Assessing the Need for Supercomputing Resources Within the Pacific Area of Responsibility

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Preface

The Department of Defense's High Performance Computing Modernization Program (HPCMP) develops supercomputing resources and expertise to support the Department's research, development, test and evaluation (RDT&E). Originally managed by the Office of Secretary of Defense (OSD), the HPCMP was transferred from OSD to the Army in fiscal year (FY) 2012. This transfer was accompanied by a reduction in funds: In FY12, the program was provided with $183 million, which represented roughly a $40 million reduction when compared with the previous fiscal year. Since then, Congress added funding to the HPCMP to ensure continuity with pre-FY12 funding levels.

In fall 2014, Congress asked the Department of Defense to begin thinking about a longer-term solution to this problem. In response to this request, the Army submitted a report that offered several courses of action for closing the budget gap, which ranged from eliminating two of the program's five centers to reducing research investments in network and software development.

To help prepare for this decision, the Air Force Research Laboratory (AFRL), which manages two of the five computing sites, asked RAND to perform research on one of these two sites, the Maui High Performance Computing Center (MHPCC). Specifically, AFRL asked RAND to assess the computational requirements of Pacific area of responsibility government entities, notably U.S. Pacific Command, with respect to supercomputing assets and capabilities. The findings and recommendations contained within this report are designed to provide AFRL with important context about potential future missions and use cases for MHPCC as Congress, the Army, and AFRL decisionmakers work toward a budget gap resolution. The research does not attempt to pass judgment as to how well MHPCC supports the existing HPCMP RDT&E mission, nor does it offer a detailed appraisal of the greater HPCMP's mission, utility, and cost-effectiveness.

This research was commissioned by Dr. David Hardy, Director, Air Force Research Laboratory Directed Energy Directorate, and was conducted by the Force Modernization and Employment Program of RAND Project AIR FORCE. This report represents the deliverable to the FY15 project, "Assessing the Business Case for the Maui High Performance Computing Center." This report should be of interest to researchers and policymakers who are thinking about the future of supercomputing within the Department of Defense.

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Contents

Figures

Table

x

Summary

Located in Kihei on the island of Maui, Hawaii, the Maui High Performance Computing Center (MHPCC) was established in 1993 as a center within the Department of Defense's (DoD) High Performance Computing Modernization Program (HPCMP). As one of the five HPCMP centers, MHPCC's primary mission is to provide computing cycles and other high performance computing (HPC) capabilities to DoD's research, development, test and evaluation (RDT&E) community. DoD scientists and engineers from around the world utilize MHPCC's hardware, software, and technical talent to develop and support war-fighting capabilities. Currently, MHPCC's largest machine, Riptide, represents 3 percent of the total computing cycles across the HPCMP enterprise in support of this broader mission.[1] MHPCC is managed by the Directed Energy Directorate within the Air Force Research Laboratory (AFRL), which oversees the site's annual operating budget of $14 million and supports about 50 personnel.

In the fall 2014, Congress asked DoD to begin considering ways to cut about $45 million from the HPCMP so future fiscal years could be supported entirely by the Army's programmed budget of $183 million. Findings within this report are designed to provide AFRL decisionmakers with important context about potential future missions and use cases for MHPCC as Congress, the Army, and the HPCMP work toward a solution for resolving the budget gap.

To help provide AFRL with this context, we sought to answer the following research questions: Which of MHPCC's capabilities are used most often by customers in the Pacific area of responsibility (AOR), notably U.S. Pacific Command (PACOM)? And, specifically, is there a demand for a supercomputing resource that is located within the AOR? What recommendations should AFRL consider when making decisions about the future of MHPCC?

We adopted a three-step approach to gather the data necessary to address these questions. We began by reviewing all of the existing documentation about MHPCC. After performing this background research, we also met with HPC experts to learn about trends within both the government and commercial markets. As a final step, we met with key principals within the Pacific AOR to learn about their mission needs and future visions. Our goal during these interviews was to determine how HPC assets are currently being used to achieve these goals.

After gathering all of these data, we identified common themes and outliers, and we made a list of key findings. Specifically, our research allowed us to make the following observations:

- There is a consistent lack of understanding among the customer base as to what problems are suitable for a supercomputer or HPC assets, in general.

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[1] DoD HPC Modernization Office personnel, phone interview with author, December 18, 2014.

- While several entities within PACOM offered a stated preference for a supercomputing facility within the geographic region, we were unable to identify any entity within the Pacific AOR with a quantitative requirement for real time supercomputing. In the absence of such a requirement, we did gather anecdotal evidence for the value that PACOM users receive by having HPC expertise within the AOR.
- PACOM users value MHPCC's ability to stand up and support custom servers. These users also value MHPCC's resident expertise in programming for HPC architectures.
- MHPCC and AFRL's Maui optical observatory both benefit from being co-located.

Based on these findings, our research resulted in the following six recommendations for AFRL:

- **Be explicit about the different capabilities resident at MHPCC.** Potential users need to be aware of what MHPCC has to offer, what reach back is available from other entities within the HPCMP enterprise, and, if appropriate, what other services are available outside the HPCMP.
- **MHPCC should market itself as offering three separate products:** (1) a large, 12,096-node supercomputer; (2) a facility that has the expertise and infrastructure to host standalone HPC assets; and (3) a research staff with the capacity to develop creative solutions to operational problems. Presenting MHPCC as a center that offers separate products will allow for a more-tailored approach to solving customer problems.
- **Provide PACOM users with a framework for matching HPC assets to the desired workflow.** HPC is inherently technical, and PACOM customers need simple frameworks to understand how their problems fit into the greater context.
- **Employ both strategic and technical thought leaders to enhance Pacific AOR customer exploitation of MHPCC capabilities**. Both components are important. The strategists need to identify areas where Pacific AOR users might benefit from HPC capabilities, and the strategists need to work with the subject-matter experts to help them develop future requirements for HPC assets.
- **Rebuild trust and understanding with the HPCMP leadership**. Reestablishing trust always takes time, but MHPCC management can take some initial steps by setting up consistent communication with HPCMP leadership.
- **Recognize that aspects of the computing enterprise are changing. Develop a strategy to prepare for this change**. As computing cycles become more of a commodity, it will be more important than ever to develop a value proposition that focuses more on MHPCC's human capital and is not tied to hardware alone.

Acknowledgments

Abbreviations

AFRL	Air Force Research Laboratory
AMOS	Air Force Maui Optical and Supercomputing Site
AOC	Air Operations Center
AOR	area of responsibility
ARL	Army Research Laboratory
CMSA	cruise missile support activity
COTS	commercial-off-the-shelf
CPU	central processing unit
DoD	Department of Defense
DoE	Department of Energy
DREN	Defense Research and Engineering Network
DSRC	DoD Supercomputing Resource Center
ERDC	U.S. Army Engineer Research and Development Center
FTE	full-time equivalents
FY	fiscal year
GB	gigabyte
HPC	high performance computing
HPCMP	High Performance Computing Modernization Program
ISRD	Intelligence, Surveillance, and Reconnaissance Division
kWh	kilowatt hour
MHPCC	Maui High Performance Computing Center
MPP	massively parallel processor
OSD	Office of the Secretary of Defense
PAC	Pacific
PACAF	Pacific Air Forces

PACOM	United States Pacific Command
PB	petabyte
PMRF	Pacific Missile Range Facility
RDSM	Research and Development Site, Maui
RDT&E	research, development, test, and evaluation
RSO	Range Safety Office
SES	Senior Executive Service
TB	terabyte
UUV	unmanned underwater vehicle

1. Introduction

The Department of Defense's (DoD) High Performance Computing Modernization Program (HPCMP) was started in 1992 with the purpose of developing supercomputing resources and expertise to support DoD's research, development, test, and evaluation (RDT&E) community. From its inception to 2011, the HPCMP was managed by the Office of the Secretary of Defense (OSD), and represented a $220 million annual program element within the OSD budget.[2] Starting in fiscal year (FY) 2012, HPCMP was transferred to the Army, which assigned the program to the Army Corps of Engineers Research and Development Center for oversight and execution.[3] However, this transfer from OSD to the Army was also accompanied by a reduction in funds: In FY12, the program was provided with $183 million, a $37 million shortfall when compared with the previous fiscal year.[4] Since then, Congress has increased funding each year over the President's request by approximately $45 million to ensure continuity with pre-FY12 funding levels.

