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ASSESSING THE OPERATIONAL READINESS OF LANDING CRAFT AIR CUSHION VESSELS USING STATISTICAL MODELING

by

Frederick H. Crawford

September 2010

Thesis Advisor: Robert Koyak
Second Reader: Rachel Johnson

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A fleet of 40 Landing Craft Air Cushion (LCAC) vessels is managed by Assault Craft Unit-5 located at Camp Pendleton, CA. LCACs are used to transport weapons systems, equipment, cargo, and personnel of the assault element of the Marine Air/Ground Task Force from ship to shore and across the beach. It is important that the Commanding Officer be able to forecast, with a reasonable degree of accuracy, the number of LCACs that will be available for tasking a fixed number of days in advance. As the LCAC fleet ages its time in maintenance increases, which in turn increases the uncertainty of achieving availability targets. This thesis examines factors that contribute to the availability of LCACs on a daily basis. Using logistic regression, a forecast model is developed from past data on availability and maintenance that has a prediction standard error of approximately two to three craft. The model can be used not only to forecast the number of available LCACs, but also to assist in planning and scheduling to better manage availability.

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ASSESSING THE OPERATIONAL READINESS OF LANDING CRAFT AIR CUSHION VESSELS USING STATISTICAL MODELING

Frederick H. Crawford
Lieutenant Commander, Supply Corps, United States Navy
B.S., Norfolk State University, 1999

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September 2010

Author: Frederick H. Crawford

Approved by: Robert Koyak
Thesis Advisor

Rachel Johnsonr
Second Reader

Robert Dell
Chairman, Department of Operations Research

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ABSTRACT

A fleet of 40 Landing Craft Air Cushion (LCAC) vessels is managed by Assault Craft Unit-5 located at Camp Pendleton, CA. LCACs are used to transport weapons systems, equipment, cargo, and personnel of the assault element of the Marine Air/Ground Task Force from ship to shore and across the beach. It is important that the Commanding Officer be able to forecast, with a reasonable degree of accuracy, the number of LCACs that will be available for tasking a fixed number of days in advance. As the LCAC fleet ages its time in maintenance increases, which in turn increases the uncertainty of achieving availability targets. This thesis examines factors that contribute to the availability of LCACs on a daily basis. Using logistic regression, a forecast model is developed from past data on availability and maintenance that has a prediction standard error of approximately two to three craft. The model can be used not only to forecast the number of available LCACs, but also to assist in planning and scheduling to better manage availability.

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LIST OF ACRONYMS AND ABBREVIATIONS

AER	Alteration Equivalent to Repair
Ao	Operational Availability
ACB-1	Amphibious Construction Battalion ONE
ACE	Air Combat Element
ACU-1	Assault Craft Unit ONE
ACU-4	Assault Craft Unit FOUR
ACU-5	Assault Craft Unit FIVE
ACV	Air Cushioned Vehicle
AIT	Alteration Installation Team
ARG	Amphibious Ready Group
BMU-1	Beachmaster Unit ONE
C/A	Craft Alteration
CASREP	Casualty Report
CBM	Condition Based Maintenance
CCI	Corrosion Control Inspection
CESE	Civil Engineer Support Equipment
CMAV	Continuous Maintenance Availability
CMP	Class Maintenance Plan
CNO	Chief of Naval Operations
CO	Commanding Officer
COMM/NAV	Communication / Navigation
COMNAVSURFPAC	Commander, Naval Surface Forces Pacific
COSAL	Coordinated Shipboard Allowance List
CSMP	Current Ship Maintenance Project
CSR	Craft Status Report
CRAFTALT	Craft Alteration
C^4N	Command, Control, Communications, Computers & Navigation
DA	Depot Availability
DoD	Department of Defense

DON	Department of the Navy
ESG	Expeditionary Strike Group
FAS	Federation of American Scientists
FMAV	Fleet Maintenance Availability
FMC	Fully Mission Capable
IDTC	Inter-Deployment Training Cycle
IEM	Inactive Equipment Maintenance
IMA	Intermediate Maintenance Activity
IMAV	Intermediate Maintenance Availability
ISEA	In-Service Engineer Agent
JFMM	Joint Fleet Maintenance Manual
LANTFLT	Atlantic Fleet
LAP	LCAC Availability Predictor
LCAC	Landing Craft Air Cushioned
LCM	Landing Craft Mechanized
LCU	Landing Craft Utility
LFSP	Landing Force Shore Party
LHA/LHD	Amphibious Assault Ship
LHA(R)	Amphibious Assault Ship Replacement
LPD	Amphibious Transport Dock
LSD	Dock Landing Ship
MA	Maintenance Availability
MAE	Mean Absolute Error
MAGTF	Marine Air/Ground Task Force
MARG	Marine Amphibious Ready Group
MCA	Machinery Condition Analysis
MCT	Mean Corrective Maintenance Time
MDCS	Maintenance Data Collection System
MEU	Marine Expeditionary Unit
MEF	Marine Expeditionary Force
MPF	Maritime Prepositioning Force
NAB	Naval Amphibious Base

NBG-1	Naval Beach Group ONE
NMC	Non-Mission Capable
NSWC-PC	Naval Surface Warfare Center, Panama City
OIC	Officer-in-Charge
OMMS-NG	Organizational Maintenance Management System Next Generation
OPNAVINST	Naval Operations Instruction
OTH	Over the Horizon
O&M	Operations and Maintenance
O&S	Operations and Support
PACFLT	Pacific Fleet
PHIBRON	Amphibious Squadron
PMC	Partial Mission Capable
PMS	Planned Maintenance System
PMS377	Amphibious Warfare Program
POE	Projected Operating Environment
RAV	Restricted Availability
RCM	Reliability Centered Maintenance
RDT&E	Research, Development, Testing & Evaluation
RMC	Regional Maintenance Center
ROC	Required Operational Capabilities
RRAM	Real-time Reutilization Asset Management
R&M	Reliability and Maintainability
SEAL	Sea, Air, Land
SISCAL	Shipboard Instrumentation and System Calibration
SLEP	Service Life Extension Program
SURFOR	Commander, Naval Surface Force
TYCOM	Type Commander
UIC	Unit Identification Code

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EXECUTIVE SUMMARY

Assault Craft Unit (ACU)-5 manages a fleet of 40 Landing Craft Air Cushion (LCAC) hovercrafts from its base at Marine Corps Base Camp Pendleton located in North San Diego County, California. ACU-4 also manages a fleet of 40 LCAC hovercrafts out of its base at Little Creek Amphibious Base located in Norfolk, Virginia. ACU-4 and ACU-5 together manage the entire fleet of LCACs. The LCAC is a high speed, ship-to-shore, over the beach, Air Cushioned Vehicle (ACV) designed to operate from the well deck of amphibious ships. It is used to transport weapons systems, equipment, cargo, and personnel of the assault element of the Marine Air/Ground Task Force both from ship to shore and across the beach (FAS, 2000). The current fleet of 40 LCACs at ACU-5 was acquired from the mid-1980s to the mid-1990s. As the fleet ages, unscheduled downtime increases during which time a craft is unavailable.

In this thesis, we consider the problem of predicting periods of unavailability of Landing Craft Air Cushion (LCAC) hovercrafts due both to scheduled (preventive) maintenance and unscheduled (corrective) maintenance. On a given day, ACU-5 has about 20 LCACs available. About half of the craft that are unavailable are in that status for unscheduled maintenance. It is important the Commanding Officer at ACU-5 have the ability to quantify the number of LCACs that are available on a given day, with guidance on how to reduce that number and thereby increase mission capability. Understanding the factors that drive availability is important to bringing about changes that could help to meet the desired target. In addition, such understanding can be used to develop forecasts of the number of available craft a specified number of days into the future, which can be useful for planning purposes.

This thesis develops a statistical approach to the problem of forecasting LCAC availability. The research methods used to identify significant drivers of unscheduled downtime include data analysis and statistical modeling (logistic regression). This thesis uses past data on maintenance and availability, and data on planned maintenance and other foreseeable removals from availability, to project the number of available LCACs a

specified number of days in the future. The goal is to transform the data into a useful model for the ACU-5 Commanding Officer to not only predict how many mission-capable LCACs are available on a given day, but also to identify factors that drive unavailability.

As part of the research effort an Excel spreadsheet tool, called LCAC Availability Predictor (LAP) version 1.0, was developed to streamline implementation of the forecasting model. Using the base logistic regression model, LAP produces for each LCAC a predictive score between the values of zero (unavailable) and one (available). The availability scores are summed across all LCACs to provide a fleet-level forecast of availability. The standard error of predictions obtained with the model is approximately two to three vessels.

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I. INTRODUCTION

A. AREA OF RESEARCH

The Landing Craft Air Cushion (LCAC) is a high speed, ship-to-shore, over the beach, Air Cushioned Vehicle (ACV) designed to operate from the well deck of amphibious ships. It is used to transport weapons systems, equipment, cargo, and personnel of the assault element of the Marine Air/Ground Task Force (MAGTF) both from ship to shore and across the beach (FAS, 2000).

