Logistics Management Institute

Intelligent Collaborative Aging Aircraft Parts Support

DL122T1

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Executive Summary

Department of Defense depot-level maintenance activities often experience delays in obtaining consumable parts for aging aircraft systems and components. As part of a concerted effort to reduce these delays, the Defense Logistics Agency (DLA) awarded a contract to the Logistics Management Institute (LMI) for design, development, and prototyping of Intelligent Collaborative Aging Aircraft Parts Support (ICAAPS). LMI, in partnership with JWK International, explored the use of data mining and analysis techniques to improve long-range projections of depot-level maintenance requirements for DLA-managed consumable parts.[1]

At the Navy's request, the prototype ICAAPS demonstration focused on depot-level maintenance support for C-2 aircraft at the Naval Air Depot (NADEP) in North Island, CA. During this demonstration, operational and field-level maintenance data were correlated with NADEP data to provide a framework for projecting the DLA-managed consumable parts needed to perform standard depot-level maintenance (SDLM) on C-2 aircraft. However, because the Navy's entire C-2 inventory includes fewer than 40 aircraft, a paucity of relevant data curtailed the use of automated data mining during the ICAAPS prototype demonstration. Nevertheless, use of ICAAPS analytical tools improved the forecast accuracy for all consumable parts included in the prototype test sample. Consequently, continued use of ICAAPS should facilitate more timely consumable parts support for the C-2 aircraft maintained by NADEP North Island, enabling reductions in the number and duration of C-2 SDLM delays caused by consumable parts shortages.

Data limitations associated with the C-2 prototype demonstration precluded the ICAAPS project team from ascertaining if automated data mining can be effectively used to forecast consumable parts requirements. However, a follow-on ICAAPS demonstration at NADEP Cherry Point, NC should enable a more robust evaluation of automated data mining capabilities. Therefore, decisions on Navy-wide ICAAPS implementation should be deferred until the ICAAPS demonstration at NADEP Cherry Point is completed.

[1] The LMI/JWK ICAAPS project team included David A. Calderwood (LMI), Joseph Callender II. (LMI), Lawrence P.G. Forsley (JWK), Adrian Hernandez (LMI), Robert L. Jordan (LMI), Scott Phillips (JWK), and Galbraith D. Williams (JWK).

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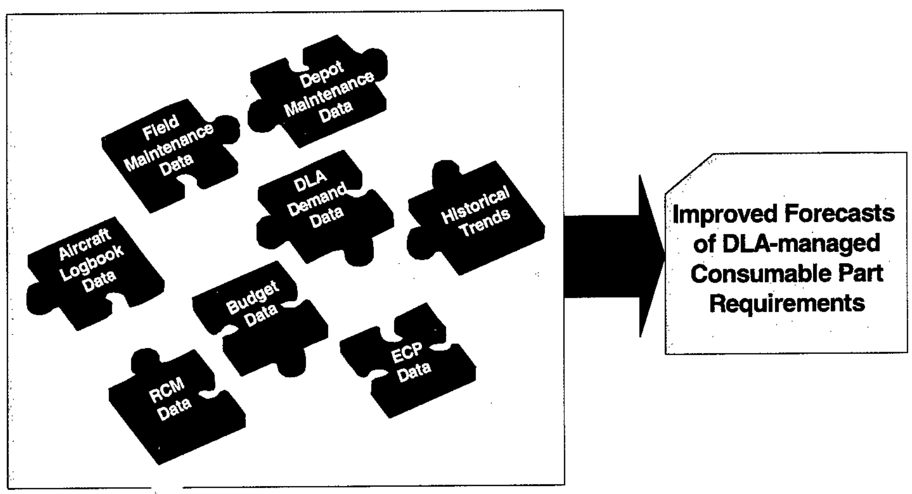
Chapter 1
Introduction

OVERVIEW

Intelligent Collaborative Aging Aircraft Parts Support (ICAAPS) is designed to synergistically integrate relevant data from multiple sources to improve projections of consumable part requirements, as depicted in Figure 1-1. In this context, ICAAPS facilitates identification and analysis of operational and logistics support data to determine the factors that affect depot maintenance requirements for the consumable parts needed to support aging aircraft.

Figure 1-1. ICAAPS Data Integration Concept



OBJECTIVES AND ANALYTICAL METHODOLOGY

The objective of this task was to develop, demonstrate, and document ICAAPS capability to accurately project consumable parts requirements for C-2 aircraft undergoing depot-level maintenance at the Naval Air Depot (NADEP) in North Island, CA. Within this context, the LMI/JWK ICAAPS project team

- analyzed the information and procedures used to determine requirements for consumable parts needed to support depot-level maintenance;
- used data mining and analysis to identify data elements and relationships that impact depot-level maintenance consumable part requirements;

- designed ICAAPS to complement and enhance current processes used by the Navy to project depot-level maintenance consumable parts requirements;
- performed a prototype demonstration of ICAAPS for C-2 aircraft undergoing standard depot-level maintenance (SDLM) at NADEP North Island;
- identified appropriate metrics for determining ICAAPS effectiveness; and
- assessed ICAAPS accuracy vis-à-vis historical projections of consumable parts requirements in support of C-2 SDLM at NADEP North Island.

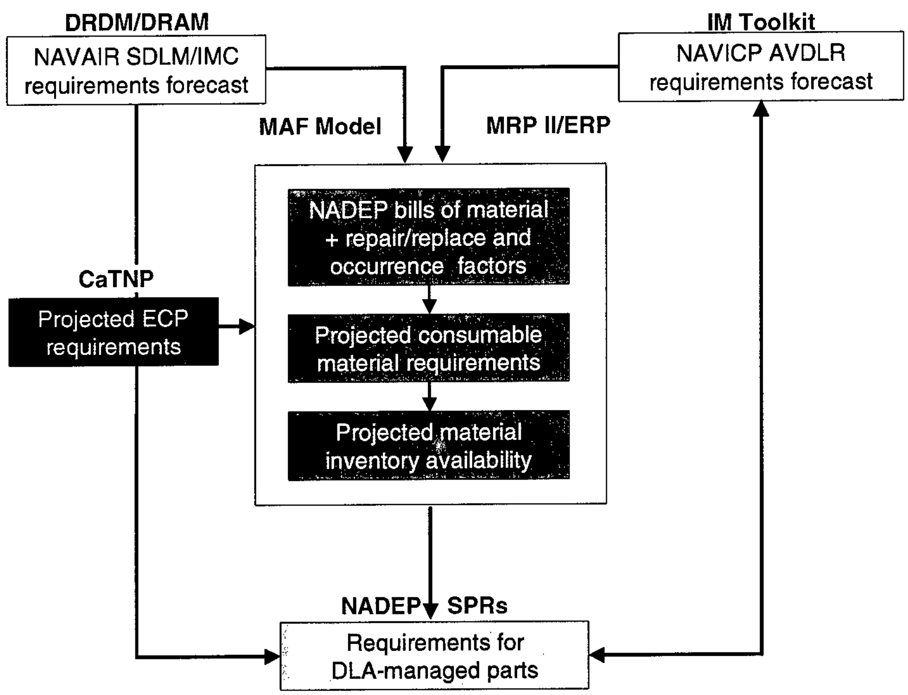
Report Structure

Chapter 2 of this report outlines the processes in use by the Navy to project future depot-level aviation maintenance requirements for DLA-managed consumable parts. Chapter 3 explains how ICAAPS enhances the Navy's current consumable parts forecasting process. Chapter 4 discusses the prototype ICAAPS demonstration, which involved C-2 SDLM consumable parts requirements and assesses the demonstration results. Chapter 5 summarizes noteworthy conclusions and recommendations. Appendix A provides amplifying information about C-2 data structures, and Appendix B defines the abbreviations used in this report.

Chapter 2
Current Navy Forecasting Process

Figure 2-1 shows the Navy's current process for projecting aviation depot-level maintenance consumable parts requirements. This process involves compilation and analysis of data generated by the Naval Air Systems Command (NAVAIR) at Patuxent River, MD; the Navy Inventory Control Point (NAVICP) in Philadelphia, PA; and the NADEPs at Cherry Point, NC, Jacksonville, FL, and North Island, CA, which generate special program requirements (SPRs) for the Defense Supply Centers (DSCs) at Richmond, VA, Philadelphia, PA, and Columbus, OH.

Figure 2-1. Current Navy Process for Projecting Consumable Parts Requirements



Most of the organizations involved in projecting aviation depot-level maintenance consumable part requirements have developed automated tools to facilitate the complex probabilistic computations that are inherent in this process; however, manual interfaces are required in many cases (i.e., Excel spreadsheets are frequently used to convey requirements between different organizations).

NAVAIR

NAVAIR forecasts aircraft depot-level maintenance requirements annually to achieve readiness goals within financial and schedule constraints. These forecasts include requirements generated under three different depot-level maintenance criteria:

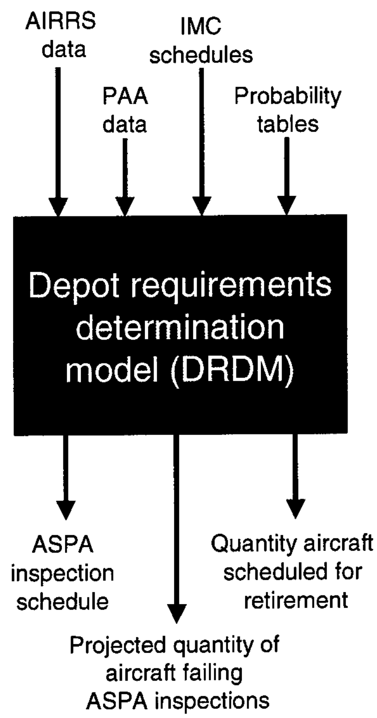
- Aircraft that undergo SDLM; the forecasts represent the average number of aircraft projected to fail Aircraft Service Period Adjustment (ASPA) inspections
- Aircraft that are maintained under the Navy's new integrated maintenance concept (IMC); the forecasts include the individual aircraft bureau numbers (BUNOs) that are scheduled for IMC events
- Aircraft involved in upgrade programs (e.g., major modifications or service life extensions); the forecasts include the BUNOs that are scheduled for induction under those programs.

