MILITARY CAPITAL PLANNING

Every service branch within the DoD must formulate its own capital budgeting formula to allocate funds across a broad time horizon amongst competing projects to maintain operational readiness. Extensive research at the Naval Postgraduate School and across other institutions incorporated facility and infrastructure investment optimization into capital planning models. The models presented in this section vary in complexity but all developed as decision support tools to provide analytical rigor to existing military problems.

The binary knapsack problem is arguably the most simplistic optimization model for military capital planning. A decision maker chooses between a set of procurement options in an attempt to maximize his/her portfolio value. When applied to installations, the knapsack model iterates through facilities and determines which should remain in the portfolio and which should be demolished, with the intent of maximizing installation readiness or facility condition. To complicate the model, most facility investments extend beyond a single year from decision to execution. As previously stated, MILCON requires up to seven years, while FRSM can cover two to three years. Brown, Dell, and Newman (2004) introduce a generic multiple-year knapsack model for weapons system acquisitions. Their model tracks the weapons systems in inventory, and accounts for operating costs that fluctuate alongside the operational life cycle of each system. The authors further present additional and continually complex models incorporating multi-year planning horizons, variable interactions and dependencies, and platform retirement.

Radke (2015) examined three different models in her thesis, including the binary knapsack optimization problem, and applied them to Special Operations Forces. She moved beyond the binary knapsack problem and into a Weighted Goal Programming

(WGP) model that plans investments based on minimizing the total weighted penalties for violating budget, procurement, and capability constraints. She further developed the WGP by adding Platform Tracking (PT) into the WGPwPT model. This final model accomplished the same goals with added consideration to retirement, portfolio value, and platform inventory constraints. Similar to Radke's findings regarding platforms, construction (procurement) and demolition (retirement) of individual facilities affects installation portfolios. Balancing the optimal allocation of funding while still ensuring there are no mission capability gaps in the planning timeline is critical for any optimization tool.

Arguably, the most extensively researched installation and facilities problem at the Naval Postgraduate School has focused on Army BRAC investments. Cost of Base Realignment Actions (COBRA) (Richardson & Kirmse 1994) was the primary tool used by all military services for their numerous rounds of BRAC. The program assessed the related expenses accompanying a recommended base closure or realignment. The cost calculations of COBRA became a source of input data for the mixed-integer linear program, BRAC Action Schedule (BRACAS) developed by Dell (1998). The 2005 BRAC recommendations relied heavily on the Optimal Stationing Army Forces (OSAF) integer linear program output (Dell, Ewing, & Tarantino 2008). Given a force size and structure, OSAF optimally stationed the unit subject to specific structure availabilities, maneuver training necessities, and range obligations. As part of the optimal stationing plan, OSAF used the Installation Status Report (Department of the Army, 2007), which gave a three-color facility rating for every square foot in the U.S. Army portfolio. All force movements are required to have "green" facilities at the new installation (green means the facility is good, yellow is fair, and red is poor). If green-rated facilities are not available, OSAF added a cost to update those facilities and it assumed yellow and red-rated facilities were vacated before green-rated facilities. Similar to the three-color ratings, the Marine Corps uses a facility rating structure of four "Q-ratings," and assumes Q3 and Q4 facilities are demolished or renovated prior to Q1 and Q2 facilities.

Field's (1999) capital investment optimization tool for Navy Force investments integrates Extended Planning Annex/Total Obligated Authority Model (EPA/TOA)—the estimated financial impact of any complete future plan, within his Capital Investment Planning Aid (CIPA). EPA/TOA is a purely descriptive model of "what-if" scenario outputs. Covering a 30-year planning horizon, CIPA formulates force structure (procurement and retirement of platforms) by minimizing penalties incurred by violating budget, production, and inventory constraints, where each planning scenario is represented as an integer linear program (Salmeron et al. 2006). Similar planning timelines can be translated from large capital expenditure procurements and capital facility investment projects.

Brown et al. (2003) discuss the U.S. Air Force's (USAF) use of the integer linear program space command optimizer of utility toolkit (SCOUT) combined with Space Command's space and missile optimization analysis for its 1997 and 1999 strategic master plans. As Brown et al. (2003) describe, SCOUT uses a 24-year time horizon and arrives at a yearly projected budget, while the USAF only uses 18 years when developing their strategic master plans. This time gap mitigates what Brown et al. (2003) call "end effect," which refers to where the program "cannot see the benefit of procuring a system that requires funding during the planning horizon but provides little operational capability before the end of the horizon." Another applicable attribute of SCOUT is its use of elastic constraints (Brown et al. 1997). These constraints mitigate the limitation that solutions that would normally violate feasibility are eliminated, and instead adds a penalty per unit of violation.

C. MODEL CHARACTERISTICS

Each of the military capital planning models previously described have unique characteristics tailored to their intended use and purpose. Here we consider three important model characteristics: utility infrastructure investment, persistence, and implementation. In November 2016, GAO reported on resilience of DoD-owned utility systems (GAO 2016). The FSRM section of MCICOM manages the utilities infrastructure on installations, while the actual utilities that pass through the network (i.e., electricity, gas, water) are owned and provided by private, local businesses under contract with the DoD. GAO found that between 2009 and 2015, there were 4,393 utility disruptions that caused a variety of operational impacts and combined to total $29 million in financial costs across DoD installations. The more prominent causes of failure were equipment extending beyond intended life cycle, degraded equipment, and poorly maintained equipment. This GAO study highlights the importance of utility infrastructure investment, and why it should be a priority in capital planning.

Another important factor in most optimization, especially capital budgeting, is the notion of persistence. Plans and budgeting are often subject to changes in information (input variables), requiring continually running models and solving for a new optimal objective function. The notion of a persistent model is one where the changes to the optimal solution are minimal between each iteration. Small adjustments in plans and schedules are more managerially acceptable than ones that fluctuate between drastically different solutions. Brown et al. (1997) review the implementation of persistence in various optimization models from cereal manufacturing to helicopter fleet modernization. They argue that one must reflect the cyclic-review process under which the model is used. A practical model must be flexible to handle unforeseeable adjustments. The authors explain how the U.S. Coast Guard's Cutter scheduler encourages persistence by pushing binary variables to keep their values corresponding to the previous optimal solution in what are called "elastic persistent variables." Each variable is assigned a target value and is penalized for any deviation from its target. To maintain costs within a reasonable range, Brown et al. (1997) explain that the original objective function is adapted into an "aspiration constraint" such that the persistent model has a surrogate objective measuring divergences. They also point out that the solving time of the persistent model is roughly three times faster than the original.

Persistence is further explored in this paper as it applies to BRACAS (Dell 1997), the U.S. Army mixed-integer linear program designed to aid in realignment and closure of bases. A "ranged persistent constraint" is used in this model, providing upper and lower boundaries for each target budget category broken down by installation. Finally, the authors investigate PHOENIX (Brown et al. 1991), which assisted the U.S. Army with modernizing its aging helicopter fleet. This model covered a multi-year planning horizon when addressing equipment replacement, maintenance, refitting, retirement, and procurement. As Brown et al. (1991) describe, PHOENIX incorporated persistence through elastic persistent constraints and variables.

Finally, because of the size and monolithic nature of this problem, implementation is an important factor to consider. Guthrie (2017) explores implementing and bounding cascade heuristics for large-scale optimization problems in her Naval Postgraduate School Master's thesis. She studies the optimal solution disparities between integer linear program implementations of a production model and the USMC Hornet Assignment Sundown Model. The cascading heuristics takes "windows" from a defined time horizon and solves each block while only considering constraints within that window and relaxing or fixing constraints and variables outside that window. The cascade fixes certain values based on the solution from that window, and then adjusts the window forward by a set parameter. Her results from a wide variety of cascading heuristic implementations showed that production model solutions came within 5% of optimal, while those for the Hornet model deviated up to 99% (Guthrie 2017). We implement similar cascading heuristics for this thesis, as running the full model is time intensive.