In fall 2014, Congress asked DoD to begin thinking about a longer-term solution to this problem. Specifically, DoD was asked to consider the effect on HPCMP if it was funded only at the President's budget request of approximately $185 million a year. In addition, Congress asked for a strategy to close this gap in future years.

In response to this request, the Army submitted a report to Congress in January 2015 that summarized the high performing computing (HPC) program and highlighted its value to the entire defense enterprise. The report also lays out a selection of courses of action that decisionmakers can take in order to close the $45 million budget gap. The options range from eliminating two of the program's five supercomputers to reducing research investments in network and software development to eliminating 30 Ph.D.-level experts currently in residence at DoD labs.[5] As of the date of this report, Congress has not yet responded with a budget decision.

Research Objective and Approach

In light of this background, the Air Force Research Laboratory (AFRL) asked RAND to evaluate the capabilities, challenges, and future options for one of the HPCMP's supercomputing sites it manages, the Maui High Performance Computing Center (MHPCC). This report, which

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[2] Department of the Army, *Report to Congress: High Performance Computing Modernization, Headquarters*, January 2015.

[3] Air Force Research Laboratory/Research and Development personnel, phone conversation with author, June 3, 2014.

[4] Department of the Army, 2015.

[5] Department of the Army, 2015.

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summarizes our research method, key findings, and recommendations, is designed to provide AFRL decisionmakers with important context about MHPCC as Congress, the Army, and the HPCMP work toward resolving the budget gap.

To help meet this objective, we sought to answer the following research questions: Which of MHPCC's capabilities are used most often by customers in the Pacific area of responsibility (AOR), notably U.S. Pacific Command (PACOM)? And, specifically, is there a demand for a supercomputing resource that is located within the AOR? What recommendations should AFRL consider when making decisions about the future of MHPCC?

We adopted a three-step approach to gather the data necessary to address these questions. We began the project by searching for and reviewing existing documentation about the MHPCC, its capabilities, and the customer base.[6] We paid particular attention to materials that provided historical context about how HPCMP and MHPCC got to where they are today. We also met with experts both internal and external to RAND to learn about the trends within the HPC community and the broader computing industry.[7]

Once we understood the basics about the site's capabilities and HPC in general, we met with MHPCC personnel to gain a more-nuanced understanding about the site's existing resources, customers, and current challenges.[8] We also met with HPCMP office personnel to get their perspective on the entire program, along with how MHPCC fit into it.[9]

As a final step in the data-gathering process, we met with key principals within the Pacific AOR to ask about their current mission needs, along with their future vision and strategy for achieving that vision. Our goal during these conversations was to help identify how HPC assets are currently used—or might be used in the future—to achieve these goals. We were also interested in ways AFRL could derive value from MHPCC beyond its HPCMP's RDT&E mandate. To that end, we had interactions with both senior leaders and technical experts within Pacific Air Forces/A2, United States Pacific Command/J8, United States Pacific Command/J9,

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[6] Charles C. Holland, *Maui Report*, Pittsburgh, Pa.: Carnegie Mellon University, July 2012; DoD High Performance Computing Modernization Program, "DoD High Performance Computing Modernization Program: Portal Program," presented May 13, 2014a, not available to the general public; Clifford E. Rhoades, "Defense Research and Engineering Network (DREN) Hawaii Overview," for Hawaii Intranet Consortium, presented January 20–22, 2015, not available to the general public; MHPCC/DSRC, *Quarterly Status Report,* July 1–September 30, 2014a, not available to the general public; DoD HPCMP, *CREATE Quarterly Update*, October 2014b, not available to the general public; DoD HPC Modernization Office, *Insights*, fall 2014; AFRL-MHPCC, "Top 10 Projects—FYTD14," Excel spreadsheet received via email on November 3, 2014, not available to the general public.

[7] Jim Brase, in-person discussion with the author at the RAND Corporation, Santa Monica, Calif., December 5, 2014; Jim Brase, phone discussion with the author from Santa Monica, Calif., to Lawrence Livermore National Laboratory, March 3, 2015; AFRL personnel, in-person discussion with the author in Arlington, Va., December 11, 2014; DoD HPCMP personnel, phone discussion with the author, February 15, 2015; Lawrence Livermore National Laboratory personnel, phone discussion with author, February 26, 2015.

[8] MHPCC personnel, phone discussion with author, July 14, 2014a; MHPCC personnel, in-person discussion with author, October 27–28, 2014b.

[9] DoD HPC Modernization Office personnel, phone interview with author, December 18, 2014; DoD HPCMP personnel, 2015.

the AFRL optical observatory on Maui, the Pacific Missile Range Facility (PMRF), and the Defense Intelligence Agency.[10]

After the data-gathering phase of the research, we summarized the key points from each discussion, and we started looking for common themes and outliers. We compiled a list of key findings, which are summarized in this report. However, we first need to provide some additional context on nomenclature, MHPCC, and two key factors that set some boundaries for MHPCC's future options.

Supercomputing Defined

One of the challenges of working on this topic is that there are different lexicons used to describe HPC. For the purpose of this report, we define three categories of computing assets: standalone computers, cluster computers, and supercomputers.

We define *standalone* machines as conventional commercial-off-the-shelf (COTS) boxes that are deployed in standard business, scientific, or personal settings. Standalone machines can certainly be very powerful, but their defining characteristic is that they are off-the-shelf consumer parts that utilize existing software packages for solving general computing tasks.

We will use the term *cluster computer* to refer to loosely coupled collections of computers— typically COTS grade or higher—that are architected to work on computational problems in concert. Clusters are best suited for problems with subparts that can be solved in parallel, for example, when searching a large database for records satisfying a particular condition. To solve this, the database can be divided into smaller shards that are distributed to many nodes, and each node performs the search in parallel with the rest. The desired records are then collected after the parallel searches are completed. However, during the time that the search is being performed on each shard, none of the nodes has reason to communicate with one another.

We based our use of the term *supercomputer* on a convention set by Dongarra and reflecting trends highlighted by Bell in the ranks of top-performing HPC assets.[11] Supercomputers are

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[10] Pacific Air Forces (PACAF) A2 personnel, in-person discussion with author, October 27, 2014; PACOM/J8 personnel, in-person discussion with author, October 27, 2014; PACOM/J8 personnel, phone conversation with author, March 12, 2015; 613 AOC personnel, in-person discussion with author, October 27, 2014; Defense Intelligence Agency personnel, in-person discussion with author, October 27, 2014; PACOM/J9 personnel, in-person discussion with author, October 27, 2014; Pacific Missile Test Range personnel, in-person discussion with author, October 28, 2014; Pacific Missile Test Range personnel, in-person discussion with author, January 26, 2015; Pacific Missile Test Range range safety personnel, phone conversation with author, March 3, 2015; PACOM/J8I personnel, phone conversation with author, January 30, 2015; AFRL/RDSM personnel, ongoing email discussion with authors, March 30–April 16, 2015c.

[11] Gordon Bell and Jim Gray, "What's Next in High-Performance Computing?" *Communications of the ACM*, Vol. 45, No. 2, 2002, pp. 91–95; Jack Dongarra, Thomas Sterling, Horst Simon, and Erich Strohmaier, "High-Performance Computing: Clusters, Constellations, MPPs, and Future Directions," *Computing in Science and Engineering*, Vol. 7, No. 2, 2005, pp. 51–59.

custom-designed integrated systems made up of a tight-knit collection of top-grade cores.[12] Supercomputers include low-latency parallel clusters, massively parallel processors (MPPs), and some descendants of vector processing supercomputers.

Supercomputers excel at problems where subtasks need to be fed back into the computation. Physics-based simulations are the most-common example of this type of problem: As the model run evolves, the results from the Nth iteration will serve as the boundary conditions for the {N+1}th iteration. To address this need, the computing architecture must offer low latency between the processor and memory elements within the system, so supercomputers (by our definition) are characterized by the use of high-speed, low-latency interconnects among the processor and memory elements.