NAVAIR uses the Depot Requirements Determination Model (DRDM) and the Depot Requirements Assessment Model (DRAM) to establish annual aircraft maintenance induction requirements and rank the priority of requirements based on funding constraints and required readiness.

DRDM

The DRDM is an Access-based application used to define overall aircraft maintenance requirements. It identifies the annual quantity of aircraft expected to fail ASPA inspections, undergo IMC events, or require depot maintenance associated with other requirements, such as major modifications. As illustrated in Figure 2-2, DRDM inputs include Aircraft Inventory and Readiness Reporting System (AIRRS) data, primary aircraft allowance (PAA) information, IMC schedules, and probability tables on expected number of ASPA failures. DRDM outputs include ASPA inspection schedules, projected ASPA failure quantities, and scheduled aircraft retirements.

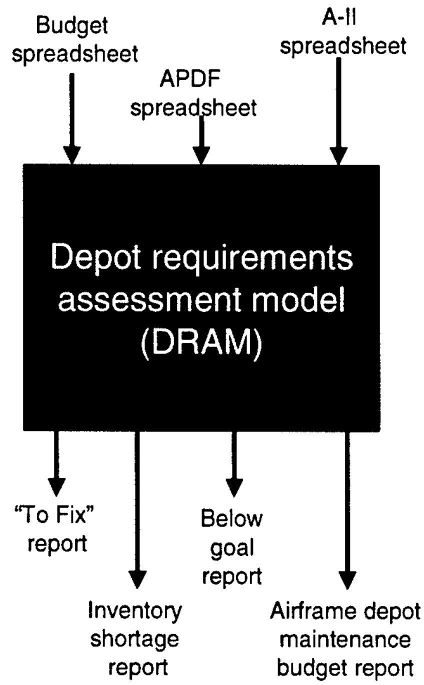
Figure 2-2. DRDM Inputs and Outputs



DRAM

The DRAM is an Access-based application used to determine the effects of depot maintenance budget constraints on aircraft readiness. It facilitates optimization of depot-level maintenance induction priorities by balancing available funding with readiness requirements and aircraft inventories. As Figure 2-3 illustrates, DRAM inputs include funded requirements and cost data from the budget spreadsheet, PAA levels from the Aircraft Program Data File (APDF), and current inventory levels from the A-II spreadsheet. DRAM outputs consist of a series of reports that assess readiness for a given funding level and indicate the number of depot inductions needed to meet readiness goals.

Figure 2-3. DRAM Inputs and Outputs



NAVICP

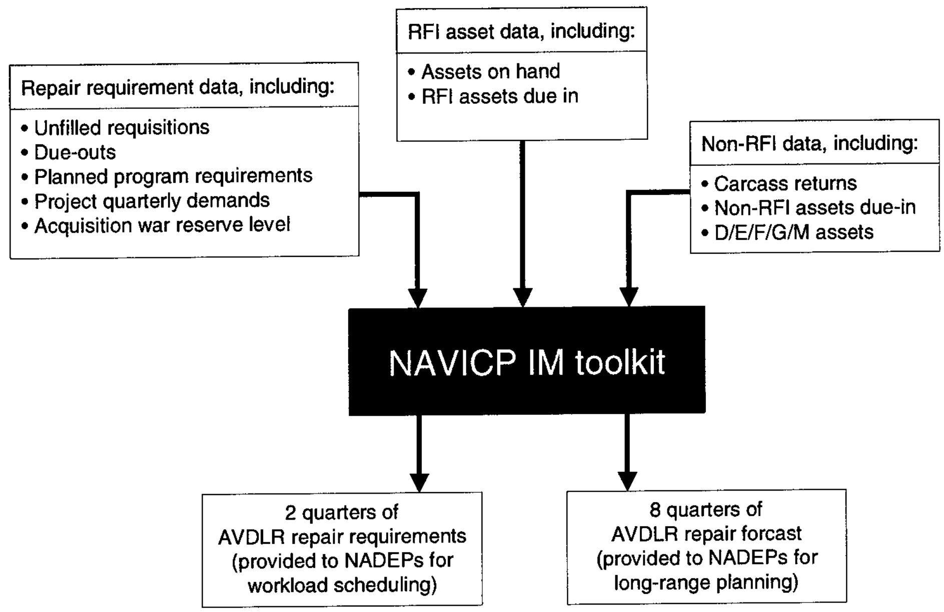
NAVICP forecasts aviation depot-level reparable (AVDLR) induction requirements based on projected ready-for-issue (RFI) inventory levels. NAVICP negotiates quarterly repair schedules with individual NADEPs based on projected availability of reparable carcasses and consumable parts. NAVICP also transmits parts usage forecasts and configuration changes to DLA so that cognizant item managers can make appropriate adjustments in future procurements.

Key NAVICP applications involved in the AVDLR consumable parts forecasting process include the Inventory Manager (IM) Toolkit, Configuration Item Status Sheet (CISS), and Configuration and Technical Notification Program (CaTNP).

IM Toolkit

NAVICP uses the IM Toolkit to forecast AVDLR requirements. A 2-quarter forecast is used as the basis for negotiating firm depot induction requirements, subject to the availability of reparable carcasses. In addition, an 8-quarter forecast provides long range requirements based on historical carcass availability and known future fleet requirements. As illustrated in Figure 2-4, IM Toolkit inputs include unfilled fleet requests, quarterly forecasted demands, and carcass availability. The output consists of a 10-quarter forecast (2 quarters of requirements used to negotiate near-term induction schedules with the NADEPs and an 8-quarter, long-range forecast).

Figure 2-4. IM Toolkit Inputs and Outputs



CISS/CaTNP

The CISS provides part configuration changes to DLA based on Design Change Notice (DCN) data regarding approved engineering change proposals (ECPs). CaTNP is a web-enabled version of the CISS. DLA item managers receive notification of relevant changes by e-mail, and then log onto the CaTNP website to view specific details. CaTNP conveys the following information:

- Part number replacements
- Interchangeability
- Disposition of material
- SMR code changes
- Engineering remarks
- Cost avoidance data
- Weapon system designation codes.

NADEPs

The NADEPs satisfy the SDLM, IMC, and AVDLR induction requirements for which they serve as the designated repair point (DRP). SDLM workloads and related consumable parts requirements are subject to significant variation because they depend heavily on the material condition of the individual aircraft that fail ASPA inspections. In contrast, IMC consumable parts requirements are more predictable because the IMC work content is relatively stable. It should be noted, however, that the consumable parts needed to complete "over and above" maintenance during IMC must be readily available because the time allowed for IMC is usually shorter than the time allowed for SDLM.

The NADEPs use NAVAIR and NAVICP forecasts of aircraft and AVDLR repair requirements to develop workload projections and identify the consumable parts needed to support those requirements. In recent years, the NADEPs have used the following legacy applications to project consumable parts requirements:

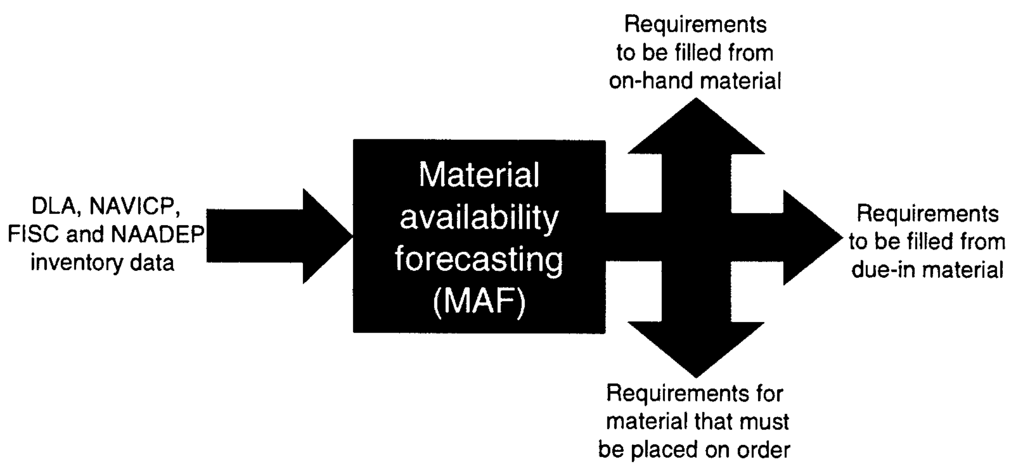
- Cherry Point and Jacksonville—Material Availability Forecasting (MAF)
- North Island—Depot Bill of Materials (DepBOM)

In addition, all NADEPS are implementing a Manugistics *Compass*CONTRACT manufacturing resource planning (MRP II) system that includes maintenance, repair, and overhaul (MRO) functionality.