III. FACILITY INVESTMENT OPTIMIZATION MODEL

MILCON boards release project approvals annually along with Presidential budgets that breakdown expected spending among the four levers of investment. With these new construction projects, MCICOM schedules and distributes the annual budget allotments to the individual regions. This chapter presents a mixed-integer linear program, the Installation Readiness Optimization Model (IROM), to generate optimal investment actions that ensure mission essential readiness is maximized within budgetary constraints. As discussed in Chapter I, MILCON and O&M funded projects are selected by an investment board, thus the square footage and costs are determined as fixed inputs. Additionally, the FSM calculates the annual 100% sustainment requirements for each facility in the USMC's real property portfolio. With these project approvals and sustainment requirements, IROM determines the optimal investment breakdown across all installations and facility type.

We incorporate a discount factor for each year in the objective function. In doing so we ensure going over budget in year one is costlier than going over budget in future years. This strategy follows the understanding that one cares more about the earlier budget than future budgets because we know year one is more likely to be executed, while future years are more flexible and are subject to change.

A. MODEL ASSUMPTIONS

Various assumptions are necessary to facilitate completion and usability of IROM:

- To maintain consistency with the DoD's FSM assumptions, we formulate a linear degradation function with a constant degradation factor per year, even though the expected degradation of a facility is non-linear (see Figure 4).
- All environmental costs of clean-up are incorporated in the given cost of demolishing a facility.
- Dollars are allocated to each facility from only one lever of investment each year.

- Each restoration and demolition project is completed in full or not at all. There are no fractional completions that incur fractional costs.
- Maintenance and repair requirements are known a certain number of years in advance based on inspections.
- Recapitalization costs are calculated as 1% of PRV per FCI point, and it is assumed that if a building in restored to Q1, its life cycle begins again starting from zero. For simplicity we recap the building completely (to a FCI of 100) or not at all.
- We limit recapitalization to facilities with FCI between acceptable levels (e.g. 20 and 80).

B. ELEMENTS OF THE MODEL (NPS FORMAT)

Indexes and Sets [Cardinality]

c	DoD facility class that designates the type of facility [8]
	1: Operation & Training; 2: Maintenance & Production; 3: Research; Development; Test & Evaluation; 4: Supply; 5: Hospital & Medical; 6: Administrative; 7: Housing & Community; 8: Utility & Ground Improvements
f	Facility [19,011]
i	Installation [21]
m	Mission dependency category code
	(critical, significant, moderate, relevant, low) [5]
n	New MILCON project
r	Major commands (region) receiving O&M funding [5]
	(MCIPAC, MCIEAST, MCIWEST, MCINCR, MFR)
y,y'	Year ($y = 0, 1, 2, \dots, 20$)
$f \in D_y$	Set of facilities eligible for demolition in year y
$f \in FR_r$	Set of facilities in region r

$f \in FC_c$	Set of facilities that are class c
$f \in FM_m$	Set of facilities with mission dependency code m
$y \in G$	Set of years with demolition goals

<u>Data & Parameters</u>

bud_y	Total MCICOM budget for a given year y [$M]
deg_f	Linear degradation factor for facility f
$demo\_cost_{fy}$	Calculated cost of demolishing facility f in year y [$M]
$demo\_req_y$	Reduction in net square footage required by year y [square feet]
dev_pen_y	The penalty cost imposed for exceeding the budget in a given year
$discount$	Yearly discount factor applied to objective function
fsm_{fy}	Calculated sustainment requirement (FSM) for facility f in year y [$M]
$hist_f$	National Registry Historical Property type of facility f
max_demo_y	Total demolition cost allotted for each year [$M]
max_recap_y	Total restoration cost allotted for each year [$M]
$maxdemo_{iy}$	Maximum number of facilities to demolish at installation i in year y
$maxrecap_{iy}$	Maximum number of facilities to restore at installation i in year y
$mindemo_{iy}$	Minimum number of facilities to demolish at installation i in year y
$minrecap_{iy}$	Minimum number of facilities to restore at installation i in year y
mdi_{fy}	Mission dependancy index rating of facility f in year y
$milcon_{ny}$	MILCON project n approved in year y
mmf_{my}	Minimum FCI for each facility in mission dependency group m in year y
m_per_{fy}	Minimum sustainment percent required for facility f in year y [$M]

msf_f Square footage of facility f [square feet]

o_per_y Overall minimum sustainment percent in year y [$M]

rmf_{ry} Minimum funding for region r in year y [$M]

$recap\_cost_{fy}$ Cost of restoring facility f in year y [$M]

rU_{fy} Maximum FCI allowed for facility f restored in year y

rL_{fy} Minimum FCI allowed for facility f restored in year y

tmf_{cy} Min FCI for facility type c in year y

Variables

$DEMO_{fy}$ Binary variable with value 1 when facility f is demolished in year y

DEV_y The amount above bud_y in year y

$DEVD_y$ The amount above max_demo_y in year y

$DEVF_{fy}$ The amount below mmf_{my} by facility f in year y

$DEVM_y$ The amount below $demo\_req_y$ in year y

$DEVR_y$ The amount above max_recap_y in year y

FCI_{fy} Facility condition index rating of facility f in year y $[0, 100]$

$RECAP_{fy}$ Binary variable with value 1 when facility f is recapitalized in year y

$SUST_{fy}$ Sustainment allocation to facility f in year y [$M]

$IFCI_{fy}$ FCI improvement to facility f in year y [0,100]

Objective Function & Constraints

$$Max\sum_{fy}(mdi_{fy}\cdot FCI_{fy}\cdot discount^{y-1})-\sum_{y}(dev\_pen_{y}\cdot(DEV_{y}+DEVR_{y}+DEVD_{y}+DEVF_{fy}$$
$$+DEVM_{y})\cdot discount^{y-1})-\sum_{fy}([(demo\_cost_{fy}\cdot DEMO_{fy})+SUST_{fy}+(recap\_cost_{fy}\cdot$$
$$RECAP_{fy})]\cdot discount^{y-1})\cdot(1/bud_{y})$$

Subject to:

$$\sum_{f\in D_y}(demo\_cost_{fy}\cdot DEMO_{fy})+\sum_{f}SUST_{fy}+\sum_{f}(recap\_cost_{fy}\cdot RECAP_{fy})\le bud_{y}+DEV_{y} \qquad \forall y \qquad (1)$$

$$\sum_{f}(demo\_cost_{fy}\cdot DEMO_{fy})\le max\_demo_{y}+DEVD_{y} \qquad \forall y \qquad (2)$$

$$\sum_{y'\le y}\sum_{f}(msf_{f}\cdot DEMO_{fy'})-\sum_{y'\le y}\sum_{n}(msf_{n}\cdot milcon_{ny'})+DEVM_{y}\ge demo\_req_{y} \qquad \forall y\in G \qquad (3)$$

$$\sum_{f}SUST_{fy}\ge o\_per_{y}\cdot\sum_{f}(fsm_{fy}\cdot(1-\sum_{y'\le y}DEMO_{fy'})-fsm_{fy}\cdot RECAP_{fy}) \qquad \forall y \qquad (4)$$

$$SUST_{fy}\ge m\_per_{fy}\cdot fsm_{fy}\cdot(1-\sum_{y'\le y}DEMO_{fy'})-fsm_{fy}\cdot RECAP_{fy}) \qquad \forall f,y \qquad (5)$$

$$\sum_{f\in FR_r}SUST_{fy}\ge rmf_{ry}\cdot\sum_{f\in FR_r}(fsm_{fy}\cdot(1-\sum_{y'\le y}DEMO_{fy'})-fsm_{fy}\cdot RECAP_{fy}) \qquad \forall r,y \qquad (6)$$

