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Open architecture, inventory pooling and maintenance modules

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ABSTRACT

The adoption of open architecture has several economic implications in the life of an asset, including developmental, production, storage, training and maintenance costs. This research responds to an inquiry by the Program Executive Officer—Integrated Weapons System (US Department of the Navy) regarding the value of open architecture (OA) in the design of complex assets. With this intent, we evaluate how the inventory allocation of spare engines for the F-16 operations in the continental United States would be affected with and without the adoption of open architecture, focusing on the benefits of inventory pooling to meet the demand of many users from a small number of storage sites. We use a distance-constrained version of the Ardalan heuristic for solving the facility location problem, responding to practical limitations exposed by the model. This article shows that open architecture may provide substantial supply chain cost reduction, and simplification of the distribution network when combined with proper inventory storage policies.

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1. Introduction

The combined use of commonality and modularity in product design has allowed automobiles, aircraft, computers and a host of other machines (including most military systems) to be reusable beyond their first lifecycle and to be given many more years of operation. This versatility substantially impacts the availability and maintenance cost of many durable assets. Modularity enables the division of the product development effort among many specialists (firms or individuals), ensuring the development of the most advanced and competitive systems. Modularity facilitates the separation of component-wear phenomena as the system ages, enabling maintenance professionals to locate and repair damaged modules without affecting the integrity of other modules in the system.

Commonality, however, presents a disadvantage that many engineers will recognize: the adoption of common design in a competitive environment hinders creativity and innovation in product development; suppliers of high-technology products would prefer to develop their own designs than to share them with competitors. The design team would rather showcase its capabilities, especially in the development of advanced systems or in the adoption of new technologies. Hence, while modularity remains a powerful product-development philosophy that brings agility and cost reduction to product design, the adoption of common designs for complex products may be not the best approach to system acquisition—especially in circumstances requiring the development of advanced technologies. In these scenarios, the traditional "commonality" must be enhanced with the adoption of "open architecture" features—allowing modules from competing sources to be used in the same system, without constraining the creativity and innovation from the designers involved in the development of the module.

Open architecture provides the opportunity to introduce product aggregation, one of the three aggregation (or *pooling*) approaches to managing and improving supply-chain performance, along with time aggregation and place aggregation. Product aggregation is intended to reduce product variety without compromising the functionality required by the user.

The purpose of this case study is to evaluate open architecture as the design philosophy for the acquisition of complex systems with advanced technologies. This is done by analyzing the case of the F-16 spare engines, showcasing the cost benefits that the US Air Force might be enjoying today had the aircraft engine suppliers been required to adopt open architecture. This study assumes that a complex system (such as the Joint Strike Fighter, or other weapon systems acquired by the uniformed services of the US Department of Defense) is a combination of hardware and software components that may be acquired from multiple developers or suppliers. This study proposes that the adoption of open architecture in the acquisition of these systems can substantially reduce the costs of these programs.

Next section describes the problem that motivated this study, and Section 3 explains how open architecture affects product development and life-cycle management. Section 4 describes current inventory management policy and allocation of F-16 spare engines at Air Force bases in the contiguous United States. Section 5 introduces a brief literature review of the methodology used to

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rationalize F-16 spare engine allocation. Section 6 analyzes the case under three scenarios: the benchmark scenario, which is based on current policy, a scenario with limited inventory pooling, and a third scenario with open architecture of engine design. Section 7 presents the conclusions and suggestions for future research.

2. Motivation: F-16 alternative engines

Modularity facilitates the development of new systems using modules that were previously designed and developed for other systems, providing major time and cost savings product development initiative that can exploit these benefits. Moreover, because of commonality, high-value modules in a system may be recovered at the end of the system's life and used in another product—a process often called cannibalization. In the case of complex models with high engineering content, such as aircraft turbines, it may be desirable to have multiple suppliers offering competing designs, which could be accomplished with the adoption of open architecture. The Defense Acquisition University (2006) defines open architecture as follows:

> The confluence of business and technical practices yielding modular, interoperable systems that adhere to open standards with published interfaces. This approach significantly increases opportunities for innovation and competition, enables reuse of components, facilitates rapid technology insertion, and reduces maintenance constraints.