MAF

MAF is a flexible Access-based application developed by NADEP Jacksonville that can be used to compare projected consumable parts requirements for both aircraft and AVDLRs with available inventories to determine if additional procurements will be needed. MAF does not have the functionality needed to create and maintain Bills of Material (BOMs), but it does contain algorithms that compare projected consumable parts requirements with expected inventory levels to determine if procurement of additional parts will be needed to satisfy projected requirements, as illustrated in Figure 2-5.

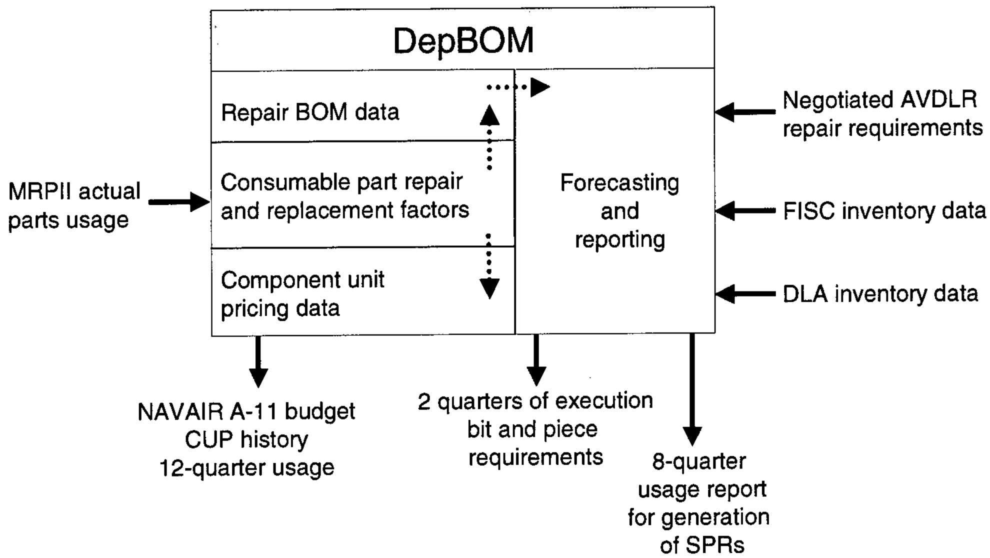
Figure 2-5. MAF Inputs and Outputs



DepBOM

DepBOM is an Oracle-based application used by NADEP North Island to support component repairs. As Figure 2-6 shows, DepBOM functionality can be divided into four distinct areas: BOM data development and maintenance, repair and replacement factor maintenance, component unit pricing, and consumable part forecasting and reporting (using MAF algorithms).

Figure 2-6. DepBOM Inputs and Outputs

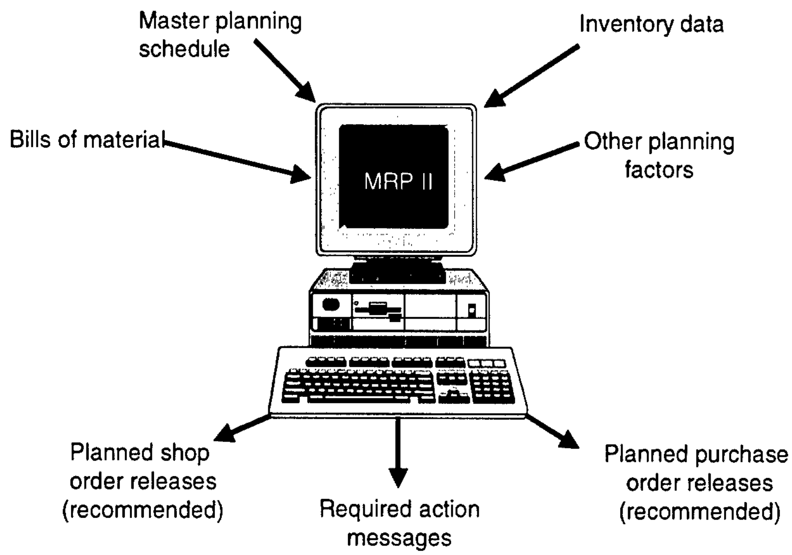


Repair BOMs are developed and maintained within the DepBOM application. Actual parts usage information from the *Compass*Contract MRP II System is used to maintain consumable part repair and replacement factors within DepBOM. Component unit pricing information provides data for competitively awarded workloads and maintains supporting data for audit purposes.

*Compass*CONTRACT MRP II System

The MRP II system contains dynamic repair and replacement factors for items contained in the BOMs to accommodate MRO operations. These repair and replacement factors are used in calculating time-phased material requirements. Figure 2-7 shows the master planning schedule, inventory status, related BOMs, and other planning factors that are *Compass*CONTRACT inputs. The output of the MRP II system consists of recommended purchase orders and shop orders, with exception messages where actions must be taken to achieve the plan.

Figure 2-7. Compass*CONTRACT Inputs and Outputs*



DLA

DLA procures consumable parts for use by all services, based primarily on

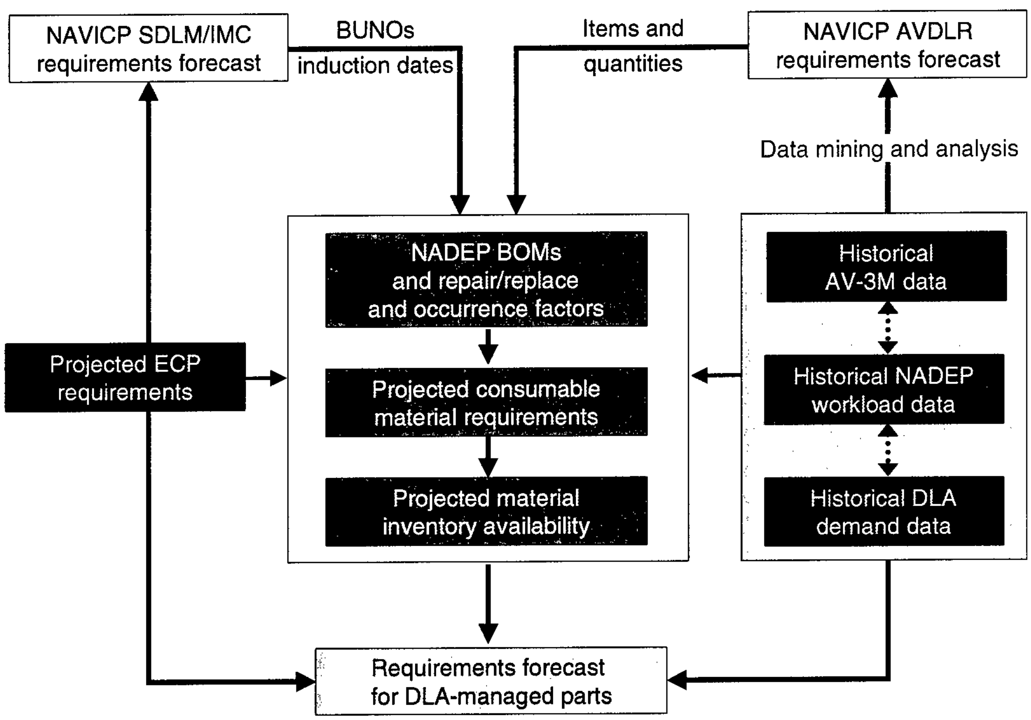
- an order-point stock replenishment methodology for items that have well-defined historical demand patterns, and
- numerical stocking objectives (NSOs) for items that, if not available when needed, would seriously impact military effectiveness or efficiency. Consequently, investment in such items is warranted despite a high probability that those items will seldom be needed.

In addition, the services submit SPRs for items they anticipate will experience significantly increased demands. However, when actual demands exceed projected requirements or deplete on-hand inventories, the associated procurement delays often cause maintenance work stoppages. As part of a concerted effort to alleviate this problem, DLA tasked LMI (in partnership with JWK International) to design, develop, and prototype ICAAPS as a tool for improving long-range projections of depot-level maintenance requirements for DLA-managed consumable parts.

Chapter 3
ICAAPS Forecasting Process

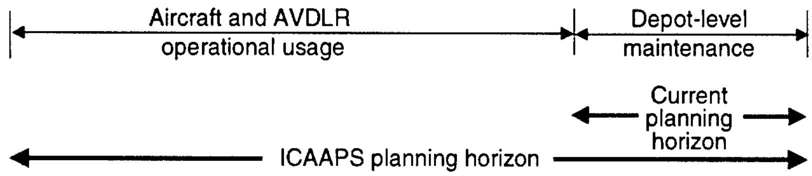
ICAAPS enhances the Navy's current process for projecting aviation depot-level maintenance consumable parts requirements. It does this by compiling and correlating a broad range of operational and logistics data from the Navy's Aviation Maintenance Material Management (AV3M) system as well as historical NADEP workload and DLA supply support data. Figure 3-1 illustrates how ICAAPS data mining and analysis augments the Navy's current process for forecasting DLA-managed consumable parts requirements.