$$FCI_{fy}\le FCI_{f(y-1)}-\deg_{f}\cdot(1-\sum_{y'\le y}DEMO_{fy'})-\left(\frac{fsm_{fy}-SUST_{fy}-fsm_{fy}\cdot\sum_{y'\le y}DEMO_{fy'}}{fsm_{fy}}\right)+IFCI_{fy} \qquad \forall f,y \qquad (7)$$

$$FCI_{f(y-1)} + IFCI_{fy} \leq 100 \qquad \forall f, y \qquad (7.1)$$

$$IFCI_{fy} \leq RECAP_{f(y-1)} \cdot rU_{fy} \qquad \forall f, y \qquad (8)$$

$$IFCI_{fy} \geq RECAP_{f(y-1)} \cdot rL_{fy} \qquad \forall f, y \qquad (9)$$

$$SUST_{fy} \leq fsm_{fy} \cdot (1 - RECAP_{fy}) \qquad \forall f, y \qquad (10)$$

$$FCI_{fy} \geq tmf_{cy} \cdot (1 - \sum_{y' \leq y} DEMO_{fy'}) \qquad \forall c, f \in FC_c, y \qquad (11)$$

$$FCI_{fy} + DEVF_{fy} \geq mmf_{my} \cdot (1 - \sum_{y' \leq y} DEMO_{fy'}) \qquad \forall f \in FM_m, y \qquad (12)$$

$$\sum_{f} (recap\_cost_f \cdot RECAP_{fy}) \leq max\_recap_y + DEVR_y \qquad \forall y \qquad (13)$$

$$\sum_{y} DEMO_{fy} \leq 1 \qquad \forall f \qquad (14)$$

$$FCI_{fy} \leq 100 \cdot (1 - \sum_{y' \leq y} DEMO_{fy'}) \qquad \forall f, y \qquad (15)$$

$$RECAP_{fy} \leq 1 - \sum_{y' \leq y} DEMO_{fy'} \qquad \forall f, y \qquad (16)$$

$$SUST_{fy} \leq fsm_{fy} \cdot (1 - \sum_{y' \leq y} DEMO_{fy'}) \qquad \forall f, y \qquad (17)$$

$$\sum_{f \in FI_i} DEMO_{fy} \geq mindemo_{iy} \qquad \forall i, y \qquad (18)$$

$$\sum_{f \in FI_i} DEMO_{fy} \leq maxdemo_{iy} \qquad \forall i, y \qquad (19)$$

$$\sum_{f \in FI_i} RECAP_{fy} \geq minrecap_{iy} \qquad \forall i, y \qquad (20)$$

$$\sum_{f \in FI_i} RECAP_{fy} \leq maxrecap_{iy} \qquad \forall i, y \qquad (21)$$

$$DEMO_{fy} \in \{1,0\} \qquad \forall f, y \qquad (22)$$

$DEV_y \in \mathbb{R} \geq 0$ $\forall y$ (23)

$DEVD_y \in \mathbb{R} \geq 0$ $\forall y$ (24)

$DEVR_y \in \mathbb{R} \geq 0$ $\forall y$ (25)

$FCI_{fy} \in [0,100]$ $\forall f, y$ (26)

$RECAP_{fy} \in \{0,1\}$ $\forall f, y$ (27)

$SUST_{fy} \in \mathbb{R} \geq 0$ $\forall f, y$ (28)

$IFCI_{fy} \in [0,100]$ $\forall f, y$ (29)

- Constraint sets (1) and (2) record any deviations from the overall and demolition yearly budgets respectively.
- Constraints (3) ensure the net square footage meets the yearly targets.
- Constraint sets (4) and (5) set overall and individual facility minimum sustainment levels.
- Constraint (6) allocates regional funding.
- Constraints (7) and (7.1) track yearly FCI for each facility.
- Constraint sets (8) and (9) record FCI improvement that is only allowed if a facility's FCI falls between two thresholds.
- Constraints (10) limit sustainment spending to the FSM level for each facility, and prohibits both restoration and sustainment in that same year.
- Constraints (11) set minimum FCI requirements by facility type.
- Constraints (12) records any deviation below FCI requirements by facility mission rating.
- Constraints (13) records any deviation above yearly restoration budgets.
- Constraints (14) ensure each facility is demolished at most once.
- Constraints (15) fix the FCI of a demolished building to zero.
- Constraints (16) ensure each demolished facility is not also restored.

- Constraints (17) ensures a demolished facility is no longer sustained.
- Constraint sets (18) and (19) provide lower and upper bounds on the number of demolished facilities at each installation in a given year.
- Constraint sets (20) and (21) provide lower and upper bounds on the number of restored facilities at each installation in a given year.
- Constraint sets (22) to (29) declare variable bounds.

IV. COMPUTATION

Data provided by MCICOM for this research is extensive, but not all data and parameters described in the previous chapter are currently tracked by the USMC. In this chapter we describe the available data, how we manipulated certain fields to work programmatically, and how we adjust the Installation Readiness Optimization Model (IROM) to fit the data. We demonstrate the capabilities of IROM and run sensitivity analysis on parameter adjustments to show how changing budgets impacts installation and USMC readiness. Coded in the Python language (Python 2019), using the Pyomo optimization package software (Hart et al. 2011), we use CPLEX (IBM 2017) to solve IROM.

Due to the long execution time, we implement IROM two different ways, comparing the objective function values to determine accuracy of each approach. The monolithic approach generates over 550,000 variables (228,132 binary) and nearly one million constraints, runs on a 2.30 GHz dual processor with 128 GB RAM, and takes a day to achieve a near optimal solution. The second approach involves cascading blocks (Guthrie, 2017) in which we run a three-year time horizon, lock the first two years, and shift the block to the next three years. We shift a total of three times, each time locking two years, ending with the full six year POM. We implement the cascading block approach on a 1.8 GHz single processor with 4 GB RAM and reaches a solution within six hours.

A. DATA AVAILABILITY AND ASSUMPTIONS

The data maintained by MCICOM is collected and recorded by the individual installations and their inspectors. We remove any facilities that do not have a full profile (i.e., no MDI, or a sustainment or restoration value of zero). After combining and cleaning the data, the result is 19,011 individual facilities with usable data. The 19,011 facilities we use in this thesis are spread around the world across 19 different installations (Figure 9). Although not the largest in land area, Camp Lejeune houses the most facilities (4,353) by a large margin over the next closest Camp Pendleton (2,811).