To our knowledge, most assets within the HPCMP enterprise can be classified as standalone machines and supercomputers, using this definition. However, in order to avoid confusion, we will use the term *high performance computing assets* as a generic way to describe the HPCMP's computing resources when we lack the technical specifications needed to label them with a specific category.

In practice, recent non-standalone assets often fall on a spectrum between cluster computers and supercomputing. This reflects rapid developments in the HPC market in response to an emerging unified demand for both kinds of capability. A lot of modern scientific data analyses (e.g., for CERN's Large Hadron Collider,[13] searches on large genomic databases) require raw data-analytic power typically found in cluster computers. There is a pressing need for assets that can apply complex iterative algorithms to manage the flood[14] of new data from ubiquitous sensors. Thus, the asset classes highlighted here are best thought of more as extremes on a spectrum than as categorical definitions.

Some additional context related to these definitions is shown in Table 1.1.

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[12] A *core* refers to a low-level data-processing element capable of executing instructions independently. This includes traditional cores on multithreaded central processing units (CPUs), graphics processing unit cores, and other programmable hardware or virtual implementation. Core count is a useful index of how many processes a system can run concurrently.

[13] Michael, Schmelling, Markward Britsch, Nikolai Gagunashvili, et al., "RAVEN–Boosting Data Analysis for the LHC Experiments," *Applied Parallel and Scientific Computing*, Vol. 7134, 2010, pp. 206–214.

[14] Isaac R. Porche, Bradley Wilson, Erin-Elizabeth Johnson, Shane Tierney and Evan Saltzman, Data Flood: Helping the Navy Address the Rising Tide of Sensor Information, Santa Monica, Calif.: RAND Corporation, RR-315-NAVY, 2014.

Table 1.1. Comparison of Different Computing Assets

	Standalone	Cluster Computer	Supercomputer
Typical Data Load	Local. Smaller data sets <10GB.	Distributed. Larger data sets GBs to 100s of TB	Distributed. Larger data sets GBs to PBs.
Parallelizability	Mostly sequential. Minimal multithreading (1–16 threads) with poor scalability.	Highly parallelized on up to 100Ks of compute nodes. Often high-latency between nodes. Highly scalable (often dynamically so).	Sequential + parallel workloads. Often parallelized at the processor level. Low latency among 100,000s of cores.
Responsiveness	Small fast systems, suitable for small real-time processing	Large scale can cause slow response. Mostly batch processing.	Large scale but with fast, custom interconnects. Low latency, fast response.
Software Ecosystem	Large market of COTS software. Large expertise pool for custom development.	Dominated by a smaller number of large-scale commercial solutions (Hadoop/Spark). Lots of open source code. Development expertise plenty. Some software monopolies.	Lots of small-scale commercial and bespoke software (MPI/Coarray FORTRAN). Custom hardware demands specialized/rare development tools and expertise.
Typical use cases	Watching a DVD (~1.4GB). Analyses of 3-D medical images (~10GB)	Indexing and ranking "all" worldwide web pages (~30 trillion pages). Training a movie recommendation system using past preferences of millions of users (~40 million users).	Real-world simulation of airflow and turbulence for new aircraft designs. Simulation of in-water wave and keel behavior for sea vessels in design. Simulation of flames and explosions for fuel safety research.

HPC assets are crucial to U.S. defense and technology leadership. The DoD acquisition program relies heavily on computer simulations run on HPCs administered through the HPCMP (formerly under OSD, now under the Army). They are important at each RDT&E phase in the development of frontier technology (e.g., jet engines for the Air Force). HPCs also help guarantee the efficacy of the U.S. nuclear weapons stockpile—helping to maintain the U.S. nuclear deterrence posture in spite of test ban treaties in force. And, going forward, HPCs can be key assets for effectively managing the massive amounts of data involved in cyberwarfare.

2. MHPCC Overview

Located in Kihei, on the island of Maui, Hawaii, the MHPCC occupies two physical locations. We will refer to the main HPC Center as Building 90, and it contains the MHPCC's largest HPC asset. The second facility is nearby (Building 50), which contains offices for the administrative and technical staff, along with secure areas for classified workstations. MHPCC also operates and sustains two small HPC assets.[15] In addition to MHPCC personnel, the administrative building also houses the staff and some support functions for AFRL's optical observatory, which is located on top of nearby Haleakala volcano.

For FY15, MHPCC has a projected operating budget of $14.1 million and supports about 55 personnel.[16] The total operating expenses are shown in more detail in Figure 2.1. The single largest expense is the support of the HPC Center. Half of this $5.0 million is used to pay for labor; the rest is for electricity ($1.1 million), rent ($0.9 million), and the supercomputer's warranty support ($0.5 million). The next largest expense is $3.6 million for common shared services that support software development and HPC Center operations, which includes site management, office equipment, financial reporting, utility servers, the local help desk, water, networking, and outreach. The administration building (Building 50) costs about $2.6 million, and we list this in Figure 2.1 as "combined support to AFRL/MHPCC," because both organizations use this facility. (AFRL pays a commensurate portion of this cost because its observatory personnel reside in this building.) This $2.6 million covers the administration building's lease ($1.0 million) and electricity ($0.6 million), along with security costs and facility maintenance. The remaining slice in Figure 2.1 is $2.9 million, which is devoted to supporting software development for HPCMP. This software development capability is enterprisewide in support of the HPCMP, and it is located at MHPCC.

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[15] AFRL/RDSM personnel, 2015c.

[16] MHPCC DSRC, "Organizational Chart as of October 15, 2014," received via email, November 18, 2014c, not available to the general public; AFRL/RDSM personnel, email correspondence with author, March 18–31, 2015a; AFRL/RDSM personnel, "Maui Top Line Budget Information," received via email, March 19, 2015b, not available to the general public.

Figure 2.1. MHPCC Budget Overview ($14.1M)
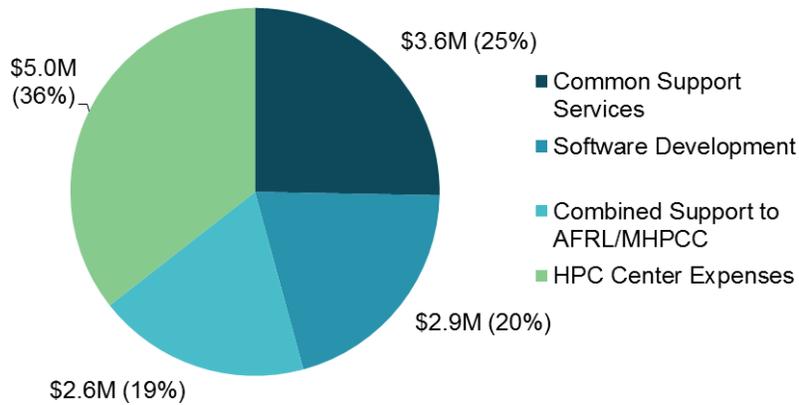
SOURCE: Data from MHPCC DSRC and AFRL/RDSM.

MHPCC supports a workforce of 55 full-time equivalents (FTE). Figure 2.2 shows more details on how these resources are used; and the result aligns closely with the financial support previously outlined. The largest group (19 FTE) works in support of the HPC Center, and the second largest group (18 FTE) represents general administrative duties, such as human resources, communications, external affairs, and site management. Eleven FTE support the HPCMP's Portal and CREATE programs (we group these two programs together as "Software Development"), and seven FTE are devoted to security and facility upkeep.[17]

Figure 2.2. MHPCC Personnel Overview (Total FTE = 55)
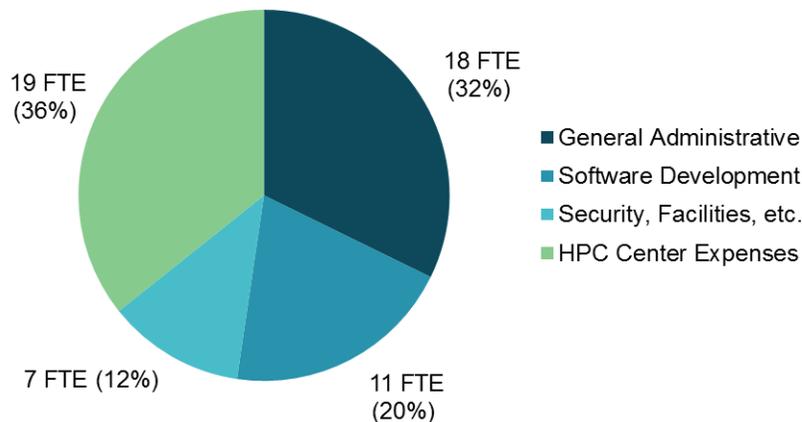
SOURCE: Data from MHPCC DSRC and AFRL/RDSM.