Figure 3-1. ICAAPS Depot-Level Consumable Parts Forecasting Process



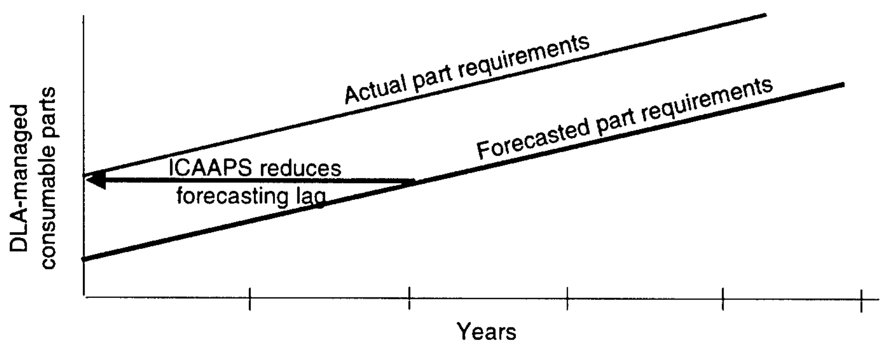
Current projections of depot maintenance requirements for consumable parts are based on historical depot-level maintenance data. Consequently, these projections frequently underestimate the range and depth of consumable parts required, particularly for aging aircraft that experience unexpected increases in consumable parts requirements. As depicted in Figure 3-2, ICAAPS expands the current planning horizon for depot-level maintenance to include relevant information gathered during the entire operating service period.

Figure 3-2. ICAAPS Versus Traditional Depot-Level Maintenance Planning Horizon



Because current projections of depot-level maintenance consumable part requirements are based primarily on historical depot-level maintenance data, there is a delay of about 2 years from the time unexpected consumable part requirements are first discovered to the time when those parts are reflected in projections of future requirements. By expanding the depot-level maintenance planning horizon to include relevant information gathered during the entire operating service period, ICAAPS reduces this inherent forecasting lag, as depicted in Figure 3-3.

Figure 3-3. ICAAPS Effect on Forecasting Lag



DATA MINING AND ANALYSIS

ICAAPS data mining and analysis involves the following steps:

- Identification and collection of relevant operational, maintenance, and supply data, based on interviews with cognizant DoD personnel; the following data elements are valuable inputs to ICAAPS data mining and analysis:
  - Aircraft logbook data
    - Squadron and reporting custodian
    - Number of flight hours (lifetime total and since last depot visit)
    - Number and length of shipboard deployments

- Number of catapults and arrested landings
- Time spent out of reporting status ("hangar queens")

➤ Field maintenance data

- Average number of maintenance labor-hours by work unit code
- Landing gear "drop" checks
- Engine changes (lifetime total and number since last depot visit)
- Other noteworthy squadron maintenance actions

➤ Depot maintenance data

- Data and turnaround time of last depot visit
- Type and location of "over and above" repair work
- Size, location, and number of bushings and oversized fasteners used
- Repair and replacement parts usage

➤ DLA demand and requisition history data

◆ Standardization of data from disparate data sources so that values and definitions of data fields are consistent; some data fields must be "scrubbed" and normalized to eliminate errors and redundancy

◆ Development and testing of various hypotheses regarding potential cause-and-effect relationships among the operational- and field-level maintenance factors that may affect future depot-level maintenance requirements; following is a list of key hypotheses:

➤ *Configuration*—Different aircraft configurations are likely to have different material condition profiles and use different consumable parts

➤ *Overall time in service*—Aircraft tend to require more extensive maintenance as they get older; in fact, NAVAIR analysis of several aircraft types has revealed that direct maintenance labor-hours per flight hour increase by about 3 percent per year as aircraft age[1]

➤ *Time elapsed since last depot-level maintenance*—Field-level maintenance personnel do not normally have the skills and equipment needed

[1] Naval Air Systems Command, *Aging Aircraft Trends and Cost Drivers Associated With Naval Aviation Systems*, Dr. Laurence W. Stoll, October 2000.

to accomplish complex maintenance tasks, particularly those tasks that involve correction of corrosion-related problems associated with composite structures and bonding between dissimilar metals; consequently, the amount of time since the last period of depot-level maintenance should indicate how much depot-level maintenance will be required in the future

- *Employment and utilization*—Location and intensity of operations may have a significant effect on aircraft material condition (for example, aircraft that operate for long periods at sea tend to deteriorate faster than those that operate primarily in less corrosive environments); similarly, aircraft that are heavily used and experience numerous catapults and arrested landings generally require more depot-level maintenance than aircraft that experience less stressful usage

- *Primary custodian/user*—Different aircraft custodians often have different procedures for maintaining their aircraft, particularly for corrosion control (for example, one squadron may wash its aircraft weekly, while another squadron washes only them monthly); consequently, aircraft material condition should reflect the maintenance practices of aircraft custodians just as the material condition of automobiles reflects the maintenance practices of their owners

- *Field-level maintenance or cannibalization actions*—The type and quantity of field-level maintenance performed on a particular aircraft provides excellent insights about the overall material condition of that aircraft (for example, a large amount of field-level corrosion control work usually indicates that a commensurate amount of depot-level maintenance will be required to correct corrosion discrepancies in areas that were not accessible to field-level maintenance personnel)

- Identification of relevant "clusters" of aircraft and AVDLRs that have similar material condition profiles

- Establishment of normalized forecasts of the consumable parts required during depot-level maintenance for specific clusters of aircraft and AVDLRs based on historical part usage data (for example, aircraft that operate primarily in a shipboard environment may form a cluster that has different characteristics than aircraft that operate primarily in a shore-based environment)

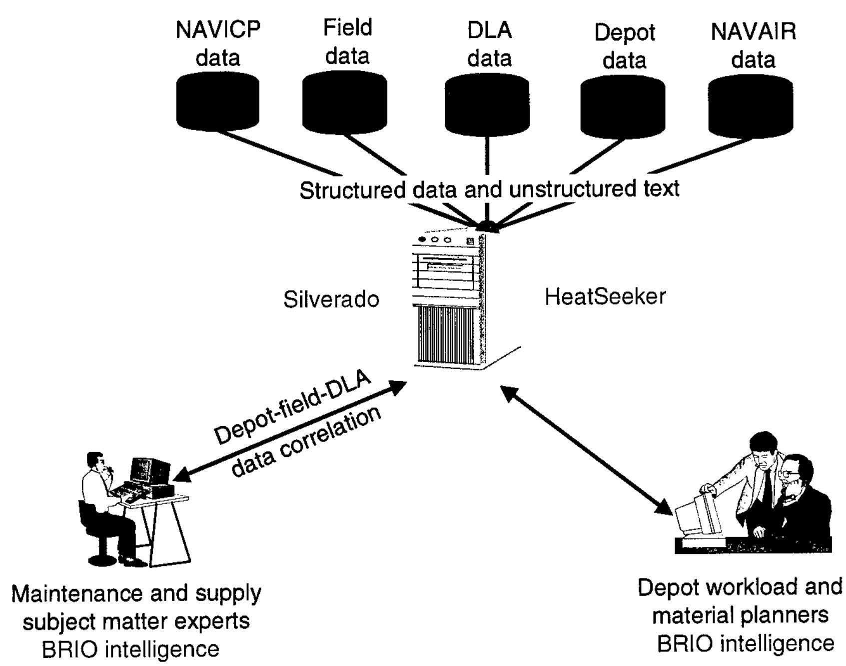
- Tailoring of projected consumable part requirements for specific aircraft and AVDLRs based on correlations between field-level maintenance data and specific depot-level consumable part requirements (for example, if the field-level maintenance data indicates an aircraft windscreen is cracked or crazed, that windscreen will almost always be replaced during the next period of depot-level maintenance).

HARDWARE AND SOFTWARE TOOLS

The initial ICAAPS demonstration performed by LMI and JWK was facilitated by use of a massively parallel data processor known as *Silverado,* which originally was developed by JWK to process signal intelligence data. *Silverado* is a high-speed Standard Query Language (SQL) linearly scaleable search engine with a scanning rate of up to 72 million records per second for the current 12 processor configuration (each processor can scan 6 million records per second). Another JWK data mining and analysis tool, *HeatSeeker,* rapidly analyzes data relationships by automatically generating thousands of correlation queries that would take much more time using conventional database systems. In addition, *BRIO Intelligence* software was used as the front-end communications processor and desktop display for the ICAAPS prototype. This software enables data analysts to build dynamic analytical applications and supports both pre-defined and *ad hoc* queries.

These tools assist ICAAPS analysts in identifying relevant data relationships by automatically generating correlation queries that would take much longer using traditional data analysis procedures. After being identified by subject matter experts, these relationships can be used by depot and DLA personnel to develop more accurate forecasts of depot workloads and associated requirements for consumable parts, as depicted in Figure 3-4.

Figure 3-4. ICAAPS Reduction in Consumable Part Forecasting Time Lag



Chapter 4
ICAAPS Prototype Demonstration

The overall objective of the ICAAPS prototype was to demonstrate how ICAAPS can improve projections of consumable repair part requirements for C-2 aircraft scheduled to undergo SDLM at NADEP North Island. To accomplish this objective, we focused on the following activities:

- Identification of current practices and key data sources
- Collection of relevant data
- Evaluation of data structure and elements
- Import of heterogeneous data into a common data repository
- Use of data mining and analysis to identify relationships between
  - SDLM discrepancies and consumable repair part usage,
  - field-level maintenance actions and SDLM discrepancies, and
  - field-level maintenance actions and depot-level part usage.