Modularity and commonality are the two aspects in product design that support the adoption of an open architecture. They facilitate the execution of an agile product development program with a wide-reaching product line that meets the requirements of multiple users with different needs. The renewed emphasis on open architecture allows strategic resource allocation, facilitating the acquisition of better assets with lower costs. A current example of this design approach is the F-35 Lightning II, Joint Strike Fighter, a multi-role aircraft currently in production for the uniformed services of the US Department of Defense (DoD) and for many of the US allies. The Federation of American Scientists (2005a) indicates that among its strengths, "JSF … will capitalize on commonality and modularity to maximize affordability."

In practice, previous developments and acquisitions of weapon systems by the DoD usually did not have this focus. For instance, Pratt & Whitney (P&W) and General Electric Aircraft Engines (GEAE) produce engines for the F-16 aircraft used by the US Air Force and a few foreign military forces. The P&W F100-PW-200 aircraft engine was originally selected over GEAEs as the sole source engine for the F-16. The original F-16 was designed as a lightweight, air-to-air day-fighter. Air-to-ground responsibilities transformed the first production F-16s into multi-role fighters. The first operational F-16A was delivered in January 1979 to the 388th Tactical Fighter Wing at Hill Air Force Base, Utah. The delivery of 2200+ aircraft to the US Air Force continued until March 2001 (Federation of American Scientists, 2005b).

The decision to choose an alternate fighter engine for the F-16 led to the development of the General Electric Aviation Engine's F110 series. With the implementation of the Alternative Fighter Engine competition for the F-16 in 1985, GEAE fielded the F110-GE-100 version to compete with Pratt & Whitney's F100-PW-220 engine. Throughout the production of the F-16, the performance requirements for both suppliers were identical, but the engines delivered were not interchangeable. In fact, the airframe manufacturer, Lockheed-Martin, had to deliver structurally different frames to use the different engines. For example, aircraft with production numbers ending in zero are designed and built with significantly larger air intake to accept the GEAE F110 series engine. Aircraft with production numbers ending in two are designed and built with smaller air intake to use the P&W F100 series engine. Each engine type (GEAE or P&W) uses different control software (with implications in the cockpit controls and pilot training), requiring unique airframe interface. With the exception of the engine, the airframe interface and the control software, aircraft of the same generation would otherwise be identical.

The adoption of two engine suppliers for the F-16 fighter aircraft was intended to eliminate the monopoly held by Pratt & Whitney as the sole-source engine supplier for that aircraft. However, allowing the newcomer (GEAE) to design a product that was not interchangeable with the existing engine did not eliminate some of the monopoly effects in the long-term, and created costly logistics constraints.

Similar to the F-16 acquisition experience in the 1980s and the 1990s, the ongoing acquisition process of the Joint Strike Fighter includes the development of two competing power plants: the Pratt & Whitney F135, and the GEAE F136, developed in partnership with Rolls-Royce. On its website, the Federation of American Scientists states that the F-35 propulsion systems will be "physically and functionally interchangeable in both the aircraft and support systems." According to the Joint Strike Fighter Program Office, "the F135 and F136 teams are working closely to develop common propulsion system components" (F-35 JSF Program, 2007).

In this study, we analyze current usage data of P&W and GEAE spare engines held in various bases in the continental United States to support the F-16 operations to identify substantial cost reduction from the pooling effects that could be achieved with the use of better inventory allocation (place aggregation), as well as the adoption of open architecture (product aggregation). One important caveat exists, however: considering the limited amount of usable data available about the acquisition and use of these aircraft, the reader is cautioned that this analysis is not a critique of the acquisition of the F-16 aircraft or its engines. Rather, it intends to discuss how it would have benefited had it adopted open architecture.

3. Open architecture as a design approach to simplify the supply chain

This section presents open architecture and how it generally benefits product design. The concept stems from the development approach used by many software houses, in which sub-routines (modules) are developed by individual designers having only two major constraints: the functionality (i.e., the sub-routine does what is expected to do) and the standardized interface with the main program (i.e., the sub-routine has seamless integration with other modules in the software).

Nelson (2007) indicates that open architecture principles have been around since at least 1981, when IBM developed its personal computer. The design of the IBM-PC was a major breakthrough in that it was made of a set of physical modules that could be replaced by similar modules of different design, make or performance, as long as they satisfied a limited set of interface requirements and fulfilled the expected functions. For example, a hard disk drive of a given capacity and make could be upgraded by another hard disk of different make and greater capacity, as long as it satisfied a simple set of interface constraints. By contrast, one is not usually able to replace the engine of an automobile by one from a different maker, even if the two have similar performance, size or functionality.