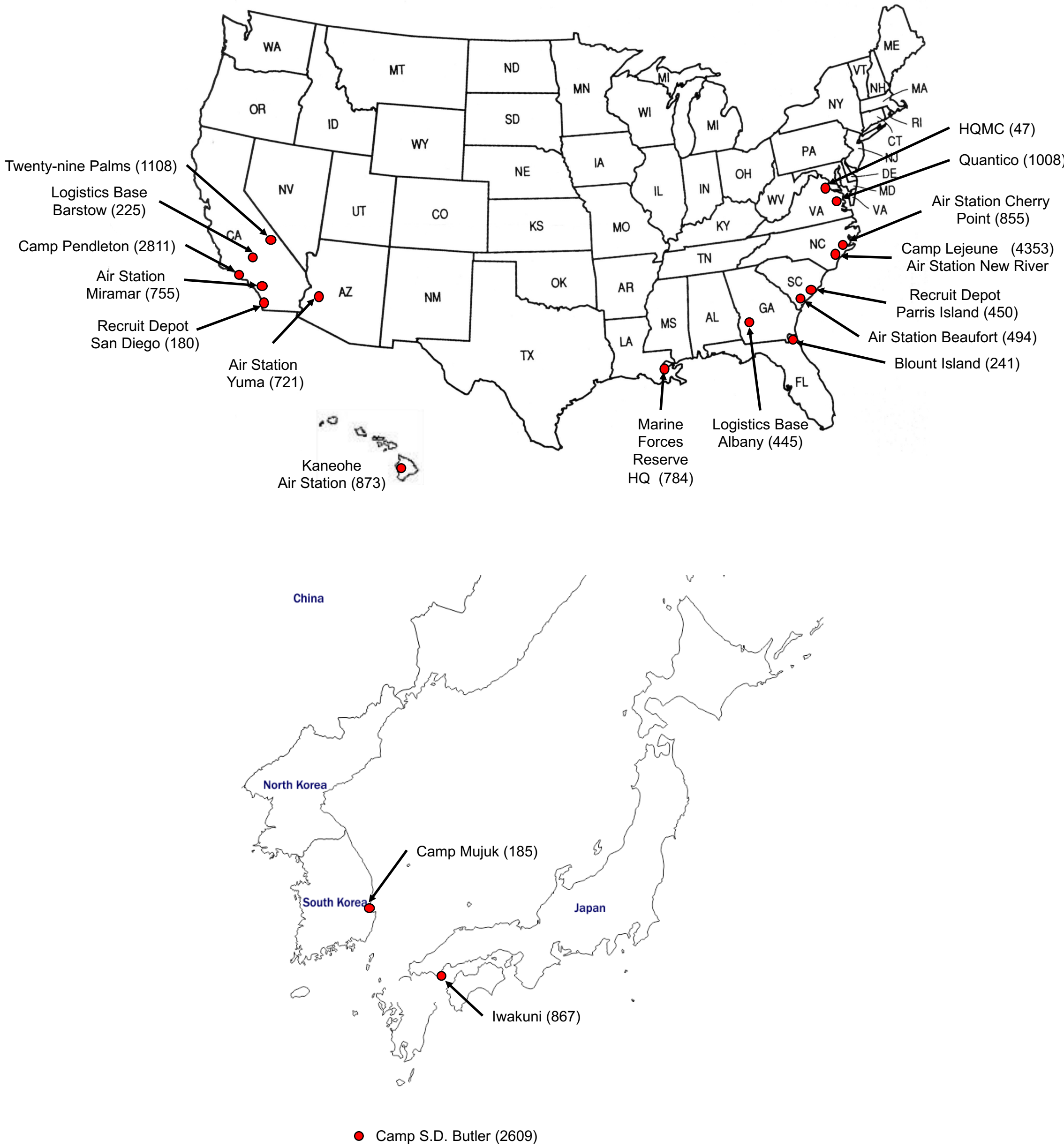


Figure 9. Graphical Distribution of Data Facilities among USMC Installations. Adapted from: Passport Status (2019).

As the data are too voluminous to publish in this thesis, we describe the data with summary statistics and examples. Each facility is identified by a unique 12-digit Facility ID number following the three-letter Naval Facility Asset identifier (e.g. NFA100000093301, a supply facility at MCRD San Diego). The USMC divides facilities into the five regions (MCINCR, MFR, MCIEAST, MCIWEST, and MCIPAC), and eight

Facility Activity Categories: 1—Operation & Training; 2—Maintenance & Production; 3—Research, Development; Test, and Evaluation; 4—Supply; 5—Hospital & Medical; 6—Administrative; 7-Housing & Community; and 8-Utility & Ground Improvements. Data for each facility includes total square footage, current FCI and MDI, estimated demolition cost, estimated recapitalization cost, FSM sustainment calculations, and heritage asset code. The DoD tracks historical significance with 10 heritage asset codes: 1-Building (non-multi-use); 2-Multi-use building; 3-Structure (non-multi-use); 4-Multi-use structure; 5-Monument/memorial; 6-Cemetery; 7-Not a heritage asset; 8-Site; 9-Object; and 10-No Data (Naval Facilities Engineering Command [NAVFAC], 2008). For this thesis, we consider only facilities with asset codes 7, 10, or no asset code as contenders for demolition. This assumption results in only 854 facilities that are not candidates for demolition.

The following details the initial assumptions used to define the remaining data IROM requires:

- The data list 45 of these facilities as "Not Mission Dependent" with MDI anywhere from 14–96. Because of the inconsistency between MDI and the labels, rather than rely on a binary categorization of "Mission Critical" or "Not Mission Critical," following MCICOM direction, we divide the MDIs into three tiers using the scale: 0–20 Tier III, 21–60 Tier II, and 61–100 Tier I.

- We set the linear degradation factor (deg_f) to 1% annually for all facilities. Past models used by the USMC followed an assumption that if a facility is sustained to 100% of its FSM, then the facility sees no degradation. One can easily adjust this factor to any level.

- Lacking specific target data, we do not set values for constraint sets (4) minimum overall sustainment, (5) minimum sustainment spending per facility, (6) regional restrictions on sustainment funding, (18) & (19) restrictions on demolition allotments per installation, and (20) & (21) restrictions on recapitalization allotments per installation.

- Following the Marine Corps' Facilities Investment Plan FCI average goals, we increase mmf_{my} yearly by 10, for each MDI tier, starting at Tier I - 40, Tier II - 30, and Tier III - 40, until we reach Tier I - 80, Tier II - 70, and Tier III - 60 (Dunford 2015).

- Square footage data concerning MILCON and O&M funded projects was unavailable for this thesis. Thus, constraint set three does not consider new MILCON square footage when hitting yearly facility reduction goals of 11 MSF by 2023 and 31 MSF by 2028. As a result, the total demo required may underestimate the true goals. For the cascading block implementation, we average the required demo square footage across the first four years (2019-2022) and across the last six years (2023-2028), based on only using data of roughly two thirds of all the facilities. Thus, demo goals are reduced to 1,815,000 for each of the first four years (2019-2022), and 2,200,000 for the last two years of the POM (2023-2024). For the monolithic implementation we target 7,260,000 MSF before 2023, and 11,660,000 MSF before 2025.
- We keep FSM output constant throughout the six-year POM. While this is a simplification since the FSM increases slightly in future years, the increase within a single POM cycle is negligible.
- As a facility degrades, the cost to restore it to a FCI of 100 increases proportionally. For simplicity, we keep RECAP constant throughout the six-year POM, and leave modeling for the interaction between degradation and RECAP for future work.
- Initial budgetary levels follow 66% the FY19 President's Budget Submissions for these facilities to account for the reduced number of facilities in our data set: Demo budget: $51 million, Sustainment: $458 million, FSRM: $41 million (Operation and Maintenance Marine Corps 2018).

In the rest of this chapter, we explore two scenarios. The first being how much the MCICOM budget (each lever of investment) must be adjusted from the current values in order to achieve the specified facility condition and demolition goals set by the USMC and congress. Next, we determine how close to the targets MCICOM can get with a fixed budget.

B. FIXED BUDGET RESULTS

The first implementation answers the question of how close can the USMC get to its target goals while adhering to the current fixed budget? Using the monolithic approach, IROM produces a solution within 3.57% of optimal in 35.2 hours. We get a lower bound of -21,328,800,000 for the optimal solution, and an upper bound of -20,568,300,000. Our cascading block implementation reaches a solution of -28,015,741,938 in 3.14 hours. We sacrifice substantial optimality with the cascading block approach but do save over 32 hours of computing time. For the remainder of this analysis we report the monolithic results.

We see decreased FCIs across the board of mission dependencies due to constrained resources. The budget is fully used every year, however, IROM is unable to meet the demolitions goals by over 1.2 MSF because of the limited funds. The fixed budget only results in the demolition of 172 facilities. Figure 10 shows the resulting facility FCI distribution by mission dependency tiers. Less than 2% of facilities are left as failing (FCI < 60). Q2 and Q3 each make up 23% of all facilities, and Q1 facilities are nearly 49%. Overall, the number of Q1 facilities increases by only 13.1%, the number of Q2 and Q3 facilities decrease by 18% and 10% respectively, and the number of Q4 facilities (our target population for demolition) actually increases by 52%. The limited budget allows for minimal change or improvement from the current facility condition distribution.