We conducted interviews with representatives from DLA, NAVAIR headquarters, and NADEP North Island to identify specific issues regarding C-2 SDLM requirements for DLA-managed consumable parts. Our discussions with DLA, NAVAIR, and NADEP North Island provided the following key insights:

- NADEP North Island historically has been unable to accurately predict consumable parts requirements for individual C-2 aircraft until the aircraft are inspected by depot artisans in conjunction with SDLM induction.
- Delays in obtaining consumable parts often cause depot personnel to "back-rob" parts from other C-2 aircraft or stop work while awaiting parts.
- Consumable parts delays may become more critical as C-2 aircraft shift from SDLM to IMC because IMC events are more time constrained than SDLM and unexpected "over and above" requirements have a greater impact on cost and schedule.
- Because the C-2 has a shrinking supplier base and very low demand rates for most consumable parts, the fill rate for C-2 parts is unlikely to improve unless better methods are used to project consumable part requirements.

At NADEP North Island, aircraft workload requirements are defined in *Open Plan* project management software and the associated consumable parts requirements are defined in *Compass*CONTRACT, but AVDLR repair part requirements continue to be defined in DepBOM.

NADEP North Island personnel enter the negotiated schedule for 2 quarters of AVDLR repairs into DepBOM using Excel spreadsheets. Based on this schedule, DepBOM produces consumable parts requirements for 2 quarters; these requirements are forwarded to FISC San Diego. Because NAVICP also provides an 8-quarter AVDLR repair projection, DepBOM develops an 8-quarter consumable parts requirements projection using MAF algorithms. These algorithms assess Fleet and Industrial Supply Center (FISC) inventory data, DLA inventory data, and historical demand data to identify parts where the expected availability will not satisfy the projected requirement. When a projected shortfall is identified, the additional requirements are forwarded to DLA through NAVICP in the form of SPRs that alert DLA to an increase in the requirement for a particular part. DLA then can adjust procurement quantities to meet projected demands.

KEY DATA SOURCES

As previously noted, we hypothesized that depot-level consumable part requirement projections could be improved by correlating aircraft characteristics and field-level maintenance events with depot-level discrepancies and associated consumable parts usage. To analyze these relationships, we compiled the following data from DLA, NAVAIR, and NADEP North Island:

- DLA
  - Requisition history
  - Item headers
  - Procurement history
  - Contracting technical data
  - Active contract data
  - Weapon system data
- NADEP North Island
  - Maintenance planning and execution data
  - DepBOM
  - ASPA and SDLM history

- NAVAIR
  - AV3M data
  - ECP data.

Initial Data Evaluation

It quickly became apparent that the AV3M and C-2 SDLM data were particularly valuable in identifying cause-and-effect relationships between field-level maintenance activities and depot-level consumable parts requirements. (Noteworthy AV3M and C-2 SDLM data structure issues are discussed in Appendix A.)

The C-2 SDLM file provides comprehensive data regarding the material condition of each C-2 that underwent SDLM between September 1988 and June 2001. Key data elements include all discrepancies noted, aircraft zones involved, corrective actions taken, and consumable parts used.

The AV3M database historically has had numerous data accuracy problems because of the numerous organizations that provide AV3M data; however, this did not cause serious problems during the ICAAPS prototype demonstration because the AV3M data used for ICAAPS analysis had previously been "cleansed" by the Center for Naval Analysis (CNA). In fact, the major problems we encountered in that regard were data gaps that resulted from the CNA cleansing process. The following overview provides insight into the depth and breadth of AV3M information available:

- *MAF1*—Contains summary-level data on individual maintenance actions associated with specific aircraft BUNOs; it also includes attributes such as job control numbers (JCNs), work center, BUNO, and job timestamps
- *MAF2*—Contains more detailed data associated with the maintenance actions identified in MAF1; it includes transaction codes, work unit codes (WUCs), malfunction codes, actions taken, labor hours expended, and so forth
- *RT60*—Contains information about the repair and replacement parts associated with particular maintenance actions identified in MAF1
- *Flights*—Contains operational data such as number of landings, flight hours, catapult shots, and arrested landings for each aircraft BUNO.

Extract, Transform, and Load Process

One of the most challenging aspects of data mining is compiling disparate data from multiple sources in a manner that can be queried easily. The extract, transform, and load (ETL) process involves extracting data from its source, standardizing and cleaning that data, and uploading the data into target database tables. Several iterations of data loading were required during the ICAAPS prototype because of situations in which the rules for a given data type were violated by the data values (e.g., alphanumeric values were rejected when inserted into a field containing only numbers). Standardization and cleaning of data generally were accomplished following the data load rather than as part of the ETL process.

Automated Data Mining and Analysis

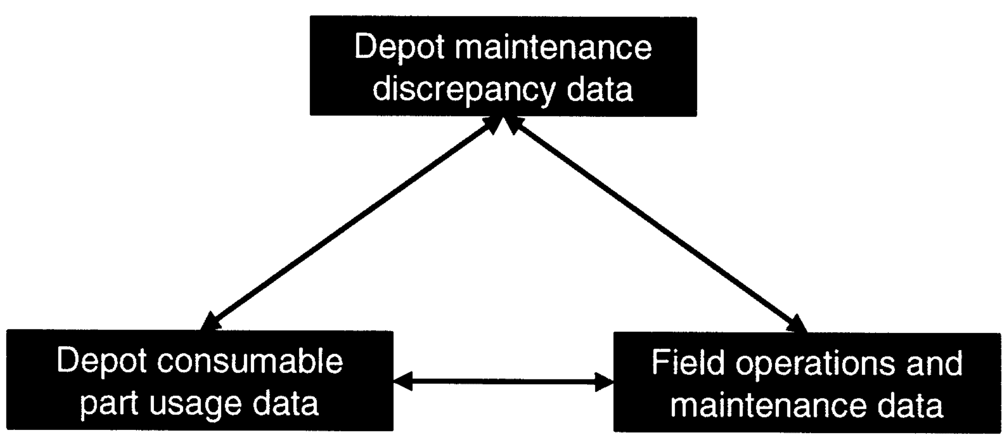
Application of automated data mining techniques was a fundamental objective of the ICAAPS prototype. In this regard, we attempted to identify average aircraft material condition profiles through analysis of relevant field-level indicators to predict depot-level discrepancies and associated consumable parts requirements. Our initial attempts to establish baseline material condition profiles through automated data mining techniques were unfruitful, however, because of the small population of C-2 aircraft and limited amount of relevant data.

Because data mining applications work best in a data-rich environment, the paucity of C-2 data represented a significant obstacle to the use of automated data mining techniques. Consequently, we decided to adopt a more traditional analytical approach that involved developing and testing various hypotheses regarding potential cause-and-effect relationships.

C-2 Data Analysis

Our first objective was to identify data correlations that provided a context for prediction of depot-level consumable parts usage based on aircraft characteristics and field-level maintenance. Our overall hypothesis was that depot-level maintenance discrepancies can be correlated with both consumable parts usage and field-level maintenance actions, as illustrated in Figure 4-1.

Figure 4-1. ICAAPS Data Analysis Framework



We first attempted to determine if there was a correlation between depot-level discrepancies and associated consumable parts usage. We then attempted to associate maintenance activities that occurred in the field with depot-identified discrepancies. Because field-level maintenance is categorized by WUCs rather than physical locations or aircraft zones, we needed a taxonomy for relating WUCs and aircraft zones to provide a linkage between field-level maintenance actions and depot-level discrepancies.

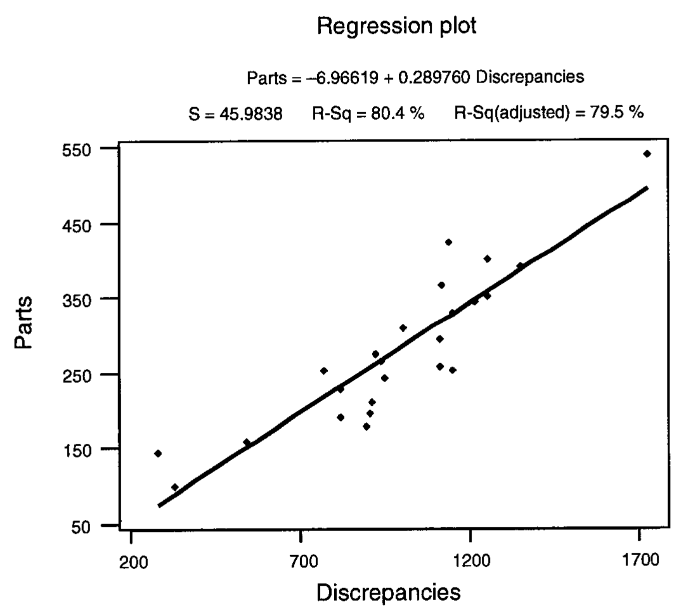
Relating WUCs to Aircraft Zones

Our initial analysis indicated that a given C-2 WUC could relate to one or more aircraft zones. Some WUCs can be directly related to a single zone because they have a one-to-one relationship (e.g., WUC 11C20 refers only to the outer wing panel of the aircraft); however, we found other WUCs that relate to more than one aircraft zone (e.g., WUC 11C6B00 covers the entire cargo bay floor, which encompasses several different zones). In these latter cases, we first related a WUC to specific consumable parts, then related those parts to the aircraft zone where they are used. By using this approach, we were able to associate specific field-level actions with depot-level discrepancies so we could identify relevant cause-and-effect relationships.