In this thesis, we consider the problem of predicting periods of unavailability of LCAC hovercrafts due both to scheduled (preventive) maintenance and unscheduled (corrective) maintenance. Assault Craft Unit Five (ACU-5) manages a fleet of 40 LCAC hovercrafts for the United States Navy out of its base at Marine Corps Base Camp Pendleton located in North San Diego County, California. ACU-4 manages a fleet of 40 LCAC hovercrafts out of its base at Little Creek Amphibious Base located in Norfolk, Virginia. ACU-4 and ACU-5 together manage the entire fleet of LCACs owned and operated by the U.S. military.

The current fleet of 40 LCACs at ACU-5 was acquired from the mid-1980s to the mid-1990s. As the fleet ages, unscheduled downtime increases during which time a craft is unavailable. On a given day ACU-5 has about 20 LCACs available. About half of the craft that are unavailable are in that status for unplanned reasons. ACU-5 wants to have the ability to quantify the number of LCACs that are unavailable on a given day, with guidance on how to reduce that number and thereby increase mission capability (G. Baker, Command Data Historian for ACU-5, personal communication, September 10, 2010).

Understanding the factors that drive availability is important to bringing about changes that could help to meet the desired target. In addition, such understanding can be used to develop forecasts of the expected number of available craft, which can be useful for planning purposes.

B. RESEARCH GOALS

This thesis applies statistical analysis methods to the problem of forecasting LCAC availability. The research methods, used to identify significant drivers of unscheduled downtime. This thesis uses historical maintenance and availability, data, both scheduled and unscheduled, to project the number of available LCACs in the future. The goal is to transform the data into a useful model for ACU-5 Commanding Officers (COs) to not only predict how many mission-capable LCACs are available on a given day, but also to identify factors that drive unavailability.

An approach similar to that of this thesis also can be used to analyze the availability of the LCAC fleet at ACU-4 in Little Creek Virginia. The results may be useful to the Assault Hovercraft Program Office located in Panama City, Florida.

C. FOCUS OF THE THESIS

This thesis addresses the following research questions:

1. How should existing maintenance and mission-capability data on LCACs be used to define quantitative indicators that are useful to predict availability?
2. What kind of a statistical model should be used to predict the availability status of an LCAC?
3. How can the statistical model be converted into a tool for a Commanding Officer to predict how many mission-capable LCACs are available on a given day?

To answer these questions we adopt the following approach. We begin by selecting LCAC availability and maintenance data collected over a recent two-year period, for their use in a statistical modeling effort. Using the data, we then develop a statistical model to forecast availability of an individual LCAC vessel using a set of predictor variables. The unit-level forecasts are then combined to forecast the number of available LCACs on a fleet-level basis, and the predictive accuracy of the forecasts is assessed. Finally, the forecast model is developed into a software tool that can be used by ACU-5 to forecast the number of available LCACs.

D. BENEFITS OF THE STUDY

This research uses ACU-5 maintenance and mission-capability data to produce a statistical model to forecast future availability of the LCAC fleet at ACU-5. The forecasted LCAC status can be utilized by COs to identify operational readiness. This predictive capability can assist in managing preventive maintenance and serve as a quick reference for COs to allocate resources to reduce the risk of unavailable LCACs and thereby increase mission capability.

E. ORGANIZATION OF THE THESIS

The remainder of this thesis is organized as follows. Chapter II gives further background information specific to LCACs, a review of literature related to this research effort, and general readiness and maintenance policies for LCACs that affect availability. Chapter III describes the data and the development of the statistical model. Chapter IV describes the application of the methodology to the data, and the use of resulting statistical models to forecast the number of available LCACs. Chapter V presents conclusions and suggestions for future work.

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II. BACKGROUND

This chapter provides information about the system characteristics of the LCAC, a review of literature on subjects related to this thesis, and an overview of the maintenance system as it pertains to the readiness of the LCAC.

A. BACKGROUND

The LCAC is designed to transport equipment, personnel, and weapon systems from ships located beyond the horizon, through the surf zone and across the beach to hard landing points beyond the waterline. The LCAC is capable of achieving speeds in excess of 35 knots to deliver a 60-ton payload for the ground elements of a Marine Expeditionary Force (MEF). With the additional use of a Personnel Transport Module, up to 180 personnel or 145 combat loaded troops can be transported to facilitate troop movement, medical evacuation, non-combat evacuation operation and humanitarian assistance (U.S. Navy, 2007). Appendix A gives a detailed description of physical characteristics and specifications of the LCAC.

Propulsion for the LCAC is provided by four TF40B marine gas turbine engines geared to two shrouded reversible pitch propellers. During the Service Life Extension Program (SLEP), the TF40B engines are upgraded to enhanced ETF40B engines to provide additional lift and hot-day performance. The welded aluminum hull rides on a cushion of air contained by a rubberized skirt system. Four double entry lift fans, also driven by the marine gas turbine engines, provide the airflow required for the lift system. Maneuverability is provided by two pairs of aerodynamic rudders, two reversible pitch propellers, and two controllable bow thrusters. The craft is operated from a control cabin located forward of the starboard lift fan module. This cabin provides seating for eight troops; a cabin forward on the port side of the LCAC provides seating for sixteen additional troops plus the Deck Mechanic and the Load Master (U.S. Navy, 2007). Figure 1 shows an LCAC.

Figure 1. Landing Craft Air Cushion (LCAC) transiting alongside its amphibious transport dock ship (U.S. Navy, 2009a)

B. LITERATURE REVIEW

There is a small body of literature relevant to availability forecasting of LCACs or similar military watercraft. Engi (2006) provides an analytical framework for Fleet Readiness and the concept of LCAC craft availability, utilizing output of Sandia's ProOpta software that applies concepts from basic probability theory. ProOpta consists of a modeling and analysis framework, together with a collection of software tools, to facilitate reliability, fault-tree, uncertainty, sensitivity and optimization analyses (Engi, 2006). This analytical framework is designed to return valuable information on fleet readiness using existing failure and repair data. It also allows the data to be mined for additional information of significant value.

Mock, Ruminski, and Wallace (2009) analyze the operational and maintenance requirements of Landing Craft Utility (LCU) vessels assigned to Assault Craft Unit One (ACU-1) in order to develop a requirements-based financial model. LCU vessels are similar to LCAC vessels and are used to transport equipment and troops to the shore. LCUs are carried aboard amphibious assault ships to the objective area. The mission of the LCU is to land or retrieve personnel and equipment (tanks, artillery, equipment, motor vehicles) during amphibious operations (FAS, 2010a). Figure 2 gives an illustration of an LCU.

Figure 2. A Landing Craft Utility (LCU) heads to the beach during amphibious assault training. (U.S. Navy, 2009b)

Mock *et al.* (2009) attempt to quantify the number of LCUs required to perform assigned tasks based upon maintenance schedules, deployment cycles and training evolutions. A requirements-based financial model is developed taking into consideration the operational requirements of LCUs to forecast the resources needed to support the craft. The authors place emphasis on determining the current level of operational availability (Ao). Another area of their focus is to develop a better understanding of the actual requirements placed upon ACU-1; specifically, how operational availability impacts those requirements.

One of the recommendations made by Mock *et al.* (2009) is that ACU-1 should track craft status on a daily basis during operations and consolidate its information gathering into a single database. Specifically, the authors recommend that ACU-1 begin long-term daily tracking of LCU status based on three classifications: fully mission capable, partially mission capable and non-mission capable.

C. READINESS AND MAINTENANCE

1. General Policy

The LCAC Class Maintenance Plan (CMP) defines the maintenance strategy for LCACs including interfaces with related preventive maintenance and configuration management programs. The CMP specifies the maintenance strategy, procedures, responsibilities, and resources required for maintaining the craft during their life cycles. The objectives of the CMP are to define LCAC maintenance procedures and to assist in the planning, budgeting, and acquisition of resources to maintain the LCAC fleet (U.S. Navy, 2007).

The LCAC maintenance strategy is based on the concept of progressive maintenance. Progressive maintenance was originally developed for ships that were designed to operate within reduced manning requirements and that have been modified, where applicable, to reflect unique requirements of LCAC maintenance. The LCAC maintenance program is consistent with the Navy's transition to Condition Based Maintenance (CBM) which focuses on diagnostic systems and other Machinery Condition Analyses (MCA) in determining maintenance requirements (U.S. Navy, 2007).

The LCAC maintenance strategy is based on the removal and replacement of failed components to provide a quick turnaround time and maintain a high degree of operational readiness. Maintenance is performed at the lowest echelon capable of removing and replacing the component. When deployed, the craft crew and the detachment maintenance organization perform these tasks. If designated as repairable, the failed component is returned to the ACU Maintenance Department for evaluation and possible repair. Once the component has been repaired, tested and made ready it either is returned to the craft for installation, remains in the custody of the maintenance department's various repair centers, or is turned in to Real-time Reutilization Asset Management (RRAM). When maintenance tasks arise during a deployment that are beyond the capability of the detachment maintenance organization, assistance may be requested from intermediate maintenance activities within the deployed area. When craft are in a non-deployed status, the ACU Maintenance Department performs maintenance tasks that are beyond the capability of the craft crew and detachment maintenance personnel, including some PMS (Preventive Maintenance System). ACU maintenance availabilities are scheduled for accomplishment of pre/post-deployment inspections, corrosion inspection and repair, extended maintenance requirements, and previously deferred maintenance actions. Maintenance actions beyond the capability of the ACU are forwarded to depot-level activities (U.S. Navy, 2007).