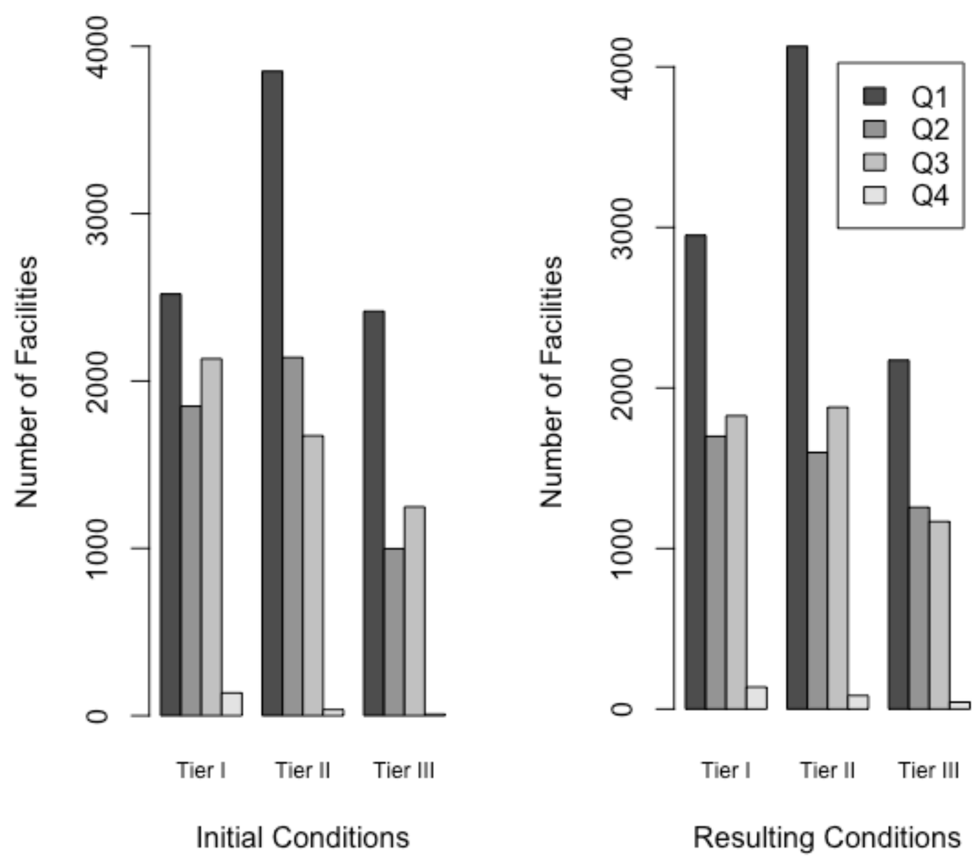


Figure 10. Resulting Facility Condition Distribution by Mission Dependency Tiers with Fixed Budget

When we look at the results broken down by region, we see that the numbers, once again, do not change drastically from the initial distribution (Figure 11). The biggest change happens in the PAC region, where the number of Q1 facilities increases by nearly 37%. To get this result, IROM still chose to forgo the more decrepit Q3 and Q4 facilities, and instead focus on restoring nearly half of the Q2 facilities in that region.

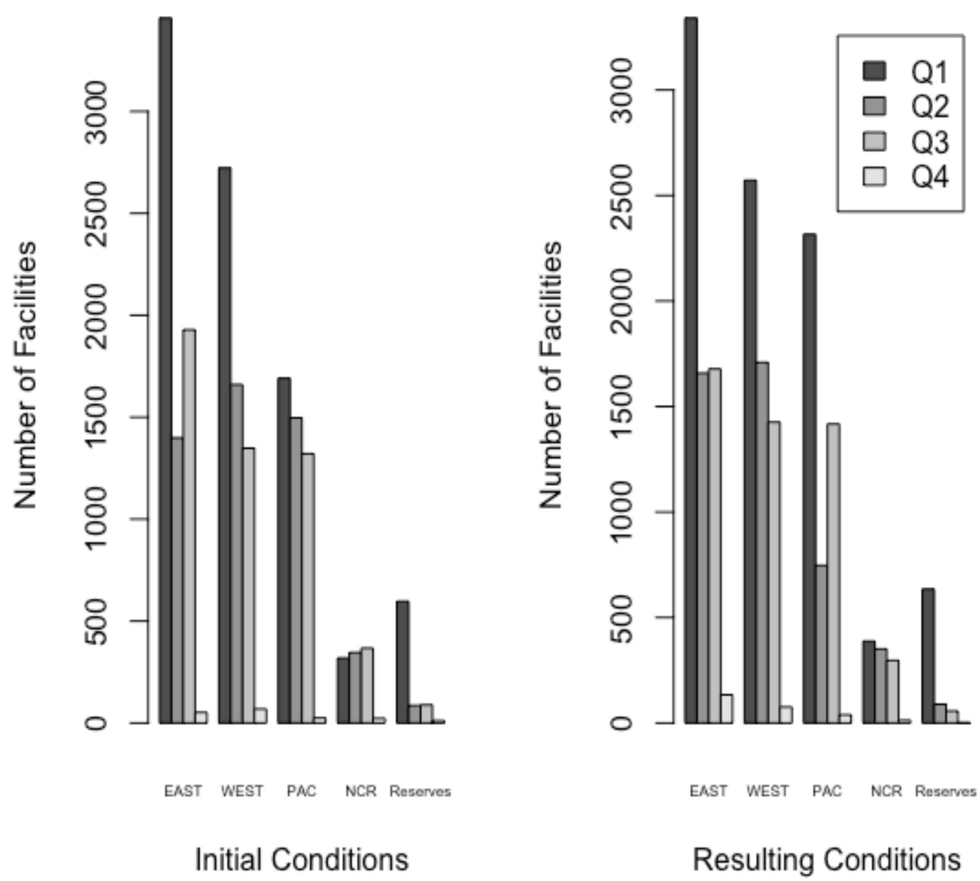


Figure 11. Comparison of Initial and Resulting Facility Condition Distribution by Region with Fixed Budget

Our results confirm what one would expect given a fixed budget. With minimal ability to manipulate any of the four levers of investment, MCICOM is forced to spread finite dollars across a widely degraded facilities inventory. IROM has minimal impact on improving readiness when constrained by the current budget.

C. FIXED FCI RESULTS

The second iteration seeks to answer the question of how much increase in budget the USMC requires in order to reach the FCI targets set forth by Congress and its campaign plans? After 24.3 hours running the monolithic approach, we get a lower bound of 459,480,511 for the optimal solution, and an upper bound of 478,686,796. Our cascading block implementation reaches a solution of 454,691,737 in 5.6 hours; nearly within 5% of optimal. We save 18.7 hours of computing time through the cascading block approach and sacrifice less than 1% of our optimality. For the remainder of this analysis we use the cascading block results. Having a flexible budget allows IROM to reach every facility condition and demolition goal we set. Figures 12 and 13 shows the significant increase in Q1 facilities for Tier I and Tier II facilities, as well as the eradication of all Q4 failing facilities.