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[17] AFRL/RDSM personnel, 2015b; AFRL/RDSM personnel, "MHPCC Cost Breakdown," received via email, April 15, 2015e, not available to the general public.

The site has a variety of computing resources, ranging from a large supercomputer to a number of smaller servers that are stationed at different classification levels. Riptide, MHPCC's largest machine, is a 12,096-core supercomputer that was most recently ranked 286 in TOP500's list of the world's fastest computers.[18] In addition to Riptide, MHPCC houses and maintains HPC assets for other DoD customers within PACOM's AOR. Finally, MHPCC provides floor space—but does not own or pay for operation and maintenance—for a large image-processing supercomputer for the University of Hawaii's Pan-STARRS optical observatory.[19]

Complementing the physical hardware, MHPCC also represents a key node on the HPCMP's proprietary network, the Defense Research and Engineering Network (DREN). The DREN offers fast, 10-gigabit-per-second Ethernet connectivity to the rest of the HPCMP enterprise, and it also offers a test bed for research focused on improving network bandwidth.[20]

Two Factors Set Boundaries for MHPCC's Future

There are two preexisting conditions that will have a big impact on MHPCC's future: the high cost of electricity and the effects from a series of recent contracting and program management missteps. Together, these factors impose some boundary conditions on the site's future options, so it is worth explaining them.

Electricity on Maui is expensive. Roughly 70 percent of the island's electrical capacity is generated by burning oil, all of which has to be shipped in from distant locations.[21] Because of this, a kilowatt-hour of electricity on Maui in 2013 averaged 36.5 cents, about five times the rate on the U.S. mainland.[22]

With its 12,096 cores, Riptide draws about 200 kilowatt hours (kWh) on average, and this translates to about $75 per hour in electricity costs when the machine is running at a nominal rate.[23] By contrast, HPCMP's other four supercomputing sites are on the U.S. mainland, where power is considerably less expensive. The price at the other sites range from 6 cents to 7.5 cents per kWh.[24] If Riptide was at one of these facilities, the same hour of electricity would cost $12 to $15 per kWh, depending on the continental U.S. location.

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[18] Ranking was 286 as of November 2014. See TOP500, "TOP500 Supercomputing Sites: Maui High-Performance Center (MHPCC)," web page, undated.

[19] MHPCC DSRC, "Computing Resources," received via email, November 2014b, not available to the general public.

[20] Rhoades, 2015.

[21] The Hawaiian Electric Companies, "Power Facts," web page, undated.

[22] AFRL/RDSM personnel, "DSRC Sites Power Forecast," received via email, April 2, 2015d, not available to the general public.

[23] AFRL/RDSM personnel, 2015c.

[24] AFRL/RDSM personnel, 2015d.

This high cost of electricity imposes a practical requirement on the site's value proposition. This means that any supercomputing job within the Pacific AOR that can afford the latency of sending the job back to the U.S. mainland should do so, because this will usually represent the least-expensive solution.

The exception to this rule is when the results from a job are needed in near-real time, and the user cannot afford to wait for the delay associated with sending the execution command, the supporting dataset, or both, to the mainland and back. Thus, there is one type of job within the Pacific AOR where it might make sense to spend a little more on MHPCC, and those are the jobs where the computation needs to happen in near-real time. For the remainder of this report, we will refer to these jobs as "real-time jobs," which we consider to be the opposite of "batch jobs." Real-time jobs are those whose results are highly perishable; high-frequency stock trading is a classic example from the civilian world. Batch jobs are calculations whose results remain valid for a measurable period of time; some examples are modeling the fluid dynamics of an airfoil or predicting the blast radius of an explosion.

The importance of MHPCC and real-time jobs was a key focus point during our stakeholder interviews. When we spoke with the community within the Pacific AOR, we continually pressed users and potential users on whether their computing jobs needed to be performed in real time, or whether the jobs could be queued in advance and the answer reported after the jobs had been run as a batch. We were particularly interested in this because any requirement for real-time calculations in the Pacific AOR represented a unique opportunity that could only be met with a supercomputer in the Pacific.

The second initial condition that will impose informal restrictions on MHPCC's future is related to contracting and program management challenges that have led to tension between MHPCC and the HPCMP. Our research uncovered three recent incidents worth noting.

The first example is related to a project that was intended to reduce the price that MHPCC pays for electricity. In FY10, MHPCC requested and was awarded $14 million from the HPCMP to build a small solar farm near MHPCC that would reduce the cost of electricity from $0.35 kWh to $0.15 kWh.[25] In FY12, MHPCC had to return $12 million because the funds were left on an expired contract and were not recycled in time. Eventually, it was determined that the funds were returned to the HPCMP, reallocated to other projects, and the solar project was scaled back.[26]

The site has also faced challenges with a 2011-issued request for proposal for the cost-plus-fixed-fee contract to operate the MHPCC. This contracting decision has been through two successive protests, with the U.S. Government Accountability Office ultimately deciding in June

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[25] AFRL/RD personnel, phone conversation with author, June 3, 2014; DoD HPC Modernization Office personnel, 2014.

[26] AFRL/RDSM personnel, 2015c.

2014 that the Air Force should reimburse two of the bidders for the costs associated with filing and pursuing their protests.[27]

As of the date of this report, this contract has been canceled and MHPCC is currently operating under a sole source transition contract via AFRL. While this arrangement will provide continuity of operations for MHPCC, the HPCMP expressed frustration that it had to modify one of its own procurement efforts to accommodate this change.[28]

Finally, in FY14, there was an issue regarding the lease of the MHPCC administration building (Building 50). The building is owned by the University of New Mexico and leased to the AFRL observatory (they pay quarterly rent in arrears).[29] In FY14, the previous occupancy agreement expired, and there was a delay in payment for seven months because the $1 million lease was above the amount that automatically triggers a congressional notification. Responding to the actions from this trigger required coordination between the lessor, the funding agency (U.S. Army), and the occupant (MHPCC/AFRL). The lease remained unpaid for seven months while the parties determined a way forward. Eventually, the problem was resolved, and the lease was paid in full through January 2015. AFRL remains current on its lease commitment as of the date of this report.[30]

While the three examples stated above are complicated and likely not entirely the fault of MHPCC, the HPCMP reported to us that it has been "very reluctant" to make additional investments in the site because it sees MHPCC's approach to program management as "high risk." As a result, HPCMP reported that it is not planning to make any additional significant investments in infrastructure at MHPCC unless mandated by Congress.[31] Because of this, the aging Riptide machine—which was once DoD's second-most powerful computer when it was installed in summer 2013—is not slated to receive a biennial replacement, as is custom within the HPCMP. Currently, Riptide represents only 3 percent of the total computing cycles across the HPCMP enterprise, and that figure will decrease to 1 percent when biennial upgrades at other HPCMP sites are completed by the end of FY15.[32]

Both of these initial conditions—the high cost of electricity and the series of recent contracting and program management missteps—have led to some initial bounding conditions. For calculations that require supercomputing, the task will only be cost-effective (for HPCMP) to run at MHPCC if the decisionmaker resides in the Pacific AOR and has a need for real-time

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[27] Government Accountability Office, *VSE Corporation; The University of Hawaii–Costs*, B-407164.11, B-407164.12, June 23, 2014; Keoki Kerr, "Lost UH Supercomputing Center Contract Worth at Least $70M," *Hawaiian News Now*, August 30, 2012.