Correlating Depot Discrepancies and Consumable Parts Usage

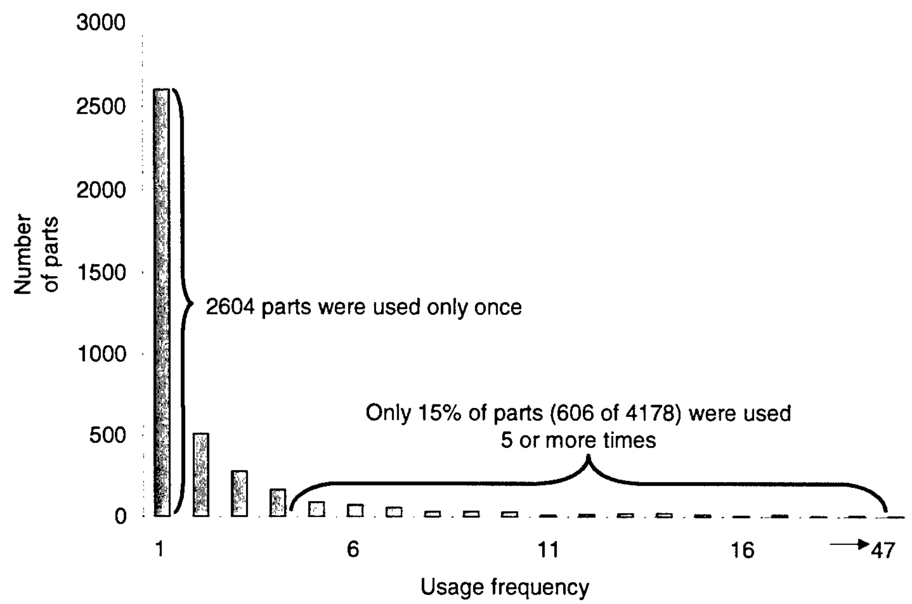
Analysis of C-2 SDLM data revealed that the number of depot-level discrepancies is highly correlated (R^2 = 80%) with the number of consumable parts required to correct those discrepancies, as depicted in Figure 4-2.

Figure 4-2. C-2 Depot-Level Discrepancies Versus Consumable Parts Usage



While this correlation suggests the number of depot discrepancies is an accurate indicator of total consumable parts requirements, it does not provide any insight about the range and depth of consumable part inventories needed to fulfill those requirements. For the C-2 aircraft that underwent SDLM during the 1990s, about 60 percent of the consumable parts were used only once, and just 15 percent were used five or more times, as shown in Figure 4-3. Consequently, forecasting the specific consumable parts required for C-2 SDLM can be extremely challenging because of the relatively small number of parts with sufficient data to determine cause-and-effect relationships.

Figure 4-3. C-2 SDLM Consumable Parts Usage

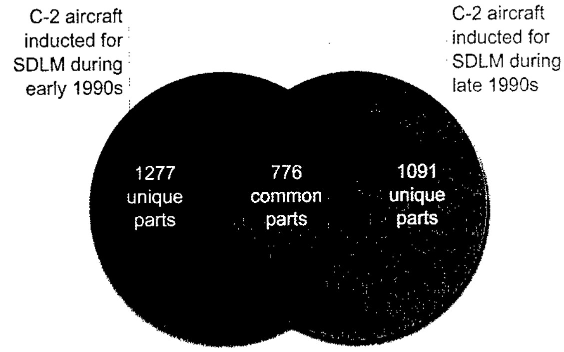


Identifying Specific Drivers for Consumable Parts Usage

Even though we identified a strong correlation between the number of C-2 SDLM discrepancies and the number of consumable parts used to correct those discrepancies, we were unable to statistically validate some of our hypotheses regarding cause-and-effect relationships among the various factors that may affect depot-level maintenance requirements. Following are some examples:

- *Configuration* was not a relevant factor because all C-2 aircraft have the same configuration.
- *Overall time in service* was not a relevant factor because all current C-2 aircraft were built within a 4-year period during the late 1980s. However, analysis of C-2 SDLM data revealed that early SDLM aircraft used different parts than more recent SDLM aircraft, as shown in Figure 4-4. Consequently, we decided to focus our analysis on C-2 aircraft that underwent SDLM during the late 1990s in order to establish the baseline for forecasting future part requirements.

Figure 4-4. C-2 Consumable Parts Usage Over Time

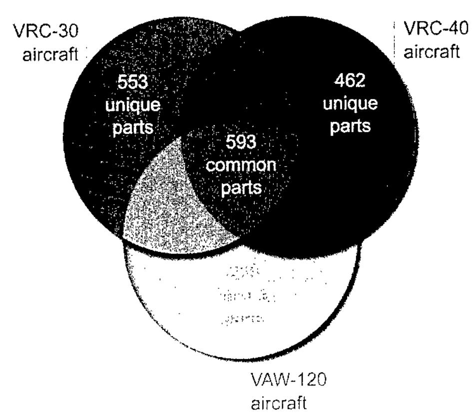


- *Time elapsed since last depot-level maintenance*—We found no statistical correlation (R^2<10%) between the amount of time elapsed since the last depot-level maintenance period and C-2 SDLM consumable parts usage. However, because about 60 percent of the consumable parts required for C-2 SDLM during the 1990s were used only once, we concluded there were insufficient data to determine if a cause-and-effect relationship exists.

- *Employment or utilization*—We also found no statistical correlation (R^2<10%) between C-2 aircraft employment and utilization and SDLM consumable parts usage, but we concluded there were insufficient data to determine if a cause-and-effect relationship exists.

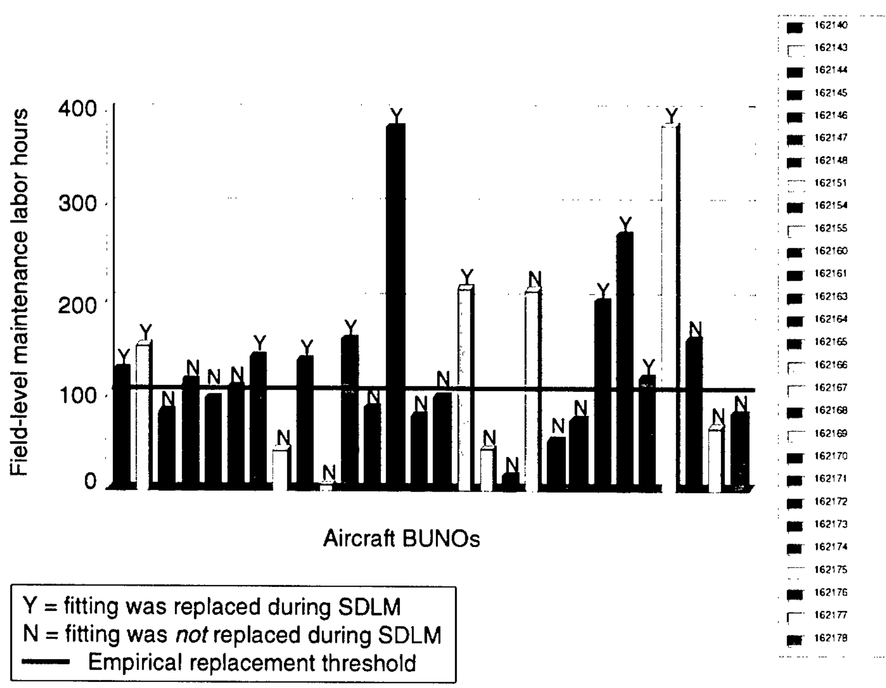
- *Primary custodian or user*—There are three different reporting custodians for C-2 aircraft: VRC-30 on the West Coast; VRC-40 on the East Coast; and VAW-120, the C-2/E-2 fleet training squadron. As illustrated in Figure 4-5, we found that almost 60 percent of the consumable parts required to complete C-2 SDLM during the late 1990s were custodian-unique. We also found some evidence of consumable part clustering among the aircraft owned by each custodian, but there was insufficient data to assess the statistical significance of these clusters.

Figure 4-5. C-2 Consumable Parts Distribution by Aircraft Custodians



- *Field-level maintenance and cannibalization actions*—Analysis of several C-2 SDLM consumable parts revealed that useful cause-and-effect relationships can be established between field-level maintenance actions and depot-level consumable parts usage in some cases. For example, Figure 4-6 reveals a strong relationship between the number of field maintenance hours expended on cargo door hinge fittings and the likelihood that those fittings would be replaced during SDLM. Specifically, most C-2 aircraft that had more than 100 hours of field-level maintenance near the cargo door hinge fittings needed new fittings during SDLM. Conversely, aircraft that had less than 100 hours of field-level maintenance near the cargo door hinge fittings did *not* need new fittings during SDLM. While there could be several explanations for this phenomenon, (e.g., excessive corrosion or damage incurred during field-level maintenance), the number of field-level maintenance hours is a reliable indicator of whether new fittings are likely to be needed during SDLM. Because our analysis revealed similar relationships for several other consumable parts, we concluded that field-level maintenance actions can be used to predict depot-level consumable parts requirements in selected cases.

Figure 4-6. Field-Level Maintenance on C-2 Cargo Door Hinge Fittings



Using ICAAPS to Forecast C-2 Consumable Part Requirements

Because we could identify a relationship between C-2 aircraft belonging to different custodians and the consumable parts used on those aircraft during SDLM, we concluded that ICAAPS can be used to tailor depot-level maintenance BOMs to reflect parts usage profiles for each aircraft custodian. For example, Table 4-1 shows the average part usage rates associated with aircraft from VRC-30, VRC-40 and VAW-120 for a representative sample of C-2 SDLM consumable parts.