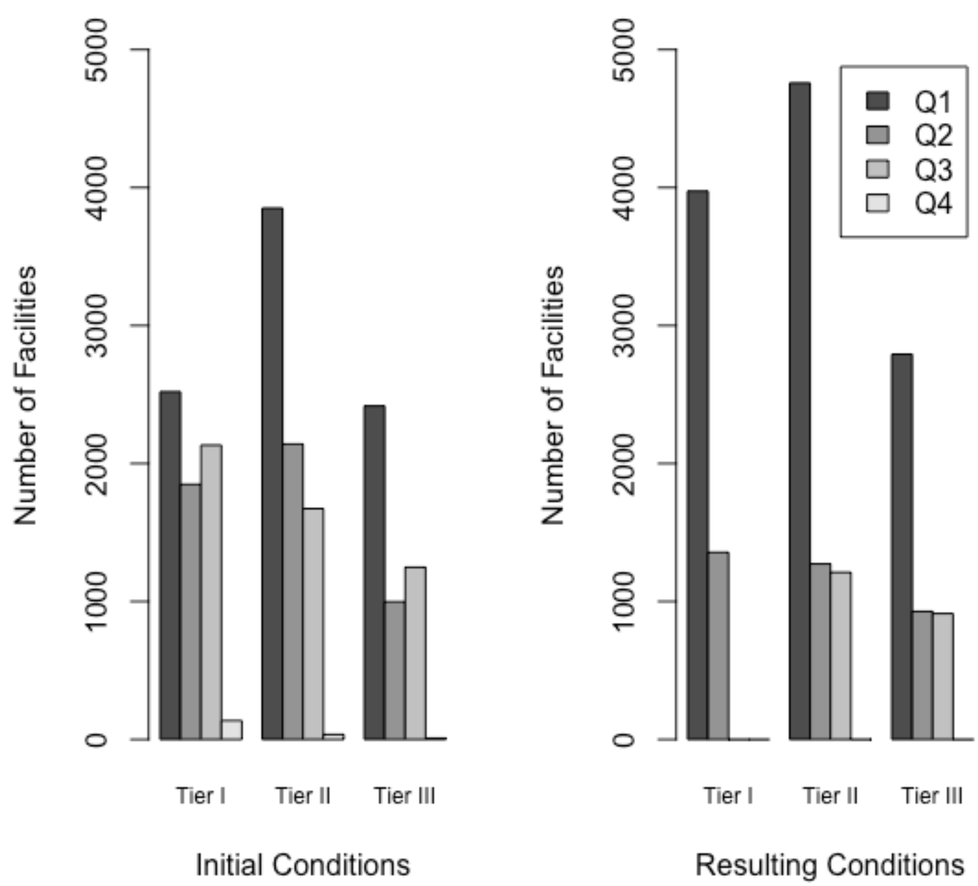


Figure 12. Comparison of Initial and Resulting FCI Distribution by Mission Dependency Tiers with Elastic Budget

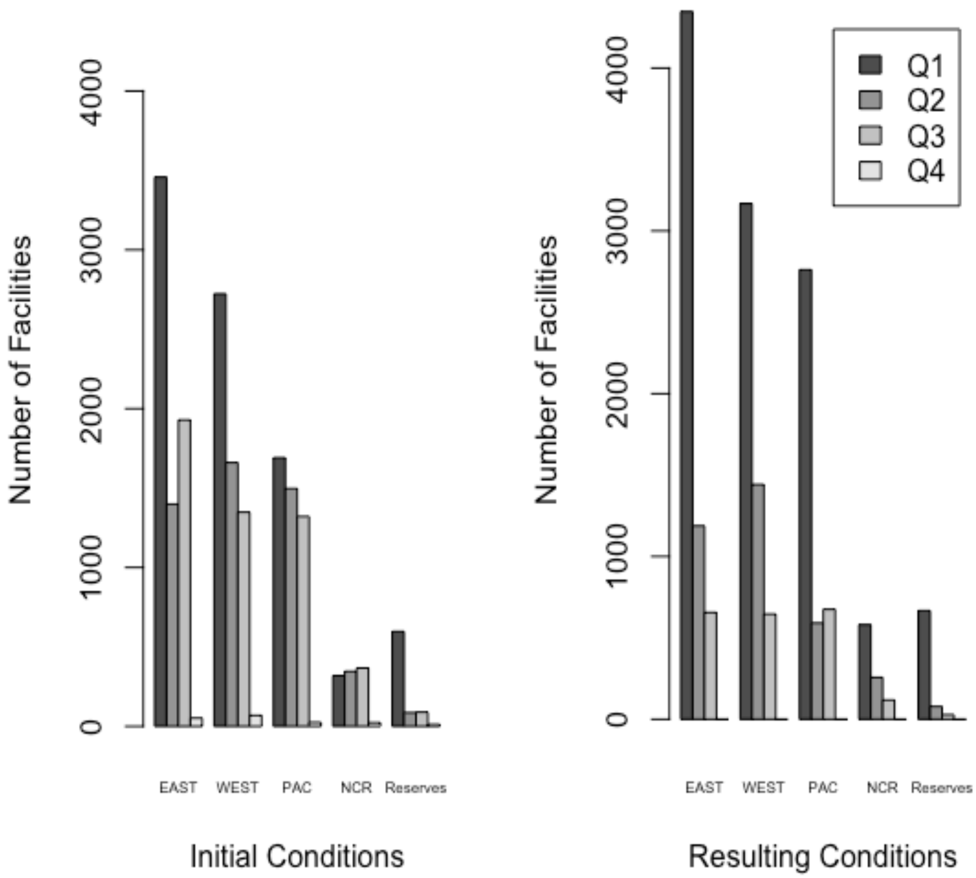


Figure 13. Comparison of Initial and Resulting FCI Distribution by Region with Elastic Budget

As expected, this increase in facility condition across MCICOM's inventory is not without a steep budgetary investment. In Figure 14, we see that year five significantly exceeds the $550 million budget by more than double at $1.3 billion. Year three is the only other year that exceeds the budget; again, the overdraft is significant at $1.1 billion. These surges are consistent with the demolition and recapitalization efforts in years three and five. IROM's optimal solution shows an increase in the number of demolished facilities in year three, and a smaller spikes in the number of restored facilities in years three and five (see Figures 15 thru 17).

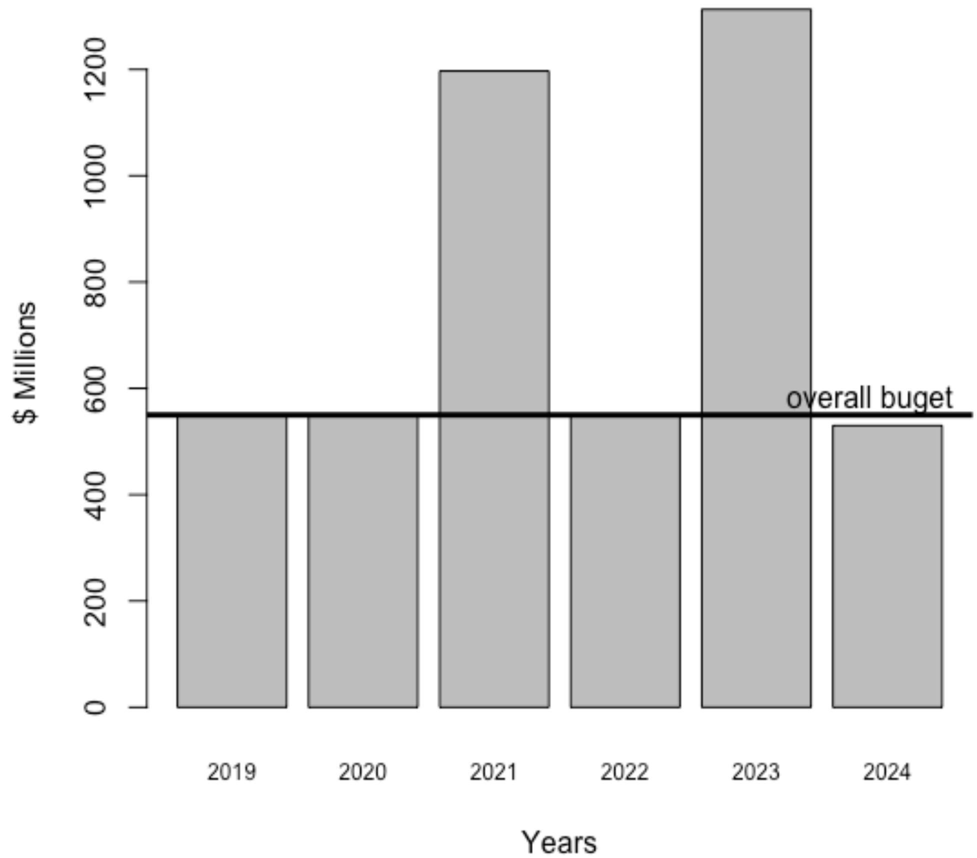


Figure 14. Budget Fluctuations Throughout Six Year POM

At roughly 72%, Tier I facilities made up the greatest proportion of facilities selected for demolition, followed by Tier II at 26%, and Tier III making 2% (see Figure 15). Taking a deeper look at the data, we see that Tier I facilities also make up the greatest percentage of Q3 and Q4 facilities. Tier I facilities make up approximately 43% of Q3/Q4 facilities, while Tier II cover 33%, and Tier III make up 24%. Furthermore, while the cost per square foot to maintain these Tier I facilities is comparable to Tier II facilities, they are almost twice as expensive to maintain per square foot than Tier III facilities. Because of this discrepancy, and the high deviation penalty, IROM chooses to sacrifice the high MDI of Tier I facilities in exchange for cheaper Tier III facilities.