[28] DoD HPC Modernization Office personnel, 2014; AFRL/RDSM personnel, 2015c.

[29] AFRL/RDSM personnel, 2015c.

[30] AFRL/RDSM personnel, 2015c.

[31] DoD HPC Modernization Office personnel, 2014.

[32] DoD HPC Modernization Office personnel, 2014.

calculations (versus batch jobs). In addition, MHPCC currently is not scheduled to receive any significant supercomputing hardware, and soon it will not be in a position to market itself as possessing one of the world's fastest 500 machines.

These two MHPCC-specific restrictions negatively impact MHPCC's value proposition, especially within HPCMP's immediate RDT&E mandate. So we visited decisionmakers within the Pacific AOR on AFRL's request to determine how MHPCC might be able to add value to current or future missions. Our findings from these discussions are highlighted in Chapter Three.

3. Key Findings

PACOM Customers View Supercomputing as "Anything Larger Than a Desktop"

The first observation that we made in our interviews with potential PACOM users was a consistent lack of understanding as to what constituted a supercomputer. In fact, for many users, a supercomputer was "anything larger than my desktop," as one user told us. In addition, most people were unaware of the distinction between tasks suited for cluster HPCs (highly parallel tasks like pattern identification) or a supercomputer (scientific computing problems like physics-based models).

The client may not need to understand all the technical details of MHPCC's assets. But a lack of understanding of key asset capabilities undermines MHPCC's ability to build a strong customer base, because the customers do not understand enough about HPC to incorporate the capabilities into their vision statements. This problem is easily addressed with a refined approach by MHPCC's business development team, and we outline a strategy for solving this problem in the final chapter of this report.

No Quantitative Requirements from Pacific AOR Users for Supercomputing in the Pacific

We were unable to identify any entities within the Pacific AOR with a quantified requirement for real-time supercomputing. In this context, we specifically use the word *supercomputing* to refer to HPCMP's largest machines, such as Riptide at MHPCC.

In the absence of numerical requirements, some of the stakeholders were able to communicate future plans that may require real-time supercomputing in the future:

- PACOM/J9 is working on an initiative for using the Hawaiian Islands as a test bed for improving infrastructure resilience in isolated geographies.[33]
- PACOM/J8 is interested in processing the real-time data streams from networks of unmanned underwater vehicles (UUVs).[34]

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[33] PACOM/J9 personnel, 2014; PACOM, correspondence from Randall Cieslak to John West, Camp HM Smith, Hawaii, June 17, 2014.

[34] PACOM/J8 personnel, 2014; PACOM/J8 personnel, 2015; PACOM, correspondence from George Kailiwai to John West, Camp HM Smith, Hawaii, June 16, 2014.

- PMRF indicated that it was likely to need real-time computing support for its live missile tests "in ten years," but it has not started thinking about the requirements needed to support such an activity.[35]

However, when pressed, none of the stakeholders that we spoke with could point to existing (or even planned) quantified requirements for real-time supercomputing that would necessitate the presence of any HPC assets within the region (for context, the geographic locations for all DoD Supercomputing Resource Centers are shown in Figure 3.1). This finding suggests that— based on our interviews, at least—there is currently not enough demand from Pacific AOR users to necessitate a high-cost, Riptide-like machine within the region.

In fact, in all of our discussions with the customer base, we did not encounter anyone within the Pacific AOR who had projects running on MHPCC's Riptide machine. This specific finding is not surprising because of the way that HPC assets are scheduled and tasked: For new project ideas, researchers will submit proposals, and the HPCMP will oversee a selection process to identify qualified applicants and eventually award hours on an HPC asset. This process means that significant portions of the jobs that run on Riptide are unrelated to the PACOM mission. As an example, the top ten MHPCC projects in FY14 used 45 million CPU hours, and none were tasked directly by PACOM. Of these projects, one managed by the Defense Threat Reduction Agency was related to a PACOM mission objective. It represented 0.1 percent of the 45 million CPU hours.[36]

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[35] Pacific Missile Test Range personnel, 2015.

[36] AFRL-MHPCC, 2014.

Figure 3.1. Geographical Locations of Current DoD Supercomputing Resource Centers, Including MHPCC
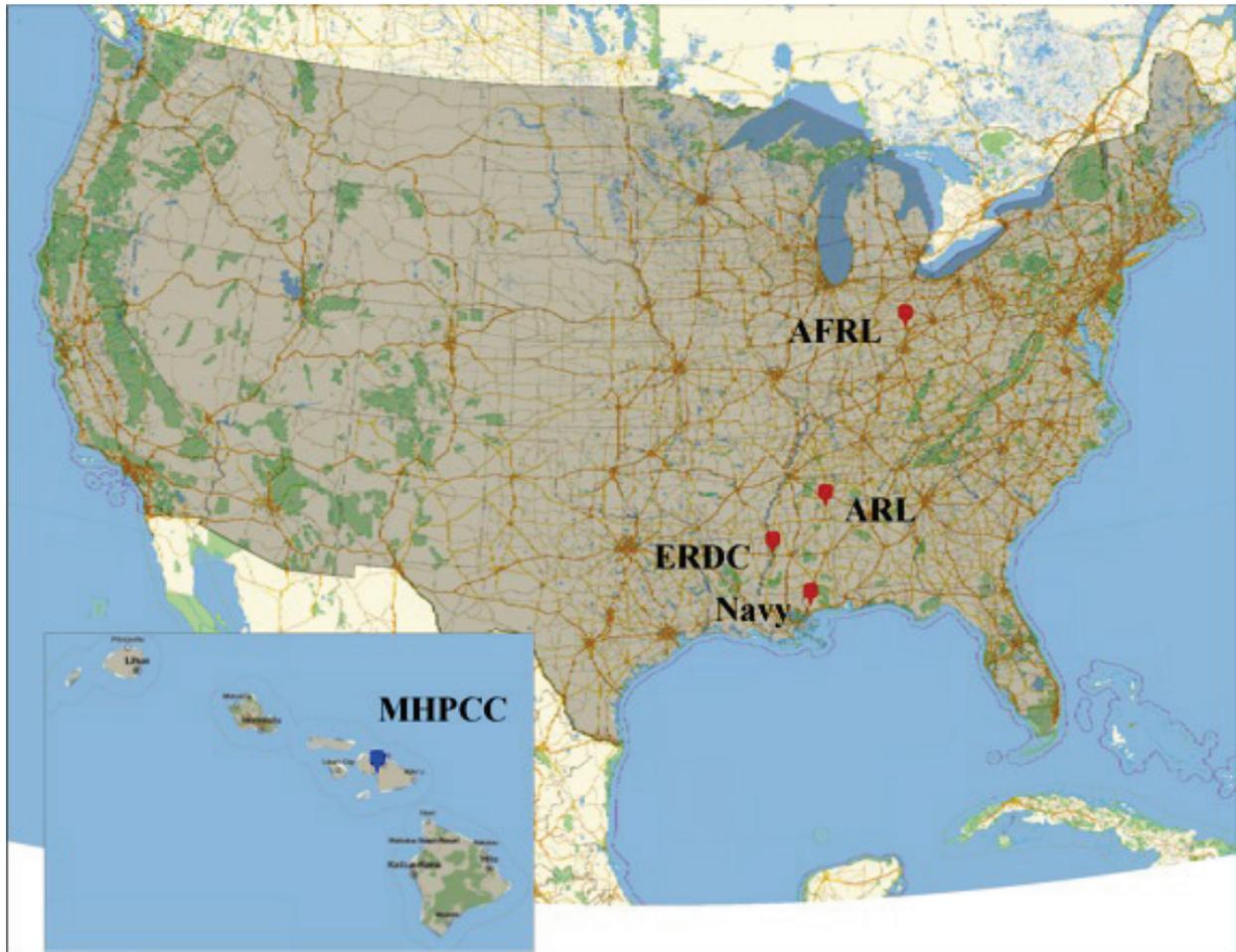
SOURCE: Data from DoD HPC.