Maintenance actions performed on the craft are documented and reported within Organizational Maintenance Management System Next Generation (OMMS-NG). These reports are analyzed by the in-service engineering agents (ISEAs) to statistically identify emerging trends to the Reliability and Maintainability (R&M) Report. This report is provided to the Naval Surface Warfare Center, Panama City (NSWC-PC) in addition to quarterly summaries of the R&M Data (U.S. Navy, 2007). Maintenance action reports and corrosion inspection results are also used in the development of work packages and specifications for SLEP and other availabilities (U.S. Navy, 2007).

2. Maintenance Requirements

The LCAC Maintenance Program includes routine preventive and corrective maintenance, maintenance of mission critical systems and equipment, maintenance tasks related to tests and inspections for personnel safety and the safe operation of the craft, and tasks directed by PMS377 (Amphibious Warfare Program). Preventive maintenance is scheduled and does not factor into availability. Availability is defined as the number of craft that are mission capable divided by the total number of craft. Mission capable craft are classified either as Fully Mission Capable (FMC), Partially Mission Capable (PMC), or Non Mission Capable. FMC is further delineated into two categories:

- FMC1, which implies that the craft is immediately ready to perform assigned duties; and
- FMC2, which implies that the craft is in an Inactive Equipment Maintenance (IEM) state whereby it can be ready for tasking within 72 hours if called upon.

NMC is further delineated into four categories:

- NMC1, which implies that the craft is non-operational due to parts requirements;
- NMC2, which implies that the craft that is non-operational due to required repairs;
- NMC3, which implies that the craft is non-operational due to scheduled ACU-5 maintenance availability; and
- NMC4, which implies that the craft is non-operational due to scheduled maintenance availability that is not performed locally (e.g. at the depot level).

The maintenance tasks summarized in the CMP are listed below (U.S. Navy, 2007):

a. Preventive Maintenance is scheduled and performed on each LCAC in accordance with PMS requirements. Maintenance actions are based on cyclical or craft operating hours. Reliability Centered Maintenance (RCM) logic was applied to the LCAC Class, both in developing PMS requirements and as an integral aspect of total craft logistic support planning.

b. Corrective Maintenance is performed when condition dictates or upon equipment failure. To minimize craft downtime, component replacement is used to the maximum extent possible. The failed component is then evaluated, repaired, and remains in the custody of the applicable work center until required for installation on a craft. Maintenance that cannot be performed immediately is scheduled for completion at the earliest feasible opportunity consistent with the availability of material and other resources necessary to accomplish the repair.

With the exception of craft in scheduled availabilities, any LCAC with a failed component that affects the Full Mission Capability (FMC) capabilities of the craft and cannot be repaired or replaced within 48 hours will be the subject of a Casualty Report (CASREP).

c. Craft Alterations (CRAFTALTS), and alterations-equivalent-to-a-repair (AERs) consisting of approved backfit changes to the craft, are installed based on priority, availability of materials, and opportunity.

d. ACU Maintenance Availabilities (MAs) for each detachment are scheduled to allow for inspections, extended maintenance requirements, corrosion control maintenance requirements, are previously deferred maintenance actions. These availabilities can range in length from six to twelve weeks in duration, but they may be extended as required to allow significant CRAFTALT installations by an Alteration Installation Team (AIT) working in conjunction with the ACU Maintenance Department. An LCAC Maintenance Availability is equivalent in function to the Intermediate Maintenance Availability (IMAV) defined by OPNAVINST 4700.7, "Maintenance Policy for Naval Ships."

e. Depot Availabilities (DAs) are maintenance actions performed by a contractor at the ACU with participation by the Planning Group, the craft In-Service Engineering Agent (ISEA), the Type Commander (TYCOM), local Regional Maintenance Centers (RMCs), and contract personnel. The DA provides the ACU with the time and technical support to perform extensive repairs, overhauls, and upgrades that would otherwise be beyond their capability. This availability is equivalent in function to the Selective Restrictive Availability (SRA) defined in OPNAVINST 4700.7.

f. Service Life Extension Program (SLEP) is a Chief Naval Operations (CNO) directed program to extend LCAC Service Life from 20 to 30 years. The SLEP work package includes major hull repair, replacements and corrosion prevention modifications. The obsolescent Command, Control, Communications, Computers & Navigation (C^4N) suite will be upgraded and an extensive corrosion abatement and alterations package will be accomplished. Enhancement to the main propulsion engines and installation of the deep skirt are included.

D. OPERATIONS-MAINTENANCE LIFE CYCLE

The CMP assumes that each LCAC is primarily utilized to meet operational commitments. While sufficient time to accomplish all required maintenance is necessary, maintenance should be planned in such a manner as to minimize craft down time and any impact on required operations. Maintenance availabilities should be scheduled by the Maintenance Department in coordination with the Operations Department. Although the ACU is not currently designated as an Intermediate Maintenance Activity (IMA) or part of the RMC, the Required Operational Capabilities (ROC)/Projected Operating Environment (POE) does require, and manning is provided, for the ACU shore Unit Identification Code (UIC) to perform LCAC specific IMA/Depot level work. LCAC scheduled maintenance availabilities should, therefore, be considered similar in function to the traditional Intermediate or Fleet Maintenance Availability (IMAV/FMAV) (U.S. Navy, 2007).

LCAC are required for a wide range of fleet operations up to and including deployments that may last six months or more. Under the Fleet Response Plan, sufficient LCAC to support four Expeditionary Strike Groups (ESGs) may be required at any time. Additional craft may be required to meet training requirements, other service allocations, amphibious ship well deck certifications, disaster relief operations, and various other missions. The ACU Operations Department schedules LCAC operations, and they should coordinate with the Maintenance Department to notify them when craft are available for a maintenance period. The Maintenance Department should provide the Operations Department with summaries of when major craft maintenance items such as 500-hour APU inspections, 1000-hour main engine inspections or propeller overhauls, Shipboard Instrumentation and System Calibration (SISCALs), Corrosion Control Inspection (CCIs), etc., are required (U.S. Navy, 2007).

When craft are not required to meet operations, maintenance availabilities should be scheduled as mentioned in the CMP for LCAC, (U.S. Navy, 2007):

a. Corrosion Control Inspection (CCI): A craft upkeep period is scheduled for one week prior to and two weeks after the CCI to facilitate preparations for the inspection and repair of deficiencies noted during the CCI. All PRI 1 and PRI 2 deficiencies are prioritized to ensure repair by the Maintenance Department and Detachment personnel during the upkeep period. All uncorrected deficiencies are deferred until they can be corrected in either a Restricted Availability (RAV) or a designated industrial availability. CCIs are scheduled semi-annually. For deployed craft, the semi-annual CCI are conducted by the maintenance detachment and scheduled in coordination with the ESG staff to best support the operational commitments of the deployment. The detachment attempts to correct all deficiencies either with assigned personnel or by screening to ESGIMA assets. Any deficiencies that cannot be corrected are prioritized and provided to the ACU Maintenance Department no later than 45 days prior to the end of deployment.

b. Shipboard Instrumentation and System Calibration (SISCAL): An LCAC also completes craft calibration at least once every three years. SISCAL is scheduled so that any deficiencies with craft instrumentation can be corrected prior to required operations for that craft.

c. Restricted Availabilities (RAVs): RAVs are scheduled to allow for major preventive maintenance work items and corrective maintenance to be performed utilizing the ACU maintenance facilities and capabilities. Craft undergo a RAV at least once every two years. RAVs are scheduled to maximize work throughput while minimizing the down time of the craft. The length of a RAV can be set by the ACU, but usually lasts about 12 weeks.

d. Craft Alterations (C/As) and Alterations Equivalent to Repair (AERs): Both C/As and AERs may be scheduled as craft availability and ACU maintenance personnel workload permits.

When scheduling RAVs, ACU Operations and Maintenance Departments should coordinate planning to minimize craft down time while maximizing utilization of the ACU maintenance facilities. Additionally, with System Upgrade Availabilities and the

SLEP program utilizing ACU hangars for production work, maintenance planners should coordinate with the Program Office to ensure that resources are not simultaneously committed to different programs and work efforts are not duplicated (U.S. Navy, 2007).

III. RESEARCH METHODS

This chapter describes the data on which the thesis research is based, and statistical methodology that is used to develop a model.

A. DATA COLLECTION

The research method used for this thesis is that of a retrospective study based on two sets of historical data:

- Craft Status Report (CSR) data, consisting of daily readiness status reports obtained ACU-5. ACU-5 maintains a collection of Excel spreadsheets on the daily readiness status and maintenance activity of all 40 LCAC vessels under its command. The data available for analysis cover a 317-day period for each of the 40 LCAC vessels from July 1, 2009 (when the data-collection effort was initiated) through May 13, 2010. The total number of records in the CSR data set is 12,680 (317 × 40).