Table 4-1. C-2 Part Usage Rates for Different Aircraft Custodians

Part number	Nomenclature	VAW-120		VRC-30		VRC-40	
		Amt.	Rate	Amt.	Rate	Amt.	Rate
123AM40034-15	Ramp level cam indicator	0	0.00	0	0.00	5	0.56
123BM40338-601	Cargo door hinge fitting	0	0.00	3	0.38	3	0.33
123B10466-501	Pilot front windshield	1	0.33	1	0.13	2	0.22
123H10074-501	R/H wing latch cylinder	1	0.33	2	0.25	2	0.22
123PM11407-601	Throttle control bracket	0	0.00	3	0.38	1	0.11
123WM10295-601	MLG door hinge support fitting	0	0.00	1	0.13	1	0.11
123WM10523-601	Inbd. engine mount support fitting	2	0.67	1	0.13	6	0.67

Note: Inbd. = inboard; MLG = main landing gear; R/H = right hand.

We also found that forecasts for some C-2 SDLM consumable parts can be refined by identifying cause-and-effect relationships with specific field-level maintenance actions. For example, Table 4-2 shows how the expected requirements for a representative sample of consumable parts can be tailored to reflect the material condition of C-2 BUNO 162143 owned by VRC-40.

Table 4-2. Tailoring C-2 Part Usage Rates for Individual Aircraft

Part number	Nomenclature	VRC-40 average usage rate	BUNO 162143 expected usage
123AM40034-15	Ramp level cam indicator	0.56	Yes
123BM40338-601	Cargo door hinge fitting	0.33	Yes
123B10466-501	Pilot front windshield	0.22	No
123H10074-501	R/H wing latch cylinder	0.22	Yes
123PM11407-601	Throttle control bracket	0.11	No
123WM10295-601	MLG door hinge support fitting	0.11	No
123WM10523-601	Inbd. engine mount support fitting	0.67	Yes

The consumable parts usage projections for BUNO 162143 reflected in Table 4-2 are based on the following information:

- *Ramp level cam indicator*—This part normally is replaced only on aircraft from VRC-40. Because BUNO 162143 is a VRC-40 aircraft, and AV3M records indicate that field-level maintenance has been performed in the area near the ramp level cam indicator, the indicator probably will need to be replaced during the next SDLM, based on ICAAPS analysis that revealed evidence of a cause-and-effect relationship between field-level maintenance and depot-level indicator replacement.

- *Cargo door hinge fitting*—Because BUNO 162143 had almost 150 hours of field-level maintenance in the area near the cargo door hinge fittings, those fittings probably will be replaced during the next SDLM (100 hours of field-level maintenance is the empirical threshold for replacing cargo door hinge fittings during SDLM).

- *Right hand wing latch cylinder*—BUNO 162143 data analysis revealed that field-level work repeatedly was performed in the wing fold area, which normally indicates that the wing latch cylinder will need to be replaced during SDLM.

- *Throttle control bracket*—BUNO 162143 data analysis revealed that no adjustments were made to the throttle cables by field-level maintenance personnel, which normally indicates that the bracket is within limits and will *not* need to be replaced during SDLM.

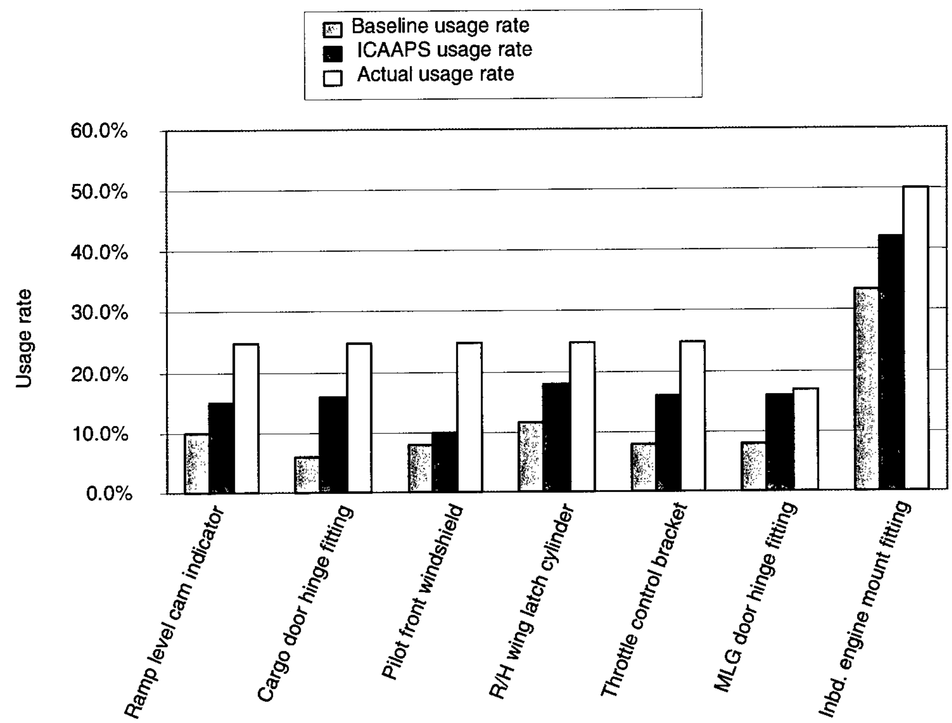
- *Main landing gear door hinge support fitting*—Although the main landing gear doors on BUNO 162143 were replaced by field-level maintenance personnel, the malfunction code profile did not indicate any problems with the door hinges. Consequently, the hinge support fittings probably will *not* need to be replaced during SDLM.

- *Inboard engine mount support fitting*—Because BUNO 162143 had more than 250 hours of field-level maintenance in the area near the inboard engine mount support fittings, at least one of those fittings probably will be replaced during the next SDLM (100 hours of field-level maintenance is the empirical threshhold for replacement of engine mount support fittings during SDLM).

C-2 Prototype Assessment

To assess ICAAPS accuracy, we compared ICAAPS forecasts for a representative sample of C-2 consumable parts against (1) a baseline projection reflecting historical C-2 SDLM usage rates and (2) the actual usage rates for the sample parts during C-2 SDLMs that were performed in the 1999–2001 timeframe. As shown in Figure 4-7, the ICAAPS forecast was more accurate than the baseline projection for each of the consumable parts depicted in Tables 4-1 and 4-2.

Figure 4-7. Sample Part Forecast Comparison



Chapter 5
Conclusions and Recommendations

The ICAAPS prototype demonstration for C-2 aircraft undergoing SDLM at NADEP North Island initially focused on automated mining and analysis of numerous data elements to discover cause-and-effect relationships that could be used to predict depot-level discrepancies and associated consumable parts requirements. However, because the paucity of C-2 data severely limited the use of automated data mining techniques, we adopted a more traditional analytical approach that involved developing and testing of hypotheses regarding suspected cause-and-effect relationships between various operational factors, field-level maintenance actions, and depot-level consumable parts requirements. This analytical approach produced the following results:

- We identified a strong correlation between the number of C-2 SDLM discrepancies and the number of consumable parts used to correct those discrepancies, but we were unable to statistically validate several of our hypotheses regarding the operational factors that may affect depot-level consumable part requirements. Even so, the ICAAPS prototype demonstrated how information regarding aircraft custodians and field-level maintenance actions can be used to improve forecasts of the DLA-managed consumable parts required during C-2 SDLM.
- ICAAPS improved the forecast accuracy for each of the C-2 SDLM consumable parts included in the prototype test sample. Consequently, ongoing use of ICAAPS should facilitate more timely consumable parts support for the C-2 aircraft maintained by NADEP North Island, enabling reductions in the number and duration of C-2 SDLM delays caused by consumable parts shortages.

The data limitations involved in this prototype demonstration precluded an assessment of whether ICAAPS can be effectively used to forecast consumable part requirements Navy-wide. However, insights gained from the C-2 analysis should facilitate conducting a more robust follow-on ICAAPS demonstration involving H-46 aircraft and selected AVDLRs (dynamic components and mission avionics) at NADEP Cherry Point.

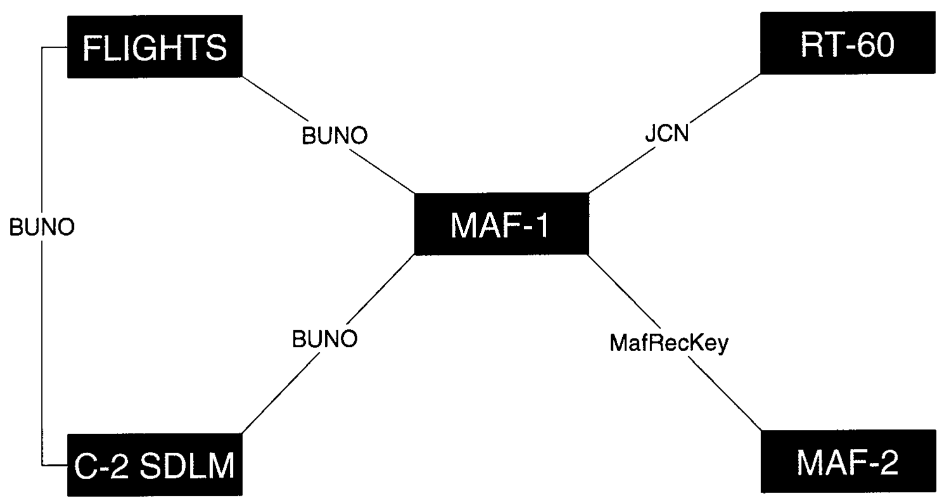
In view of the fact that much more data is available for the H-46 than for the C-2, the ICAAPS demonstration at NADEP Cherry Point should provide sufficient insight to assess the efficacy of using automated data mining techniques to forecast depot-level maintenance consumable part requirements. In accordance, we recommend deferring consideration of Navy-wide ICAAPS implementation until completion of the ICAAPS demonstration at NADEP Cherry Point.