PACOM Users Value MHPCC's Support for Custom Servers and Programming Expertise

If DoD users within the Pacific AOR are not running jobs on MHPCC's largest machine, how are they interacting with the site? We found that regional customers are far more likely to use smaller HPC assets and MHPCC's knowledge capital. Specifically, we found that customers within the region are most likely to use one of two capabilities: MHPCC's ability to stand up, operate, and maintain custom HPC assets, and MHPCC's resident programming expertise in optimizing algorithms for HPC architectures. To provide context around these two capabilities, we offer two examples that we observed during the course of our research.

Based on a request from PACOM/CC to increase the rate at which operational plans could be developed, PACAF approached MHPCC in March 2011 about hosting a dedicated machine to support these calculations.[37] As a result of this request, MHPCC stood up an 80-core Dell PowerEdge machine named Anamake, and the computation time for a single run was reduced from 12 hours to less than 10 minutes.[38] This significant reduction in time allows weaponeers to develop high-fidelity solutions by running more iterations in shorter amounts of time.

The technical experts that run the modeling software come from three groups: cruise missile support activity (CMSA) Pacific (PAC); 613 Air Operations Center (AOC) Intelligence, Surveillance, and Reconnaissance Division (ISRD); and 607 AOC ISRD.[39]

According to our interviews, there are several benefits to having this capability at MHPCC. First, one staff member anecdotally told us that it is difficult to find suitable space for computing resources on Oahu, noting that finding the actual real estate in a server room and setting up the information technology infrastructure are often the biggest road blocks when establishing a new computing resource.[40] MHPCC had both the floor space along with established infrastructure, so placing the machine on Maui was relatively straightforward.

Customers also noted that having an HPC within the PACOM geographic region means that MHPCC personnel understand the command's mission space and culture. Several PACOM staffers told us that having an HPC in theater resulted in more responsive service, something they had not experienced when using other HPCMP sites.[41] As one person told us: "Having MHPCC in theater means we do not have to worry about the 'out of sight, out of mind' problem that we sometimes see when working with other resources on the mainland."[42]

One potential issue that we observed for this use case relates to the mismatch between PACOM's operational needs and MHPCC being primarily a research-and-development resource. PACAF/A2 representatives noted they are taking a risk in using MHPCC to host the weaponeering software because MHPCC is not a 24/7 operation. However, in the same sentence, they noted they are willing to take that risk because the hosted server significantly reduces the processing time. As one weaponeer told us: "We are not executing [operational] plans right now. If we ever have to start doing that, the existing resources may be insufficient."[43]

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[37] MHPCC, "Integrated Munitions Effects Assessment Technical Interchange Meeting," trip report, signed by Thomas Gemuend, Air Force Research Laboratory, April 9, 2014.

[38] PACAF/A2 personnel, 2014; 613 AOC personnel, 2014.

[39] 613 AOC personnel, 2014; MHPCC, 2014.

[40] PACOM/J8 personnel, 2015.

[41] PACAF/A2 personnel, 2014; PACOM/J8 personnel, 2014; PACOM/J8 personnel, 2015; 613 AOC personnel, 2014.

[42] PACAF/A2 personnel, 2014; PACOM/J8 personnel, 2014.

[43] PACAF/A2 personnel, 2014; 613 AOC personnel, 2014.

Since November 2014, the software team at MHPCC has been supporting the Range Safety Office (RSO) at PMRF in Kauai. When it participates in a missile test, PMRF may launch one or more of the test assets from Kauai, or it may simply observe a test that originates from another location. In either case, before every test, safety officers run Monte Carlo simulations that predict where debris is likely to fall under nominal and abnormal conditions. The results of these calculations are used by the Federal Aviation Administration to plan "no-fly zones" during the test, and the Coast Guard issues similar warnings for marine surface vessels.[44]

The safety officers at PMRF initially approached MHPCC personnel because they were suffering from the same problem as the PACOM weaponeers—their Monte Carlo runs were taking too long to implement on their existing hardware.[45] Like all Monte Carlo simulations, a large number of analytic runs are needed in order to generate a meaningful result, and the safety officers had to start their calculations six weeks ahead of the launch date in order to ensure they would be completed in time.[46] Of course, if any key element of the planned test procedure was changed during this time, the RSO would have to begin the calculation anew, potentially delaying the start of the test.

In addition to the need for faster computing cycles, PMRF's Monte Carlo runs also need a lot of networking bandwidth and a classified computing environment. Each test configuration requires data to be transmitted to the computer that is performing the calculation, and it is challenging to transmit this amount of data over the Nonsecure Internet Protocol Router Network (NIPRNet) or Secret Internet Protocol Router Network (SIPRNet).[47] The final requirement is that these calculations run on a classified SECRET machine, because of the sensitivity of the data.[48]

Because of some restrictions associated with PMRF contracting guidelines, PMRF personnel decided to turn to the HPC program rather than stand up their own machine.[49] To solve this problem, MHPCC engineers worked with PMRF personnel to develop a solution that runs on Army Research Lab's (ARL's) Hercules computer at Aberdeen Proving Ground in Maryland.[50] (The analysis is run in Maryland because MHPCC does not have a suitable SECRET-level machine for this purpose.) Initially, MHPCC personnel logged into the ARL machine on PMRF's behalf because ARL was short-staffed and unable to support PMRF directly. In fact, this problem was eventually solved when a system administrator from MHPCC traveled to Aberdeen for a week in order to automate the workflow.[51]

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[44] Pacific Missile Test Range range safety personnel, 2015.

[45] Pacific Missile Test Range personnel, 2014.

[46] Pacific Missile Test Range personnel, 2014; Pacific Missile Test Range range safety personnel, 2015.

[47] Pacific Missile Test Range range safety personnel, 2015.

[48] Pacific Missile Test Range personnel, 2014.

[49] Pacific Missile Test Range personnel, 2014.

[50] AFRL/RDSM personnel, 2015c.

[51] AFRL/RDSM personnel, 2015c.

PMRF personnel reported that MHPCC's onsite expertise was instrumental in facilitating the relationship with ARL's machine and then providing onsite support to get the analysis up and running. Specifically, MHPCC's knowledge of both the local client and the HPC enterprise was what made it successful in this instance. As a result of MHPCC standing up these services, PMRF has reduced the time of running a single iteration from 84 hours down to less than five minutes.[52] Like the weaponeering mission, this increase in efficiency allows PMRF safety officers to develop a higher-fidelity result in a much-shorter time.

Anecdotes from PACOM Highlight Value of MHPCC

As we mentioned earlier, none of the stakeholders that we met with were able to provide quantitative requirements for how supercomputing resources are needed to meet their mission, nor were they able to demonstrate a clear strategy for generating these requirements in the near-term future. However, while we were not able to find a clear requirement for supercomputing resources, we did hear several anecdotes for how MHPCC adds value to PACOM. We recognize these are only stories, but we present them here because we heard them from multiple parties, which suggest they are salient.

The most-common theme that we heard is related to the proximity effect. Commanders and members of the Senior Executive Service (SES) told us—either directly or using language that implied as much—that they liked having an HPC asset within the AOR. Several seniors and staffers lamented that PACOM is geographically isolated, and having resources near Oahu is always the preferred solution because this is often the most-responsive option. Or, as one staffer told us, commanders like having resources "within sight of the flagship."[53]

This effect is likely happening because of cultural and organizational factors. First, having an HPC resource within the AOR means that some element of it is likely to fall under PACOM's chain of command, and this is useful when pursuing operational missions. In the case of MHPCC, PACAF/A2 helps maintain MHPCC's network connectivity to the rest of the Hawaiian islands, so both of these parties are motivated to remain responsive to one another's needs.[54]

Several of the stakeholders that we spoke with also liked that MHPCC personnel worked within the same time zone, which makes it easier for PACOM personnel to coordinate technical exchanges and receive support from MHPCC. However, it is worth recognizing that it would be straightforward to stand up a PACOM support cell on the mainland that is open during business hours in Hawaiian standard time.

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[52] Pacific Missile Test Range range safety personnel, 2015.

[53] PACOM/J8 personnel, 2015.

[54] PACAF/A2 personnel, 2014.