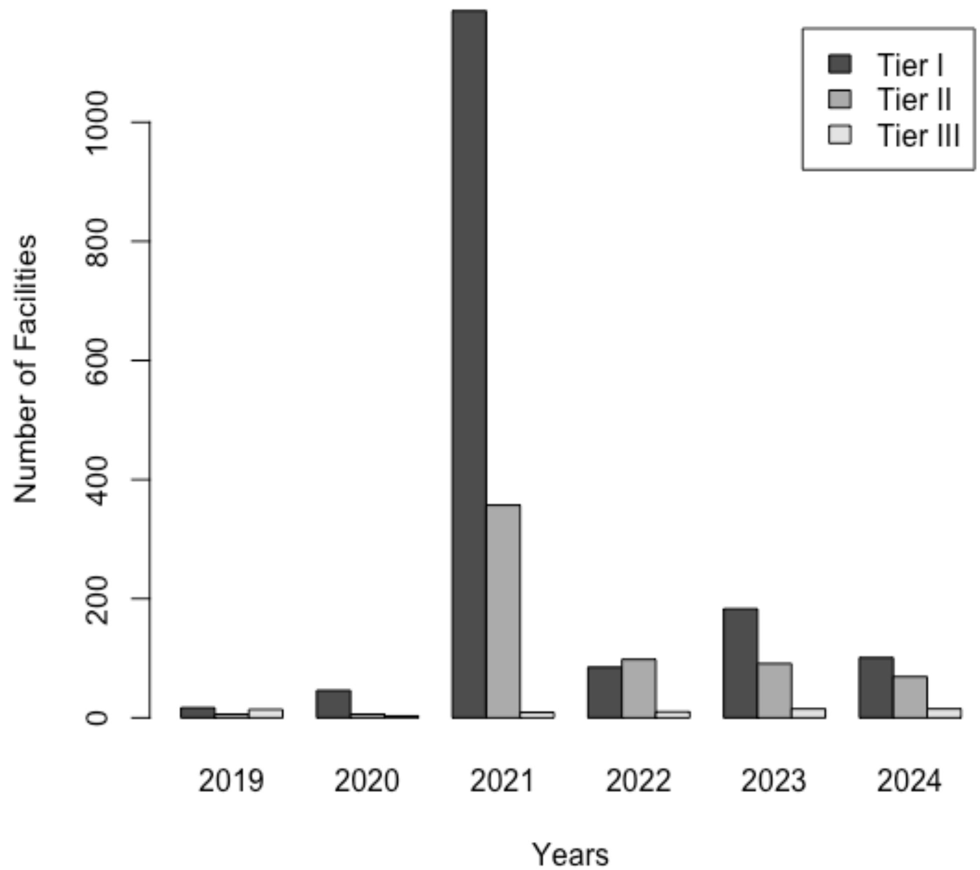


Figure 15. Tier Distribution of Demolished Facilities by Year

While IROM chooses to demolish a number of Tier I facilities, Figure 16 shows that the majority of these facilities are Q3/Q4, which are the facilities one would expect to be demolished because they are in the worst shape. Adjusting the deviation penalty parameter impacts the distribution of demolished facilities based on how important the budget is to the user. Furthermore, this parameter can influence IROM's solution based on which criteria IROM deems more important, mission dependency or facility condition.

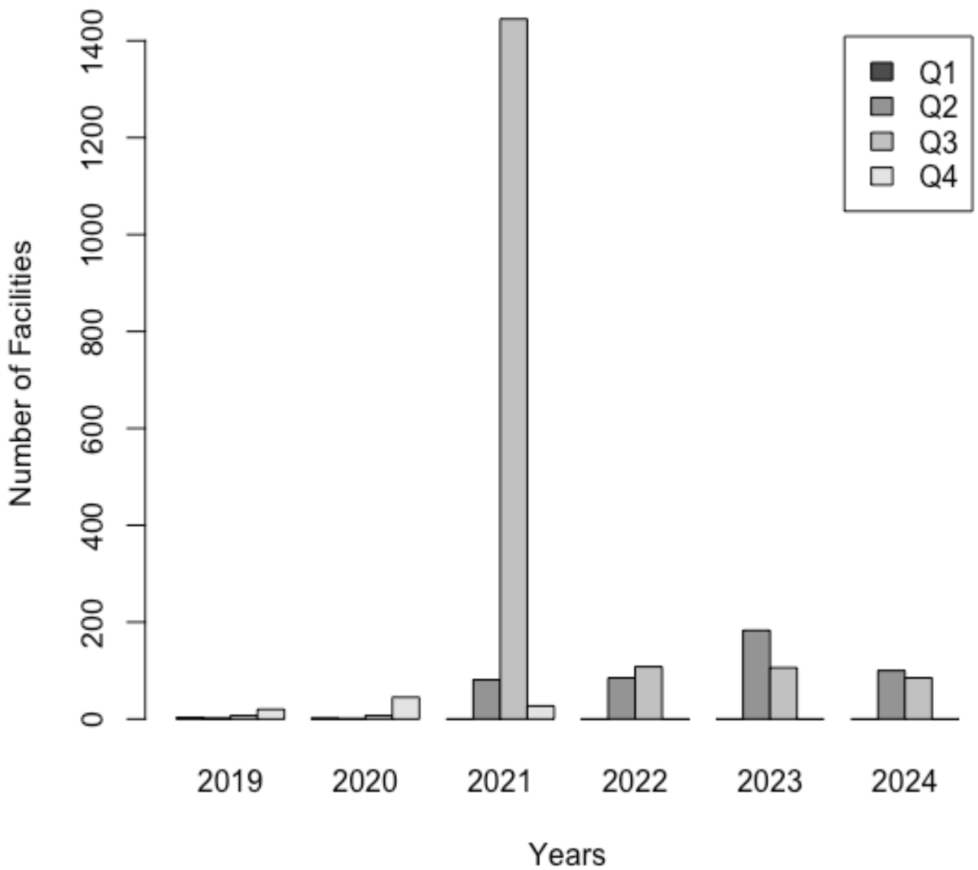


Figure 16. FCI Distribution of Demolished Facilities by Year

To reduce the significant annual budget fluctuations, we re-run IROM with an additional constraint that sets an upper bound of $350M for the budget deviation. With this implementation we manage to hit all our FCI goals by year, but we demolition significantly more than our goal. The 2297 demolished facilities cover more than 54.9 MSF, more than 4.5 times the target. In contrast to the Tier I heavy distribution of demolished facilities, Figure 17 shows that those selected for restoration are more evenly spread across all three mission dependency tiers, but still with greater influence on Tier I and Tier II. The higher restoration efforts in the initial years are most likely due to the minimum FCI requirement goals for those years (30 and 50), indicating that the current populations of these tiers are in worse conditions than our less mission dependent facilities. USMC facilities require a significant investment in the next few years simply to get facilities above a failing condition index. In order to get the USMC inventory up to par, the government must invest a significant amount up front.