Appendix A
Import and Audit of C-2 Data

Overview

Data from the Navy's Aviation Maintenance and Material Management (AV3M) system and the Naval Air Depot at North Island, CA, were acquired, cleansed, and imported. This data was compiled to forecast consumable parts usage during C-2 standard depot-level maintenance (SDLM) based on various operational and field-level maintenance characteristics of C-2 aircraft during the past decade. The overall data structure is depicted in Figure A-1.

Figure A-1. ICAAPS Data Structure



Data Definition and Audit

The first task was to create table definitions that reflected more accurately the actual data provided. Given the paucity of detailed metadata available, we used an iterative approach to import the data into a given table definition and we used the error reporting built into the **IMPORT** utility to identify format problems. At the end of each iteration, we corrected the reported problems and then re-ran the data until no additional problems were reported. Typical problems included

- different data types (field numeric, character, date, or timestamp),
- inconsistent data formats (**MM/DD/YYYY** or **DD/MM/YY**), and
- invalid data fields (outside valid range for a particular field).

Our approach was to browse the source data (provided in CSV files, often exported from an Access database) and apply the following rules:

- Fields within quotes (or double-quotes) are character fields.
- If several consecutive character fields are all two characters (**xx**) in length, define as **char(xx)** and see if the **IMPORT** process shows errors because of longer fields. If a given field repeatedly comes up with errors, redefine as something like **VARCHAR(250)** for efficiency.
- Numeric fields without delimiting quotes are truly numeric.
- If numeric fields contain a decimal point, they are defined as **DECIMAL** to allow the system to retain the decimal places.

After we created a **CREATE TABLE** statement based on these rules, we ran the **IMPORT** process and watched for errors. We then corrected any errors and re-created the table, continuing this process until all errors either were corrected or considered acceptable.

When error-free tables were fully loaded, we ran the **AUDIT** process to provide an easy-to-use method of reviewing data content and provide insight for further optimization of the table definition.

C-2 SDLM File

This was our most complex file with the largest number of data fields.

Many fields had relatively long character data; thus, we defined them as **VARCHAR(xxx)**.

This data contained a time stamp, but the hours, minutes, and seconds were all zeros, so we converted them to a pure date format **MM/DD/YYYY**.

There were some **DECIMAL** fields, and we defined them accordingly; however, some decimal places contained all zeroes.

The **AUDIT** output shows that some of the numeric **INTEGER** fields could be redefined to save space.

MAF1

This file contained 564,133 data records, and incorporated a key that was a concatenation of four job control number (JCN) fields (**JCNOrg**, **JCNDay**, **JCNSer**, and **JCNSuf**). Initial attempts to concatenate these fields showed that in some cases the JCN suffix (**JCNSuf**) was null; therefore, any concatenated JCN string with a null JCN suffix also was null. To work around this, we created files called **AV3M_RT60_CONCAT** and **AV3M_MAF1_CONCAT**, containing both the original

JCN fields and a concatenated JCN where any null **JCNSuf** data was changed to **xxx** to ensure that the concatenated data retained the contents of the first three fields. This file contained time stamps with both date and time fields with real data

MAF2

This was the biggest data file with 8,370,563 records. It was a straightforward **IMPORT**. The **MAFRECKEY** field joins it to the MAF1 file, and some **DECIMAL** fields have significant decimal data, but others do not.

RT60

The RT60 file contains 98,650 records, and it is related to the MAF1 data through the combined JCN field. RT60 data can be joined to MAF1 data through the combined JCN. Initial attempts to concatenate these fields showed that in some cases the JCN suffix (**JCNSuf**) was null in RT60, making any concatenated JCN string with a null JCN suffix also null. To work around this, we created views called **AV3M_RT60_CONCAT** and **AV3M_MAF1_CONCAT** containing both the original JCN fields and a concatenated JCN where any null **JCNSuf** data was changed to **xxx** to ensure the concatenated data retained the contents of the first three fields.

FLIGHTS

There were 75,908 flight records, each with a unique **FLTRECKEY**. The date fields were all "true time stamps" containing hours, minutes, and seconds.

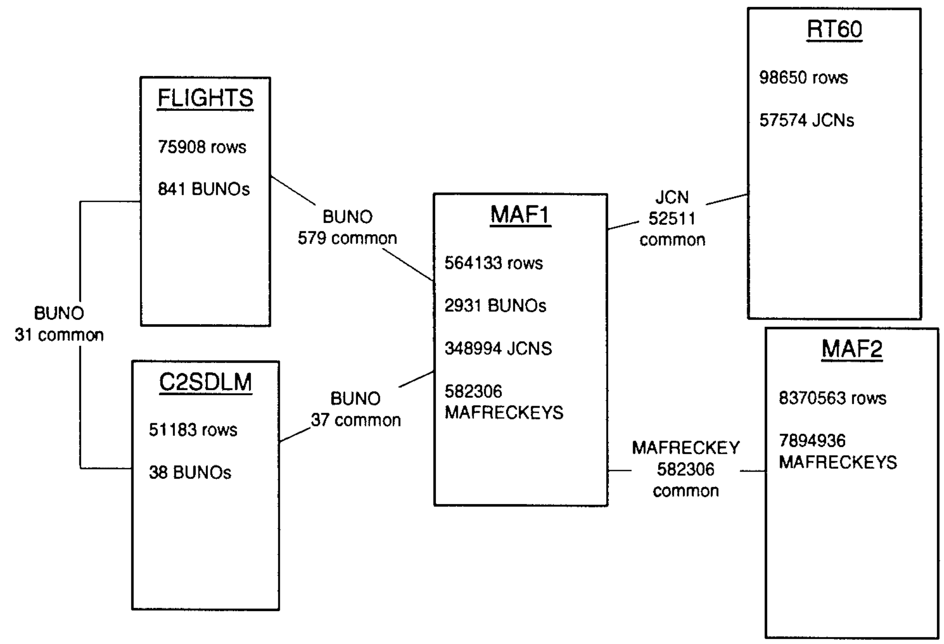
DATA ANALYSIS

Following the initial analysis of each table in isolation, we built a script designed to investigate the inter-table relationships. The script ran five pieces of Standard Query Language (SQL) against every pair of tables with a logical "join" relationship. If the two tables involved are called A and B, and the join key is called J, the script will perform the following actions:

- Count records and unique occurrences of J in Table A.
- Count records and unique occurrences of J in Table B.
- Count records and unique occurrences of J in both Tables A and B.
- Count records and unique occurrences of J in Table A but *not* in Table B.
- Count records and unique occurrences of J in Table B but *not* in Table A.

Figure A-2 depicts the annotated C-2 data structure.

Figure A-2. Annotated Data Structure



Appendix B

Abbreviations

AIRRS	Aircraft Inventory Readiness Reporting System
APDF	aircraft program data file
ASPA	Aircraft Service Period Adjustment
AV3M	Aviation Maintenance and Material Management
AVDLR	aviation depot-level reparable
AWP	awaiting parts
BOM	bill of material
BUNO	bureau number
CaTNP	Configuration and Technical Notification Program
CISS	Configuration Item Status Sheet
CNA	Center for Naval Analysis
DCN	document control number
DepBOM	Depot Bill of Material
DLA	Defense Logistics Agency
DOD	Department of Defense
DRAM	Depot Requirements Assessment Model
DRDM	Depot Requirements Determination Model
DRP	depot repair point
DSC	Defense Supply Center
ECP	engineering change proposal
ETL	extract, transform and load
FISC	Fleet and Industrial Supply Center
ICAAPS	Intelligent Collaborative Aging Aircraft Parts Support
IM	inventory manager
IMC	Integrated Maintenance Concept
JCN	job control number
MAF	Material Availability Forecasting
MAF1	Maintenance Action Form 1

MAF2	Maintenance Action Form 2
MRO	maintenance, repair and overhaul
MRP II	manufacturing resource planning
NADEP	Naval Air Depot
NAVAIR	Naval Air Systems Command
NAVICP	Navy Inventory Control Point
NSO	numerical stocking objective
PAA	primary aircraft allowance
RFI	ready for issue
SDLM	standard depot level maintenance
SMR	source, maintainability, and repairability
SPR	special program requirement
SQL	Standard Query Language
WUC	work unit code

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14. ABSTRACT
Department of Defense (DoD) depot-level maintenance activities often experience delays in obtaining consumable repair and replacement parts for aging aircraft systems and components. As part of a concerted effort to reduce these delays, the Defense Logistics Agency (DLA) sought design, development, and prototyping of Intelligent Collaborative Aging Aircraft Parts Support (ICAAPS). LMI, in partnership with JWK International, explored the use of data mining and analysis techniques to improve long-range projections of depot-level maintenance requirements for the DLA-managed consumable parts. During a prototype demonstration involving standard depot-level maintenance for C-2 aircraft at the Naval Air Depot in North Island, CA, use of ICAAPS analytical tools improved the forecast accuracy for each consumable part included in the initial test sample. Consequently, continued use of ICAAPS should facilitate more timely consumable parts support and enable reductions in the number and duration of DoD depot-level maintenance delays caused by consumable parts shortages.

15. SUBJECT TERMS
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