AMOS and MHPCC Benefit from Co-Location

MHPCC's longest relationship is the one with the co-located Air Force Maui Optical and Supercomputing Site (AMOS). AMOS is operated by the AFRL and consists of three large (meter-class) optical telescopes that provide tracking, detection, and identification of orbiting objects. Together, these telescopes provide the Air Force with a unique imaging capability over the Pacific that supports key Air Force Space Command requirements for space situational awareness.

From the early days of MHPCC, AMOS scientists have taken advantage of the sites' co-location by leveraging the resident computing infrastructure and expertise to help advance AMOS core capabilities. Today, AFRL's Remote Maui Experiment facility provides floor space for an 864-core server that is dedicated to processing the images from the observatory's 1.6-meter telescope.[55] This server runs an AFRL-developed algorithm that compensates for atmospheric blur in order to generate sharp images of overhead satellites in near-real time. These resulting images are then sent to operational users.

Today, the relationship between MHPCC and AMOS is quite integrated, especially after a 2014 move that co-located the MHPCC and AMOS administrative offices to Building 50.[56] This co-location fosters a significant sharing of expertise between the two sites, but it also results in a cost savings for both sites because they share some of the expenses associated with the building lease, maintenance costs, and support infrastructure. In fact, MHPCC personnel reported to us that DoD gains an efficiency of about $2.9 million a year by having AMOS and MHPCC co-located.[57]

MHPCC also benefits from being co-located with the observatory. AFRL is a research-oriented organization, and MHPCC has benefited by being surrounded by this culture. For example, the HPCMP's Portal program—a capability that HPCMP notes as an innovative and significant contribution to its computing enterprise—was initiated and is still led by the personnel who developed the control system for the optical observatory.[58] The combined presence of AMOS and MHPCC personnel provides a critical mass for capturing and maintaining world-class research talent.

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[55] MHPCC DSRC, 2014b.

[56] AFRL/RD personnel, phone conversation with author, June 3, 2014.

[57] AFRL/RDSM personnel, 2015b.

[58] DoD HPC Modernization Office personnel, 2014; AFRL/RDSM personnel, 2015c.

4. Recommendations

We began this report by listing a set of three research questions: Which of MHPCC's capabilities are used most often by customers in the Pacific AOR? And, specifically, is there a demand for a supercomputing resource that is located within the AOR? What recommendations should AFRL consider when making decisions about the future of MHPCC?

The findings that we describe in the preceding chapters addressed the first and second questions. This chapter offers a set of six recommendations that AFRL might consider when strategizing about the future of the site. These are not exhaustive recommendations.

Recommendation 1: Be explicit to Pacific AOR users about the different capabilities at MHPCC

Throughout our interviews, we observed a general lack of understanding among the Pacific AOR customer base about what capabilities are available at MHPCC, which reside in the greater HPCMP enterprise, and which belong to another government or commercial party.

In its basic form, this misunderstanding manifests itself as a lack of clarity about which machine is used to solve a specific problem. For example, we found one user who mistakenly believed that her job was running on a machine in Maui when, in reality, it ran on an HPC asset on the U.S. mainland. This misconception was not due to any false advertising on the part of MHPCC, but it does highlight the challenge of managing a virtual workflow, in which the user cannot directly observe the hardware.

One way to address this problem would be to develop a simple architecture diagram that shows both the entire HPCMP enterprise along with the details on MHPCC-specific resources. Having this diagram would allow MHPCC personnel to first explain how DoD's HPC enterprise works, before focusing on the resources that are local to Maui. Displaying such a diagram would also highlight the importance of the DREN network, which is what stitches together the entire architecture.

In the case of this example, walking the customer through such a diagram will help show how having MHPCC's presence in Hawaii helps connect users to the rest of the system on the U.S. mainland.

Recommendation 2: MHPCC should be described to Pacific AOR customers as offering three separate products

Every customer is different, and the answer to a client's computing problem needs to be more nuanced than "MHPCC." To help address this problem, we propose that MHPCC market itself as offering three separate products: (1) a large, 12,096-node supercomputer; (2) a facility that has

the expertise and infrastructure to host standalone assets for local clients; and (3) a research staff that has the capacity to develop innovative solutions to operational problems.

Presenting MHPCC as a center that offers separate products will allow for a more tailored approach to solving Pacific AOR customer problems. It would also help address the perception that MHPCC is only the Riptide machine. For example, if Riptide is not appropriate for a specific customer's problem, then it is easy to set that asset aside and start discussing the part of MHPCC that offers development and hosting of tailored, standalone solutions. By separating these capabilities, MHPCC and HPCMP can target development resources to the parts of the product line that will ultimately provide the most utility to stakeholders in the AOR.

Recommendation 3: Provide the Pacific AOR customer with a framework for matching HPC assets to the desired end result

Another challenge associated with HPC—besides the fact that it is often utilized virtually — is that it is inherently technical. It's hard to engage and strategize with customers when the product is virtual and requires specialized knowledge to use effectively. What is lacking right now in MHPCC's customer engagement is a way to work through these issues *alongside* the customer in the AOR, so both parties understand the problem and how HPC will be used to address it.

We recommend implementing a simple framework for helping Pacific-based clients understand the capabilities and differences between HPC assets. Table 1.1 represented one such approach for distinguishing between cluster and supercomputing architectures. The information in Table 1.1 can be taken a step further and turned into a flowchart that allows the customer to determine what kind of HPC asset is most suitable for his or her problem, Figure 4.1.

The flowchart that we show in Figure 4.1 is a simplistic example, but it offers a way for the customer to put a problem in context with the available resources. Such a flowchart is one way to counter the perception that a supercomputer is "anything larger than a desktop." It is also a simple way to start educating Pacific AOR users on the available types of HPC assets; this can serve as a first step for customers to begin incorporating HPC capabilities into their strategic plans.

One could also imagine analogous flowcharts where the possible end states list all of MHPCC's current capabilities so customers can see where their problem lands—if at all—within MHPCC's enterprise. Telling customers that they would be better served by renting space on a commercial system—or buying their own standalone machines—still solves their problem, and it frames MHPCC personnel as being a knowledgeable partner who has customers' best interest in mind.

Figure 4.1. An Example Flowchart for Matching Workload to Computing Assets
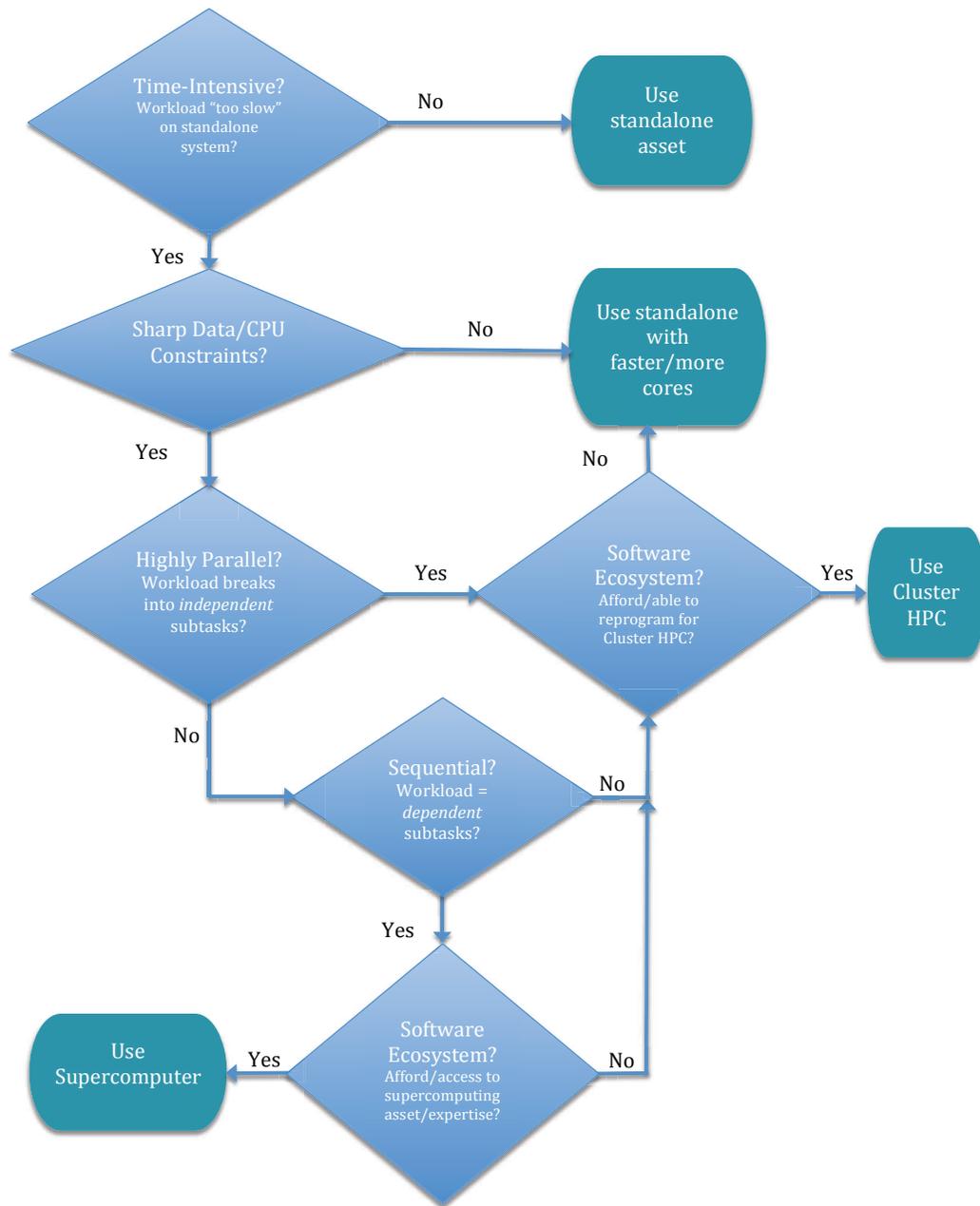
SOURCE: Authors' analysis.