- Maintenance data records obtained on LCACs from the Current Ship Maintenance Project (CSMP) database for the period January 1, 2008 through November 15, 2009. The total number of records in the CSMP data set is 15,929.

The craft status report spreadsheets obtained from ACU-5 give the status of each craft and the factors leading to a PMC or NMC status. The inferred factors that initiate unscheduled maintenance discrepancies are mapped from the system component level up to their associated high-level systems of LCAC operations. The craft employment spreadsheet identifies the current state of employment for each craft.

CSMP is a computer-produced report listing deferred maintenance identified through the Maintenance Data Collection System (MDCS) reporting. The purpose is to give shipboard maintenance managers a consolidated list of deferred corrective maintenance actions. The work center supervisor is responsible for ensuring the accuracy of the database and properly reflects the material condition of each craft.

B. SELECTION OF DATA FOR ANALYSIS

To support the thesis research the data must be sufficiently accurate and complete. In principle, the CSMP data should be satisfactory, because it is the data base of record for maintenance activity affecting LCACs. In practice, however, we find that the CSMP data are incomplete or inaccurate in critical areas. For example, an analysis of 8523 CSMP records with opening dates in 2008 shows that 10.2 percent (873 out of 8523) of these records do not have closing dates as of November 15, 2009. Although some maintenance actions may continue for extended periods of time, it is unlikely that such a large proportion of them are not completed nearly a year (or more) after they have been opened. A more likely explanation is that most of these maintenance actions were closed, but the CSMP data were not updated to reflect this fact. Additionally, we find no evidence in the CSR data that maintenance actions endure for such extended time periods at this level of frequency.

To further illustrate this point, a sample of CSMP data is evaluated against the Craft Status Report (CSR) data. The sample consists of eight identified discrepancies taken from the CSR reports of three LCAC units: 8, 23 and 29. Table 1 depicts the differences between the CSR and CSMP reporting of the listed discrepancies. In this sample no CSMP record was found in four out of the eight cases. In the other four cases the CSMP opening dates do not agree with those from CSR. Additionally, only one of the four CSMP records has a closing date.

Not having reliable closing dates is problematic because it directly affects the ability to know when an LCAC vessel is or is not in an available state. For this reason the thesis research focuses entirely on the CSR database for the remainder of the study.

Table 1. CSMP-CSR Comparison

LCAC	FMC DATE	EQUIPMENT	CSR DATE OPEN	CSR DATE CLOSED	CSMP OPEN	CSMP CLOSED
29	7/16/2009	CAMS	7/17/2009	7/29/2009	7/20/2009	ND
		STBD A/C	7/17/2009	7/30/2009	7/23/2009	ND
		#2 GBX SEAL	7/17/2009	8/5/2009	7/9/2009	9/30/2009
		STBD A/C	8/6/2009	8/16/2009	Missing CSMP entry	--
8	8/12/2009	M/E Switch	8/13/2009	8/16/2009	Missing CSMP entry	--
23	8/20/2009	SCE CARDS	8/21/2009	9/6/2009	Missing CSMP entry	--
		B/T	9/1/2009	9/6/2009	Missing CSMP entry	--
		Skirt	9/2/2009	9/6/2009	8/14/2009	ND

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IV. ANALYSIS

This chapter describes the application of the methodology to the data, and the use of resulting statistical models to forecast the number of available LCACs.

A. REQUIREMENTS ANALYSIS

1. CSR Database

We created a CSR database on S-Plus ® version 8.0.4 for Microsoft windows: 2007 using the craft status report worksheet. Table 2 depicts the CSR database.

Table 2. Craft Status Report Database

	Variable Name	**Description**
a.	LCAC	The individual LCAC vessels identified by their assigned unit numbers. The 40 vessels under the command of ACU-5 have the following unit numbers: 8,9,10,14, 16, 17, 21, 23, 24, 29, 30, 31, 32, 33, 40, 42, 43, 44, 45, 47, 48, 52, 56, 57, 58, 59, 62, 63, 64, 65, 72, 73, 74, 75, 76, 79, 80, 81, 82, and 90.
b.	Date	Any of the dates in the 317–day range from July 1, 2009 to May 13, 2010.
c.	Employment Status	Each LCAC is assigned an employment status daily consisting of ACU-5 (craft locally available for use by ACU-5); Workups (craft making preparation for an upcoming deployment); Deployed (craft currently on a deployment); Surge (craft recently returned from a deployment that is operationally ready to redeploy); Local Availabilities (craft scheduled for organizational and intermediate maintenance actions); Program Availabilities (craft scheduled for depot maintenance actions); and West Pac Alpha (craft permanently assigned to Sasebo, Japan).
d.	Craft Status	The daily status of each craft: Fully Mission Capable (FMC), Partial Mission Capable (PMC), and Non Mission Capable (NMC), with subdesignations for FMC (FMC1, FMC2) and NMC (NMC1, NMC2, NMC3, and NMC4)

	Variable Name	Description
e.	Major System	The primary system identified as causing a craft to be either NMC or PMC.
f.	CSR 1-7	These seven field identify primary, secondary, tertiary, etc. subsystems or components that are implicated in a craft not being fully mission capable.

2. System Components Database

The analysis requires a systems-components database that maps the major systems of an LCAC down to its subcomponent level (Major System, System, Sub-system, Component, and Sub-component). The major systems are classified as one of the following: Hull, Skirt, Propulsion, Craft Controls, Auxiliary, Fuel, Electrical, Communications/Navigation, Corrosion, Preventive Maintenance (PMS), or Availabilities (Local and Depot).

B. LCAC AVAILABILITY ANALYSIS MODEL

1. Model Concept

Suppose that there are L LCAC craft ($L = 40$). On day t let $A_j(t) = 1$ if craft j is available, and let $A_j(t) = 0$ if craft j is not available. The total number of craft available on day t is the sum of these variables over all craft on that day:

$$A(t) = \sum_{j=1}^{L} A_j(t)$$

Our objective is to produce a good prediction (estimate) for $A(t+d)$, d days in advance based on all information available on day t. The following are examples of the information that we would want to exploit:

1. Knowledge that on day $t+d$ craft j will not be available for deterministic reasons (e.g. SLEP or other planned maintenance activities). If that is the case then $A_j(t+d)=0$ automatically.
2. Knowledge that on day t craft j is in a particular mission capability status (NMC1, NMC2, PMC, etc.). This knowledge cannot perfectly predict availability d days in advance. In other words, future availability of a particular craft is a random outcome.
3. If craft j is in an unscheduled maintenance state (or awaiting parts) on day t it may be of interest to know which components or systems are involved.
4. Individual craft are more reliable or less reliable than others due to their ages and other factors that may or may not be known.

The outcome variable, availability, can take any of several forms. For example, availability can be taken to mean "fully mission capable" (FMC1) which implies that the craft is immediately available or FMC2 implying that it can be brought to this state within several days. Including partially mission capable (PMC) craft broadens the definition of availability even further. In this thesis we adopt the broadest definition of availability, and include FMC1, FMC2, and PMC readiness ratings.

Next we discuss predictor variables and their role in statistical modeling. On day t each craft has a set (vector) of p predictor variables that we denote $\mathbf{X}_j(t)=(X_{j,1}(t),\ldots,X_{j,p}(t))$. We make the critical assumption that factors that affect a given craft's availability are independent of those that apply to any other craft. And, we assume that availability is independent across craft.

A prediction model for number of craft available on day $t+d$ takes the following form:

$$A(t+d\,|\,t)=\sum_{j=1}^{L}E\left[A_j(t+d)\,|\,\mathbf{X}_j(t)\right]=\sum_{j=1}^{L}P\left[A_j(t+d)=1\,|\,\mathbf{X}_j(t)\right]$$

In short, this model adds all of the conditional probabilities of the individual craft availabilities. Our task is to estimate these conditional probabilities from the available data:

$$\hat{A}(t+d \mid t) = \sum_{j=1}^{L} \hat{P}\left[A_j(t+d) = 1 \mid \mathbf{X}_j(t) \right].$$

To produce the forecasts we use logistic regression, which is described by the following model:

$$\operatorname{logit}\left\{ P\left[A_j(t+d) = 1 \mid \mathbf{X}_j(t) \right] \right\} = \gamma_j + \sum_{k=1}^{p} \beta_k X_j(t)$$

$$P\left[A_j(t+d) = 1 \mid \mathbf{X}_j(t) \right] = \frac{\exp\left[\gamma_j + \sum_{k=1}^{p} \beta_k X_j(t) \right]}{1 + \exp\left[\gamma_j + \sum_{k=1}^{p} \beta_k X_j(t) \right]}$$

Note that the regression coefficients β_k are assumed to be the same across all of the craft. This is a critical assumption given the relatively small amount of data that we have. However, each craft is allowed to have its own individual "adjustment factor" given by the term γ_j, which becomes part of the availability prediction.