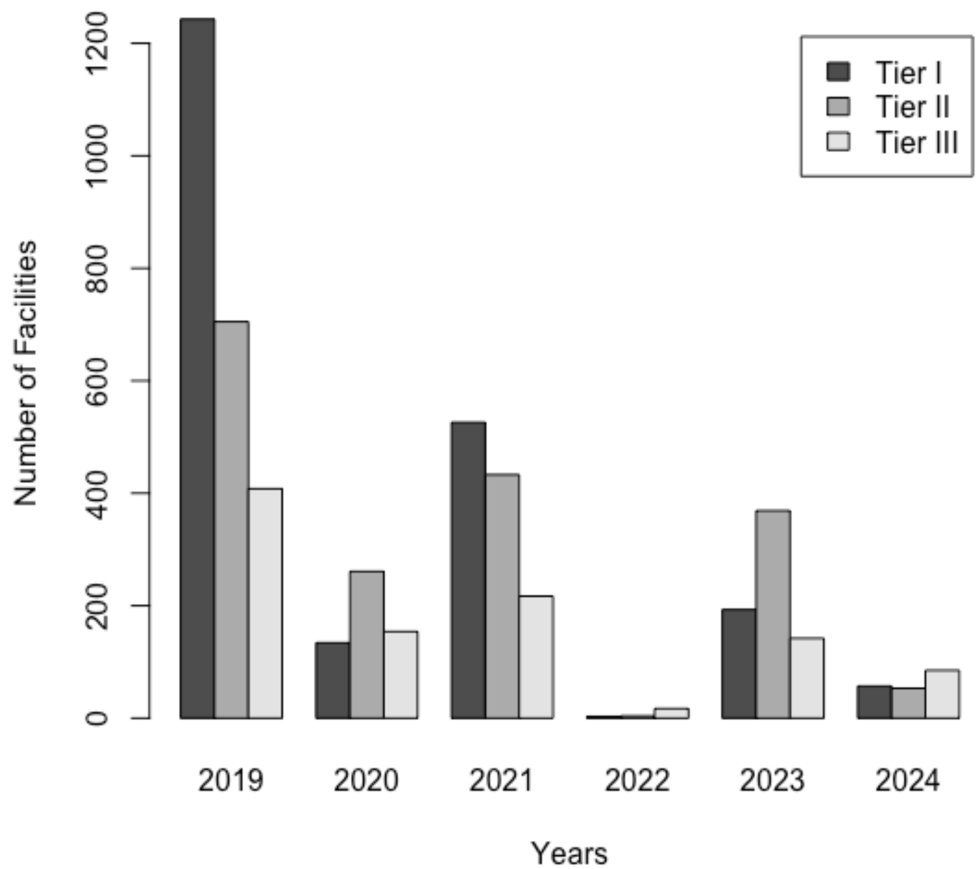


Figure 17. Number of Restored Facilities by Year

Increasing the budget from the start will decrease the yearly fluctuations across the entire POM. Figure 18 shows the USMC requires roughly 1.5 times its current annual budget to reach its FCI and demolitions goals within the next six. It is important to note that this $230 million is based on a facilities inventory that is only roughly 2/3 of the USMC's actual inventory, indicating that the required increase in funding is even greater. With an evenly distributed budget, the restoration and demolition spikes also flatten out more evenly across the six-year POM.

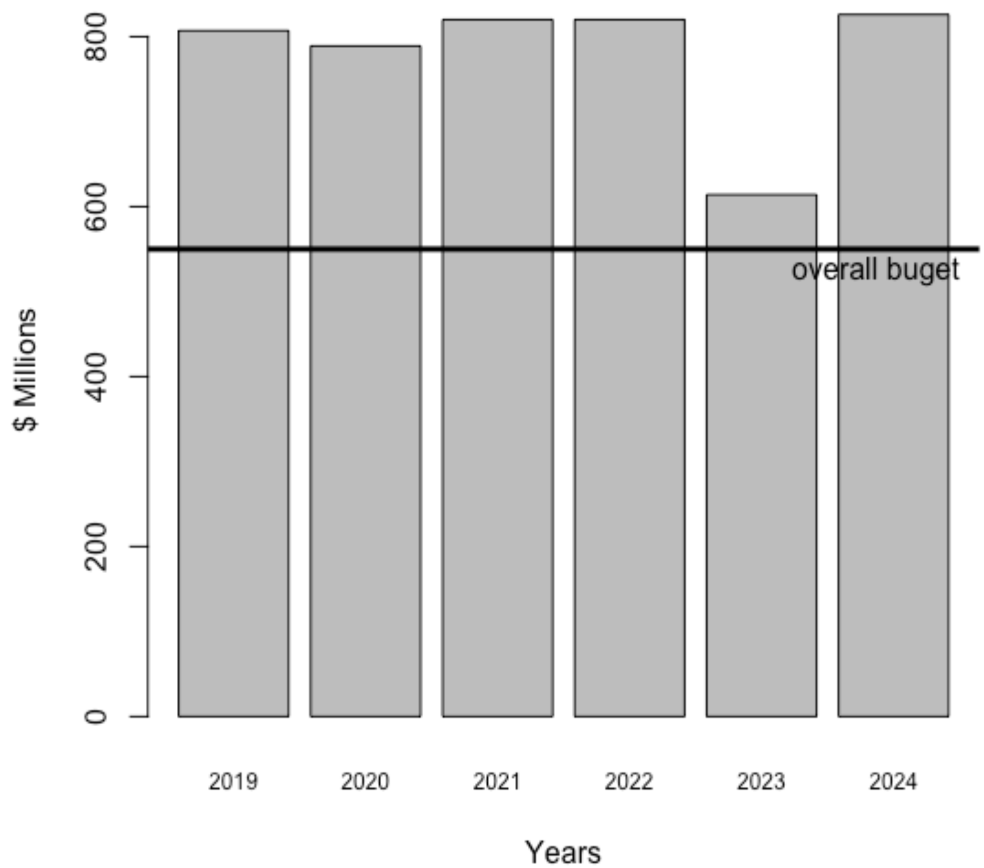


Figure 18. Reduced Spending Fluctuations

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V. CONCLUSION AND FUTURE RESEARCH

MCICOM requested NPS assistance in the development of an optimization tool capable of providing analytical justification for budget requests. IROM allows the user to change input values and factors to reflect Marine Corps policies and campaign plans which assist in recommending financial expenditures. IROM helps to balance yearly funding requirements with optimal installation readiness. By specifying levels of sustainment, demolition, and restoration, IROM assists in developing budget allocations across the regions to support campaign planning.

IROM shows that under the current budgetary constraints, MCICOM has little ability to improve installation readiness by manipulating the four levers of investment. MCICOM requires a budget of roughly one and half times its current annual value to improve installation readiness to the minimum target levels set forth by the IR strategy.

A. FUTURE RESEARCH

Due to the availability of data, we are unable to incorporate new MILCON into our calculations. Using the projected square footage of approved MILCON will legitimize the force size reduction through demolition. Furthermore, we set constant values for certain parameters in an attempt to simplify the initial problem. By incorporating changing sustainment and restoration costs over the years based on facility condition, one can gleam a more accurate picture of budgetary requirements. Modifying the degradation function from linear to piece-wise linear will more accurately portray the true degradation of facilities. MCICOM is developing a configuration index, which augments the FCI and better presents a facility's usefulness. Once implemented, using this configuration index will allow IROM to better align with campaign and mission requirements. Finally, IROM focuses solely on sustainment, restoration and modernization, demolition, and military construction. The overall activity group of Operation and Maintenance of Operating Forces includes a substantial budget for Base Operating Support (BOS). This sub-activity group is closely linked with installation readiness, and future work should look to incorporate BOS investment funding. Finally, further exploration should be done with setting limits on the number of facilities that can be demolished and restored at each installation (set values for constraint sets 18 through 21) to see how USMC campaign planning impacts installation budgeting.

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   Naval Postgraduate School
   Monterey, California