Recommendation 4: Employ both strategic and technical thought leaders to enhance Pacific AOR customer exploitation of MHPCC capabilities

Of course, developing a clever flowchart or table is only part of the solution. The other half requires a two-part customer engagement strategy: one part HPC subject-matter expert and one part strategist. (We specify two parts because these skills are likely to reside in two separate individuals or teams of individuals.) The strategists need to identify areas within PACOM that might benefit from HPC capabilities, and subject-matter experts need to work with PACOM personnel to help them develop requirements for HPC assets that will solve their problem.

For example, PACOM/J9 has some bold visions for future missions, but they are not HPC experts. J9 will require objective HPC subject-matter expertise to help them identify what types of new computing resources will be needed to help them realize their goals. The first step in this relationship might be an accessible seminar from MHPCC personnel on the differences between modern computing architectures. This might graduate to conversations where MHPCC personnel help J9 begin developing requirements. The ultimate goal of this progression should be to give J9 personnel enough context on HPC resources that they begin to think of use cases and first-order requirements on their own.

Recommendation 5: Rebuild trust and understanding with HPCMP leadership

MHPCC needs to communicate more clearly and more frequently with HPCMP management to rebuild the trust that was lost as a result of the aforementioned contracting issues. Reestablishing trust is always a challenging task, but MHPCC personnel can take some comfort in the fact that the HPCMP still recognizes Maui as being a source of innovation and creativity for the entire enterprise.[59]

The three contracting and program management challenges that we outlined earlier are important to acknowledge as mistakes. Like all missteps, it is important to learn from them and then begin thinking about the future, rather than dwelling on the past. As MHPCC begins to repair the relationship, focusing on simple things like establishing consistent communication to provide updates is a good first start. As we have observed with other Hawaii-based programs that are managed from the U.S. mainland, it is very easy for the sponsoring organization to lose context on what progress is being made if the communication between the two parties is irregular and inconsistent.

Recommendation 6: Recognize that aspects of the computing industry are changing. Develop a strategy to prepare for this change.

Throughout the course of performing this research, we observed two trends that are worth considering when developing a strategy for MHPCC's future.

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[59] DoD HPC Modernization Office personnel, 2014.

First, we saw evidence to suggest that the supercomputing industry is changing. New, scalable computing architectures, combined with a drop in the price of hardware, have the potential to turn computing cycles into a commodity.[60] The supply side of computing is changing to reflect the shift: The major supercomputing developers—IBM and Cray—have expanded their product lines to offer analytics hardware, in addition to their conventional, supercomputing offerings. As a result, a larger portion of today's research and development dollars are going toward developing machines that will be better suited for addressing big data applications. With all of these changes, HPC leaders should be addressing the following question: How will centers provide value when the world has access to inexpensive computing cycles?

The second trend that we observed offers one potential solution to this question. In the course of our research, we noted that MHPCC's desire to perform work for others mirrors what we observed within the Department of Energy's (DoE) HPC program. DoE, of course, has its own supercomputing facilities, and it reported that it has started to become more aggressive in developing partnerships with end users and applications researchers.[61] DoE recognizes that simply having the world's fastest machines is not going to remain its primary competitive advantage for more than one or two additional computing generations.[62] Instead, DoE's value will come from having the foresight to develop expertise in today's emerging problems and figuring out how HPC resources can be used to address those problems.

MHPCC is in the early stages of taking up this posture, but adopting this as a formal strategy is going to require some strategic and organizational adjustments. As an example, HPCMP is funded as an RDT&E enterprise, but many of the new customers that MHPCC is pursuing are operational in nature. Reconciling this misalignment offers an opportunity for MHPCC—perhaps even the entire HPCMP—to offer support to a greater number of government customers, just as the demand for and awareness of these powerful analytic tools is likely to increase significantly, while maintaining the critical support to the RDT&E community.

Combined with its unique geographical placement, MHPCC's increasing expertise in responding to support requests from the operational community will provide unique value to HPCMP and DoD as a whole. For example, MHPCC may be able to provide significant latency arbitrage services for future Pacific AOR real-time jobs. It can serve in a backup capacity for low-priority and high-latency research jobs from HPCMP's affiliates in the continental United States. MHPCC can also serve as a test bed for developing best practices for managing

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[60] "The Cheap, Convenient Cloud," *The Economist*, April 18, 2015; Gartner, "Gartner Says Cloud Application Infrastructure Technologies Need Seven Years to Mature," press release, February 2, 2009; Radu Sion, "To Cloud or Not to? Musings on Clouds, Security and Big Data," in *Secure Data Management*, Vol. 8425, May 2014, pp. 3–5; Yao Chen and Radu Sion, "To Cloud or Not to Cloud? Musings on Costs and Viability," in *Proceedings of the 2nd ACM Symposium on Cloud Computing*, ACM, 2011, p. 29.

[61] Brase, 2015.

[62] Brase, 2014.

operational and RDT&E workloads within the same service. HPCMP focuses on RDT&E and may benefit from MHPCC's experience.

5. Conclusion

In conclusion, we found that MHPCC has capabilities and expertise that provide value to regional users. While we did not find anyone within the Pacific AOR who currently requires the use of the Riptide machine to support operations, there are several users who rely on MHPCC's ability to stand up and support custom hardware. MHPCC's software development capability is also recognized by both the customer base and the HPCMP as being exemplary.

In the near term, MHPCC should take steps to educate the Pacific customer base and build trust with the HPCMP. For the customer base, all of the site's potential users will need to be better informed as to the site's capabilities and how these can be integrated into a user's mission. The technical staffers at MHPCC will play a significant role in this because of their experience in software development. They also represent a capacity for developing the next generation of computing technology, like the quantum computing work that is being done at MHPCC and the University of Hawaii.

As AFRL, MHPCC, the Army, and Congress work through the tradeoffs of balancing resources by eliminating unnecessary redundancies and costs, it is important that they retain the capabilities on which DoD users depend. The site provides value to a key AOR in supporting two important tasks within the geographic region. In addition, there is a strong likelihood that AOR users will leverage MHPCC capabilities in the future. As a result, users in the AOR would likely need to find alternative solutions if the MHPCC is cut entirely.

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