Estimation of the model parameters can be performed using many available statistical software packages, including S-Plus. Note, however, that the data we use are not independent due to strong serial correlation. Lack of independence does not invalidate the estimates, although it does invalidate the estimated standard errors obtained from approximations that assume independence. There are $L + p$ parameters to be estimated: $\gamma_1, \ldots, \gamma_L$ and $\beta_1, \ldots, \beta_p$. When the estimated parameters are substituted into the expression for the logistic regression model a forecast is obtained for the number of craft available d days into the future:

$$\hat{A}(t+d\,|\,t) = \sum_{j=1}^{L} \hat{P}\left[A_j(t+d)=1\,|\,\mathbf{X}_j(t)\right] = \sum_{j=1}^{L} \frac{\exp\left[\hat{\gamma}_j + \sum_{k=1}^{p} \hat{\beta}_k X_j(t)\right]}{1+\exp\left[\hat{\gamma}_j + \sum_{k=1}^{p} \hat{\beta}_k X_j(t)\right]}.$$

Because the number of available craft d days into the future is random, it is useful to provide a prediction interval for this quantity. If the availability status of each craft is assumed to be independent of others, a rough approximation of the prediction variance is obtained using the formula

$$\hat{\sigma}_d^2 = \text{est. } Var\left[\hat{A}(t+d\,|\,t)\right] \approx \sum_{j=1}^{L}\left\{\hat{P}\left[A_j(t+d)=1\,|\,\mathbf{X}_j(t)\right] - \hat{P}^2\left[A_j(t+d)=1\,|\,\mathbf{X}_j(t)\right]\right\}$$

which is the estimated variance for the sum of independent Bernoulli random variables. This formula does not account for variability due to the estimation of parameters (although it is possible to make a correction for this effect). Alternately, one can use a conservative formula based on the fact that the maximum possible variance of a Bernoulli random variable is .25, which is the right-hand side of the following inequality:

$$\sigma_d^2 = Var\left[\hat{A}(t+d\,|\,t)\right] \le .25L\,.$$

With $L = 40$, for example, $\sigma_d^2 \le 10$ and $\sigma_d \le 3.2$. An approximate 95 percent prediction interval for the number of available LCACs d days into the future uses a normal approximation and takes the form

$$\hat{A}(t+d\,|\,t) \pm 2\hat{\sigma}_d$$

2. Design Matrix Variables

We use S-Plus software to construct design matrices for use in predicting availability a specified number of days (no.days) days in advance. By default, no.days is taken to be 7 (i.e., prediction of availability one week in advance), but the software allows this value to be specified by the user. The CSR data set is used to estimate the model logistic regression parameters using maximum likelihood, accessed through the **glm** command in S-Plus. The predictor variables considered in modeling are listed in Table 3.

Table 3. CSR Data Set Variables

	Variable Name	Description
a.	LCAC	LCAC (which craft it is)
b.	Date	Date of current availability status (starts no.days after the first date appearing in X)
c.	Status	Status of the craft on that day (FMC1, NMC4, etc.)
d.	Status.Prior	Status no.days prior to that day
e.	Elig.Today	Eligible for availability based on information no.days days prior Eligible = T if it could have been available; = F otherwise
f.	No.Elig	Number of days that the craft was eligible for availability during the last reachback days, where the default is reachback = 7 (this is missing if the number of reachback days required are not available)
g.	No.Avail	Number of days that the craft actually was available during the last reachback days
h.	Consec.Avail	Consecutive days (counting back from no.days prior to current date) that the craft was available
i.	Consec.Unavail	Consecutive days (counting back from no.days prior to current date) that the craft was unavailable
j.	Maj.Sys.Prior	Major System indicated no.days prior to the current day. Useful if Status on that day is NMC1 or NMC2
k.	Corr.Prior	In a Corrosion-related state no.days prior to that day (T/F)
l.	Prop.Prior	In a Propulsion-related state no.days prior to that day (T/F)
m.	Hull.Prior	In a Hull-related state no.days prior to that day (T/F)
n.	Skirt.Prior	In a Skirt-related state no.days prior to that day (T/F)
o.	Aux.Prior	In a Auxiliary-related state no.days prior to that day (T/F)

	Variable Name	Description
p.	Fuel.Prior	In a Fuel-related state no.days prior to that day (T/F)
q.	Elec.Prior	In an Electrical-related state no.days prior to that day (T/F)
r.	Comm.Prior	In a COMM/NAV-related state no.days prior to that day (T/F)
s.	Craft.Prior	In a Craft-controls related state no.days prior to that day (T/F)

A number of logistic regression models are compared using Availability as a binary independent variable and various subsets of predictor variables listed in Table 4. The **stepAIC** function provided in the S-Plus library MASS is used to identify subsets of predictor variables that have good explanatory power leveraged against the number of parameters that the models require. Some of the models identified by **stepAIC** are listed in Table 4.

Table 4. Model Comparisons

Model	Mean Absolute Error	Predictor Variables
1.	1.65	LCAC + All individual Major System regressors
2.	1.74	LCAC + Corr.Prior + Prop.Prior + Skirt.Prior
3.	1.71	LCAC + Corr.Prior + Prop.Prior + Skirt.Prior + Consec.Unavail
4.	1.76	LCAC + Corr.Prior + Prop.Prior
5.	1.98	LCAC + Corr.Prior
6.	1.95	LCAC + Prop.Prior
7.	2.12	LCAC + Skirt.Prior
8.	2.16	LCAC + Aux.Prior
9.	2.08	LCAC + Fuel.Prior
10.	2.15	LCAC + Elec.Prior
11.	2.14	LCAC + Comm.Prior
12.	2.10	LCAC + Craft.Prior

Model	Mean Absolute Error	Predictor Variables
13.	1.50	LCAC + Maj.Sys.Prior
14.	1.49	LCAC + Status.Prior
15.	1.92	LCAC + Consec Avail
16.	1.77	LCAC + Consec Unavail
17.	1.49	LCAC + Status.Prior + Consec Unavail
18.	1.50	LCAC + Status.Prior + Consec Unavail + Corr.Prior + Prop.Prior

From Table 4 four models stand out as having better predictive power than others due to their having the lowest mean absolute errors: Models 13, 14, 17, and 18. It was decided that the focus would be on Models 13 and 14, due to their having fewer independent variables than Models 17 and 18. Although **stepAIC** accounts for the number of variables, this function also assumes that the observations are independent, which is not the case with the CSR data.

Figure 3 provides a graphical comparison of the forecast values of the number of available LCACs, $\hat{A}(t+d\,|\,t)$ with $d=7$, obtained from Models 13 and 14. These plots show the forecast values (solid lines) against the actual number of available LCACs (asterisks). Data for 310 days (317 minus 7) are shown in Figure 3. Table 4 suggests that Models 13 and 14 have almost the same prediction accuracy, with a mean absolute prediction error of about 1.5 vessels. Model 13 implies that, given the major systems identified as the cause of the unavailability of each LCAC on a particular day, one can predict the number of available LCACs at ACU-5 seven days later with an error of approximately 1.5 vessels for the data used to fit the model. The prediction error is expected to be slightly larger for future data. Because Model 14, which uses Status.Prior as a predictor variable, has a slightly smaller mean absolute prediction error (1.49 vessels) it was selected as the final prediction model. Logistic regression results for Model 14 are listed in Appendix B.

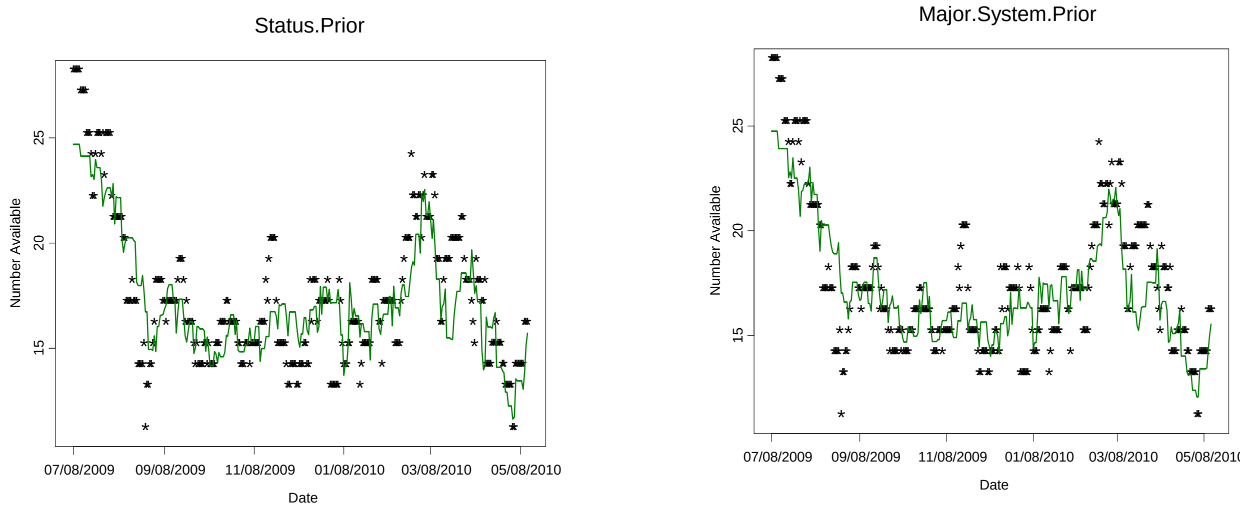

Figure 3. Comparison of Model 13 (right) and 14 (left) predicted daily availability (green line) against actual daily availability (asterisks).

3. Model Interpretation

The logistic regression model with coefficients shown in Appendix B also gives useful information about factors that are important to predicting availability. There are 39 coefficients for the 40 LCAC vessels at ACU-5, with LC08 not having a coefficient because it is assigned a value of zero by default. Coefficients for the other vessels give an indication of their availability relative to LC08. It is seen that LC10 and LC30 stand out as being more available than other vessels, while LC74 stands out as being less available. Figure 4 illustrates these relative effects.

Figure 4 also suggests that positive coefficients tend to be more associated with smaller LCAC unit numbers, and negative coefficients with larger LCAC unit numbers. It is possible that this trend is related to factors such as the age of the vessel or its pattern of usage that in turn are related to the unit number assigned to the vessel. For example, LCAC vessels with unit numbers less than or equal to 48 either had been or were undergoing SLEP during the time frame of the data used in the thesis research. Vessels with unit numbers greater than 48 had not undergone this restoration process.

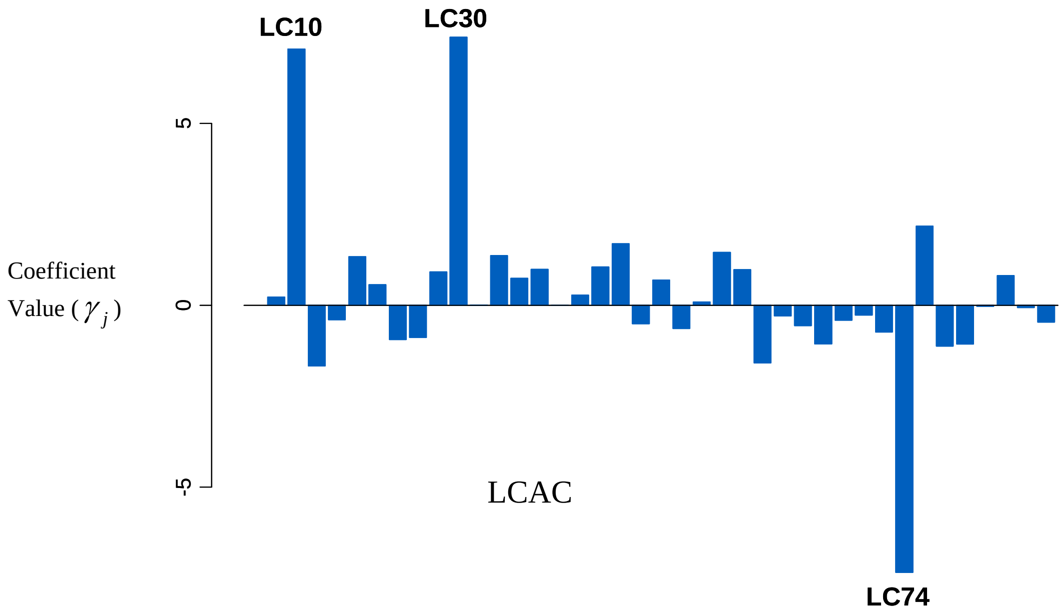

Figure 4. Bar chart of the LCAC coefficients from the logistic regression used in Model 14. Larger positive values indicate greater likelihood of availability.

Similarly, Figure 5 shows the logistic regression coefficients of the Status.Prior predictor variable in the form of a bar chart. Here FMC1 is assigned a value of zero by default. The coefficients therefore describe increased (positive) or decreased (negative) availability relative to vessels that are in FMC1 status at the time that the seven-day forecasts are generated. It is seen that FMC2 status suggests a greater likelihood of availability than FMC1, which is sensible because a craft in FMC2 status is capable of being brought to FMC1 status within a few days, but is not accumulating usage. PMC status suggests a slightly lower likelihood of availability than FMC1, and is notably better than any of the NMC status designations.

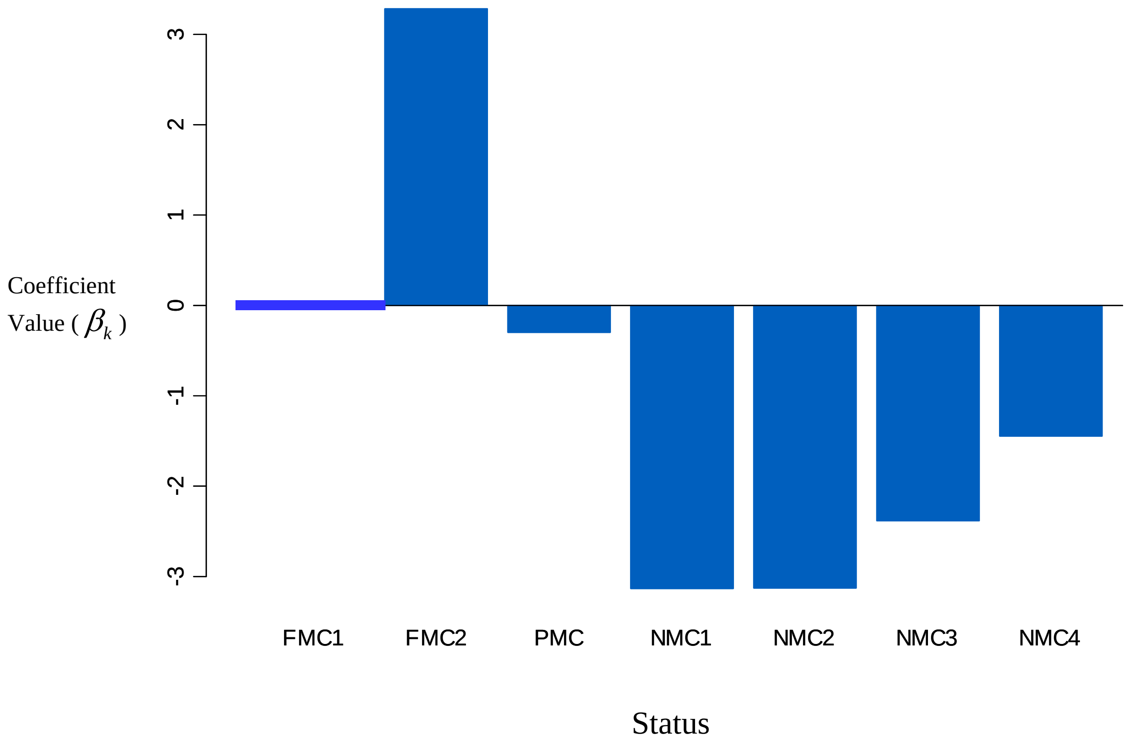

Figure 5. Bar chart of the Status.Prior coefficients from the logistic regression used in Model 14. Larger positive values indicate greater likelihood of availability.

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V. CONCLUSIONS

A. SUMMARY OF RESULTS

1. Model Selection

The results of this study suggest that model 14 (using LCAC unit and current readiness status as predictor variables) is the most accurate model for predicting availability, based on the data available for analysis. This model has a mean absolute prediction error of 1.49 vessels (for prediction seven days into the future) and a prediction standard error of 2 to 3 vessels. Model 14, which uses the LCAC unit and the system involved in any current maintenance action as predictors, has performance that is very similar to that of Model 13. Corrosion and propulsion are the two systems that are indicated most frequently in maintenance activity. The prediction error can be expected to increase if a model is used to predict availability a greater number of days into the future.

2. Individual LCAC Availability

LCAC vessels with unit numbers LC10 and LC30 stand out as being more available than other vessels, while LC74 stands out as being less available. There is a slight but observable trend whereby availability decreases as the LCAC unit number increases, which might be related to the restoration histories of these vessels.

3. Research Questions

We now revisit the three research questions posed in Chapter 1 and answer them in light of the findings obtained from the research presented in this thesis:

1. How should existing maintenance and mission-capability data on LCACs be used to define quantitative indicators that are useful to predict availability?

We should use the data to create a statistical model that predicts the future availability status of an LCAC.

2. What kind of a statistical model should be used to predict the availability status of an LCAC?

A prediction model that adds all of the conditional probabilities of the individual craft availabilities should be used to predict future LCAC availability. We can estimate these conditional probabilities from the available data and produce the forecasts using logistic regression.

3. How can the statistical model be converted into a tool for a CO to predict how many mission-capable LCACs are available on a given day?

An LCAC Availability Predictor (LAP) version 1.0 Excel spreadsheet tool can assist ACU-5 commanding officer in the decision making process. The tool applies coefficient calculations for each LCAC and current status coefficient calculations. This produces a predictive score for each LCAC between the values 0 (unavailable) and 1 (available). All of the LCAC scores can then be summed to provide an overall predictive availability. See Appendix C for the Excel Spreadsheet Tool.

B. FUTURE WORK

This thesis provides a template for research that can, and should, be continued into the future. Some areas for additional research are identified below:

1. Updating the Availability Prediction Model

As the LCAC fleet ages and its mission requirements change, it is likely that the statistical model for predicting availability will need to change as well. Periodic updates of the model with more current data are recommended. Additional data, particularly with respect to the reliability of the LCAC vessels, also would allow new explanatory variables to be derived that could improve the predictive accuracy of the model.

ACU-5 should maintain this effort level of collecting craft status data. This level of effort will support future studies that can be conducted extending past this approximate 9 months of data. A similar study can be done extending the data set past two years capturing the full Inter-Deployment Training Cycle (IDTC). This additional data can assist in creating reliability modeling techniques to identify the primary factors that drive unavailability.

An approach similar to that of this thesis also can be used to analyze the availability of the LCAC fleet at ACU-4 in Little Creek Virginia. The results may be useful to the Assault Hovercraft Program Office located in Panama City, Florida.

2. Operational Availabilities Applications

The operational availability prediction modeling developed in this thesis can be applied to other vehicle fleets (land, sea, or air) for which a readiness classification such as Fully Mission Capable (FMC), Partial Mission Capable (PMC), and Non-Mission Capable (NMC) are used.

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APPENDIX A. LCAC SPECIFICATIONS

Table 5. LCAC Specifications (FAS, 2000)

LCAC Specifications	
Builder	Textron Marine and Land systems Lockheed Avondale Gulfport Marine
Power Plant	Four Avco-Lycoming gas turbines; 12,280 bhp; two shrouded reversible-pitch propellers; four double-entry fans for lift
Length	88 feet
Beam	47 feet
Displacement	200 tons full load
Capacity	60 tons/75 ton overload
Speed	40 plus knots with payload
Armament	2 - 12.7mm MGs. Gun mounts will support: M-2HB .50 cal machine gun; Mk-19 Mod3 40mm grenade launcher; M-60 machine gun
Crew	5
Range	200 miles at 40 kts with payload 300 miles at 35 kts with payload
Availability	LCACs per Day (from a total of 54) Day One – 52 Day Two – 49 Day Three – 46 Day Four – 43 Day Five - 40
Operating Time	16 hours per day per LCAC
Time per Sortie	Vehicle Load – 6 hours, 8 min Cargo Load – 8 hours, 36 min
Sorties per Day for Vehicles	• 2.6 sorties per LCAC per day • Total = 104 LCAC sorties per day @ 40 LCACs per day

LCAC Specifications	
Sorties per Day for Cargo	• 1.86 sorties per LCAC per day • Total = 74 LCAC sorties per day @ 40 LCACs per day
Personnel Capacity	24 Troops 180 w/PTM
Short Tons per Sortie	25 STONS 50 pallets (500 lbs per pallet)
Vehicles per Sortie	12 HMMWVs per sortie 4 LAVs per sortie 2 AAVs per sortie 1 M1A1 per sortie 4 M923 per sortie 2 M923 5-Ton Trucks,2 M198 Howitzers, and 2 HMMWVs per sortie
Time Details	Transit (45 NM @ 25 kts) x 2 = 216 min Well Deck Ops 62 min for vehicles 120 min for cargo Beach Ops 30 min for vehicles 120 min for cargo Friction = 60 min Total = 368 min (for vehicles) or 516 min (for cargo)
Unit LCAC Sortie Requirements	Infantry Regiment • 269 HMMWVs = 23 sorties • 10 5-Ton Trucks = 3 sorties Tank Battalion • 58 M1A1 = 58 sorties • 95 HMMWVs = 8 sorties • 23 5-Tons = 6 sorties • 8 Fuel Trucks = 4 sorties LAV Battalion • 110 LAVs = 28 sorties • 29 HMMWVs = 3 sorties • 23 5-Tons = 6 sorties • 8 Fuel Trucks = 4 sorties
Support Ship Capacity:	• LSD 41 Class.............4 LCAC • LSD 36 Class.............3 LCAC

LCAC Specifications	
	• LPD-4 Class................1 LCAC • LPD-17 Class.............1 LCAC • LHA Class...................1 LCAC • LHD Class...................3 LCAC

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APPENDIX B. LOGISTIC REGRESSION RESULTS

There are 39 coefficients for the 40 LCAC vessels with exception of LC08, which by default, is assigned a value of zero. Coefficients for the other vessels give an indication of their availability relative to LC08. It is seen that LC10 and LC30 stand out as being more available than other vessels, while LC74 stands out as being less available.

FMC1 is assigned a value of zero by default. The coefficients therefore describe increased (positive) or decreased (negative) availability relative to vessels that are in FMC1 status at the time that the seven-day forecasts are generated. It is seen that FMC2 status suggests a greater likelihood of availability than FMC1, which is sensible because a craft in FMC2 status is capable of being brought to FMC1 status within a few days, but is not accumulating usage. PMC status suggests a slightly lower likelihood of availability than FMC1, and is notably better than any of the NMC status designations.

Table 6. Logistic Regression Results

LCAC	Coefficient	SE	t-value
8	0		
9	0.23	0.27	0.85
10	7.05	2.65	2.65
14	-1.67	0.32	-5.27
16	-0.40	0.32	-1.25
17	1.33	0.39	3.39
21	0.57	0.24	2.35
23	-0.94	0.29	-3.24
24	-0.88	0.31	-2.85
29	0.92	0.26	3.52
30	7.37	5.28	1.40
31	0.01	0.24	0.03
32	1.37	0.30	4.63
33	0.74	0.26	2.83
40	0.99	0.26	3.76
42	0.00	0.24	0.00

LCAC	Coefficient	SE	t-value
43	0.28	0.34	0.83
44	1.05	0.27	3.95
45	1.69	0.43	3.94
47	-0.51	0.29	-1.73
48	0.69	0.31	2.21
52	-0.64	0.23	-2.81
56	0.09	0.26	0.35
57	1.46	0.30	4.80
58	0.98	0.26	3.71
59	-1.58	0.28	-5.56
62	-0.29	0.21	-1.34
63	-0.56	0.22	-2.48
64	-1.06	0.23	-4.54
65	-0.41	0.23	-1.77
72	-0.26	0.22	-1.19
73	-0.73	0.25	-2.92
74	-7.34	2.50	-2.93
75	2.18	0.45	4.85
76	-1.12	0.24	-4.63
79	-1.06	0.24	-4.49
80	-0.03	0.23	-0.12
81	0.82	0.28	2.96
82	-0.06	0.23	-0.27
90	-0.46	0.30	-1.52

	Coefficient	SE	t-value
FMC1	0.00		
FMC2	3.28	1.01	3.25
NMC1	-3.13	0.09	-33.27
NMC2	-3.13	0.10	-32.09
NMC3	-2.38	0.13	-17.80
NMC4	-1.45	0.33	-4.34
PMC	-0.30	0.11	-2.60

APPENDIX C. EXCEL SPREADSHEET TOOL

An LCAC Availability Predictor (LAP) version 1.0 Excel spreadsheet tool will be delivered to ACU-5 to assist the commanding officer in the decision making process. The spreadsheet is comprised of each LCAC, a user drop down menu of the current status, and a user drop down menu depicting a future availability status based on the craft's operational schedule. This information is applied to the historical coefficient calculation for each LCAC and current status historical coefficient calculation. This produces a predictive score for each LCAC between the values 0 (unavailable) and 1 (available). All of the LCAC scores can then be summed to provide an overall predictive availability. The spreadsheet also computes a 90 percent and 95 percent confidence interval for the decision maker. Table 7 is an example of the Excel spreadsheet predictive tool.

Table 7. Excel Spreadsheet Predictive Tool

LCAC	**Status** Today	Scheduled Availability (+7)
8	FMC2	no
9	FMC1	no
10	NMC2	no
14	FMC1	yes
16	NMC1	yes
17	NMC4	no
21	PMC	yes
23	FMC1	yes
24	FMC1	yes
29	FMC1	yes
30	FMC1	yes
31	PMC	yes
32	NMC2	yes
33	FMC1	yes
40	FMC1	yes
42	NMC2	yes
43	FMC2	yes
44	NMC1	yes
45	NMC4	no
47	PMC	yes
48	FMC1	yes
52	FMC2	yes

RESULTS

Total craft Available =	23.7	
Prediction Std Dev =	2.05	
95% Prediction Interval =	20	28
90% Prediction Interval =	20	27

LCAC	**Status** Today	Scheduled Availability (+7)
56	FMC1	yes
57	NMC4	yes
58	PMC	yes
59	NMC2	yes
62	FMC2	yes
63	FMC1	yes
64	NMC2	yes
65	FMC2	yes
72	NMC1	yes
73	NMC4	yes
74	PMC	yes
75	FMC1	yes
76	FMC1	yes
79	FMC1	yes
80	NMC4	yes
81	PMC	yes
82	NMC2	yes
90	PMC	yes

APPENDIX D. ADDITIONAL BACKGROUND INFORMATION

A. BACKGROUND

The Special Combat Forces Pacific is a specialized organization tasked with supporting Naval Amphibious operations conducted by the United States Navy and the United States Marine Corps. These forces on the west coast are organized under Commander, Naval Beach Group ONE (NBG-1) headquartered at Naval Amphibious Base (NAB), Coronado, California (U.S. Navy, 2010c). Commander, NBG-1, consisting of Amphibious Construction Battalion ONE (ACB-1), Assault Craft Unit ONE (ACU-1), Assault Craft Unit FIVE (ACU-5), and Beachmaster Unit ONE (BMU-1), provides beach traffic control and security, Navy lighterage, side loadable warping tugs, bulk fuel transfer systems, landing craft (LCUs, LCM-8s, and LARC Vs), limited construction capability and surf salvage capability. Additionally, NBG-1 conducts amphibious operations and exercises in the Eastern Pacific, Western Pacific, Indian Ocean and Arabian Gulf areas (U.S. Navy, 2010c).

B. OTHER UNITS IN NAVAL BEACH GROUP ONE (NBG – 1)

1. Assault Craft Unit (ACU – 1)

ACU-1 is based at Naval Amphibious Base Coronado in San Diego, California. ACU-1 is responsible for 18 Landing Craft, Utility (LCU) and 14 Landing Craft, Mechanized (LCM-8) based in San Diego, CA and Sasebo, Japan; and support of four Naval Reserve Detachments. Established in 1947, ACU-1's mission is to operate, maintain, and provide assault craft as required by the Amphibious Task Force Commander for waterborne ship to shore movement during and after an amphibious assault. It provides crews to assist in the offload of Maritime Prepositioning Force ships to support military or relief operations ashore (Global Security, 2005a). ACU-1 is an element of the NBG-1. The mission of ACU-1 is to operate, maintain and provide assault craft as required by the Amphibious Task Force Commander for water borne ship to shore movement during and after an amphibious assault. ACU-l works together with its sister commands, ACB-1 and the Beachmaster Unit ONE (BMU-1) to fulfill a variety of missions and tasks. Various tasks from ACU-1 regularly include the provision of assault craft in support of the landing of a Marine Amphibious Brigade and a Marine Amphibious unit simultaneously over one colored and one numbered beach. ACU-1 also provides assault craft for assault operations within short distances of the assault beaches, and for transportation and installation of the amphibious assault bulk fuel system (Global Security, 2005a).

2. Beachmaster Unit ONE (BMU – 1)

Beachmaster Unit One, located at Naval Amphibious Base Coronado, California, is a member command of Naval Beach Group ONE. Beachmaster Unit One is the Naval Element of the Landing Force Shore Party (LFSP). The mission of BMU One is to support the landing movement over the beaches of troops, equipment and supplies, and to facilitate the evacuation of casualties and prisoners of war. In addition, the Beachmasters provide the following: maintain communications and liaison with designated naval commanders and naval control units; control all craft and amphibious vehicles in the vicinity of the beach from the surf line to the high water mark; coordinate the reembarkation of equipment, troops and supplies; determine and advise on the suitability for landing through coordination with the Oceanographic Section of the Sea, Air, Land (SEAL); control boat salvage; keep appropriate Navy commanders appraised of wind and surf conditions; install causeway beaching range markers and range lights; and assist in the defense of the beach (U.S. Navy, 2010b).

3. Amphibious Construction Battalion (ACB – 1)

Based out of Naval Amphibious Base Coronado, California, ACB-1 is the support element of the Naval Construction Force, better known as the SeaBees, for amphibious operations in the Pacific Fleet. The primary mission of ACB-1 is to provide ship to shore transport of fuel, materials, equipment and water in support of the Amphibious Ready Group (ARG), Marine Expeditionary Force (MEF), and Maritime Prepositioning Force

(MPF) operations. The Battalion provides barge ferry operations, camp support, perimeter defense and limited construction support for these operations. ACB-1 Motto is “We put the sea in SeaBees.” These SeaBees are trained to build facilities in support of the operations on shore with no established infrastructure. They are trained in construction disciplines such as steelwork, electrical, and equipment operations as well as ground combat skills. The SeaBee’s Motto, “We Build, We Fight,” is a testament to their ability to operate in hostile environments where they need to provide their own security and in some cases fight as infantrymen. Major systems include: Causeway Barge Ferry Transport System Side Loadable Warping Tugs (SLWTs), Powered Causeway Sections (CSPs), NonPowered Causeway Sections (CSNPs); Elevated Causeway System (Modular) ELCAS(M); Roll on/Roll off Discharge Facility RRDF; Amphibious Assault Bulk Fuel/Water System (AABF/WS); Offshore Petroleum Discharge System (OPDS); Civil Engineer Support Equipment (CESE); and over 300 construction and support vehicles, including cranes, bulldozers, electric generating plants, etc.; Expeditionary Camp (Life support up to 1200 personnel); and Defensive Combat Operations (M16 rifles, M9 pistols, M500 shotguns, M240 and 50 Cal crew-served weapons and the M203 grenade launcher) (U.S. Navy, 2010a).

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APPENDIX E. MAKEUP OF MARINE AMPHIBIOUS READY GROUP

A MARG (Marine Amphibious Ready Group) consists of a flotilla of assault ships, comprising an Amphibious Ready Group [ARG], with Marines onboard. The ARG configuration will vary with each deployment, but the configuration will always provide the ARG commander the ability to launch and recover Marine helicopters and deploy landing craft, including the LCAC, Landing Craft Air Cushioned, the Navy's amphibious hovercraft. The composition of the Group runs the entire spectrum of amphibious warfare with Amphibious Squadrons, a Naval Beach Group, a Tactical Air Control Group, and a number of ships and typically over 10,000 personnel (Global Security, 2005b).

Through the mid-1990s the LPH-2 Iwo Jima-class would deploy with one LPD and two LSDs. With the retirement of the less capable LPHs, LHAs and LHDs deploy with one LPD and one LSD. The exception is the LHD-2 Essex, which is permanently forward deployed with LPD 10, LSD 42 and LSD 43 in Japan. These ships are having a long-standing association with the forward-deployed Amphibious Squadron (PHIBRON) 11 and MEU 31. Otherwise, the composition of the MARG varies from deployment to deployment. This is unavoidable, given that there are five LHA/LHD deployable from each coast, four PHIBRON command elements, and three MEU Marine Corp Teams. The PHIBRONs and MEUs deploy in sequential rotation, as do the ships of the ARG, though the later exhibit rather more variation reflecting maintenance status (Global Security, 2005b).

Today, it is common for an ARG to be part of an ESG. The Expeditionary Strike Group—sometimes called an Expeditionary Strike Force—is a revamped amphibious ready group with the ability to disperse strike capabilities across a greater range of the force, increasing the striking power in the amphibious ready group. ESGs would enable the fleets to cover more parts of the world effectively, providing highly mobile, self-sustaining forces that are able to undertake missions across the entire spectrum. The ESG concept allows the Navy to field 12 Expeditionary Strike Groups and 12 Carrier Battle Groups, in addition to surface action groups of operations. The ESG concept could almost double the number of independent operational groups the Navy can deploy in the future, from 19 to 38. The expeditionary strike group—made up of amphibious ships, cruisers, destroyers and submarines—is a departure from the typical carrier battle group/amphibious ready group structure. An expeditionary strike group could include amphibious ships, a destroyer, cruiser, frigate, attack submarine and a P-3C Orion land-based aircraft. The new mix, which deploys in place of the amphibious ready group, allows Navy and Marine Corps forces to launch Marines and landing craft as warships and submarines strike inland targets with missiles and shells. Currently, each amphibious ready group is made up of an amphibious assault ship, a dock landing ship and an amphibious transport dock. Cruisers and destroyers deploy with carrier battle groups (Global Security, 2005c).

The amphibious fleet is organized for forward presence into twelve ARGs (which in turn become part of Expeditionary Strike Groups), each with three ships. The centerpiece of the ARG is a Wasp-class or Tarawa-class amphibious assault ship. The five ships of the Tarawa class general-purpose amphibious assault ships (LHA) reach the end of their expected service lives at the rate of one per year from 2011 to 2015. LHD 8 replaced LHA 1, leaving the LHA(R) program to replace the last four Tarawa-class LHAs (Global Security, 2008a).

The Marines Air Combat Element (ACE) is a combined squadron of 28 aircraft that embarks the LHD/LHA to offer aviation support to the MEU. The squadron consists of different aircraft types to support the various requirements of the MEU. A recent squadron deployment consisted of 12 CH-46D Sea Knight helicopters for troop/supply missions, six AV-8B Harrier II's for close in ground support, four CH-53E Super Stallion helicopters for troop/supply support, four AH-1W Super Cobra attack helicopters for close in ground support, and two UH-1W Iroquois command and control helicopters (Global Security, 2008b).

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   Assault Craft Unit Five
   Camp Pendleton, California

6. Guy Baker
   Assault Craft Unit Five
   Camp Pendleton, California