A REVIEW OF FIGHTER AIRCRAFT CAPABILITY
FOR SMART BOMBS

THESIS

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

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THESIS

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Acknowledgments

The intent of this research was to recommend an alternative for increasing the inertially guided smart bomb capability for DOD multi-role fighter aircraft. Review of the importance of smart bombs and the impact of declining budgets on fighter aircraft force structure and capability underlined the importance of finding a solution. Identification of potential alternatives and decision criteria revealed that a decision model that could account for quantitative and qualitative criteria was required.

I would like to thank Dr. David Christensen for introducing me to the Analytical Hierarchy Process for solving multiple criteria decision making problems and for later agreeing to serve as my thesis advisor. I am also thankful to Dr. Norman Ware for serving as my thesis reader. Dr. Christensen and Dr. Ware have together provided the guidance and review of my many thesis drafts that were required for its eventual completion. I am also indebted to three Air Force experts who provided data to a series of anonymous interviews without whose help I could not have finished this project.

Last but not least, I would like to dedicate this thesis to my wife, Simera, and son, Zach, because their loving support ensure my continued success in life.

David R. King

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Abstract

This study examined potential alternatives and decision criteria for inclusion in a Cost and Operational Effectiveness Analysis to recommend an alternative for addressing existing DOD multi-role fighter capability to employ inertially guided smart bombs. A survey of literature and interviews with experts were used to collect required information. An Analytical Hierarchy Process (AHP) decision model was developed for two feasible alternatives and four relevant decision criteria. The two feasible alternatives included either developing the BRU-55 smart bomb rack, or modifying F-15E conformal fuel tanks with additional smart interface wiring. Data on quantitative and qualitative decision criteria were collected to evaluate the alternatives.

This study concluded that the F-15E additional wiring alternative is the recommended solution for addressing DOD multi-role fighter aircraft inertially guided smart bomb capability, and that joint programs should not be considered as a panacea. Additionally, the Air Force and DOD should consider formally adopting AHP and the software Expert Choice in analysis of multiple criteria decision making problems.

A REVIEW OF FIGHTER AIRCRAFT CAPABILITY

FOR SMART BOMBS

I. Introduction

Introduction

The continued success of the Department of Defense (DOD) in meeting the challenges of future crises and wars requires combining lessons from history and knowledge of the present. Policies developed from historical lessons alone are limited by the fact that the technology and the international community of today are vastly different from what has existed in the past. However, policies formed today that do not account for experience increase the risk of repeating similar mistakes. Lessons learned from historical conflicts in modern times show one aspect has consistently determined success. A country needs an industrial base capable of producing military goods in peacetime and responding to increased military requirements in crisis or war (Kennedy, 1987; Toffler and Toffler, 1993; Eccles, 1965: 12; Nunn, 1992: 39). Understanding recent experience is critical in knowing what areas of industry are most crucial to continued military success.

The most recent experience of the United States military in Desert Shield/Storm has both validated the importance of an industrial base to success in war and demonstrated the growing importance of technology (Toffler and Toffler, 1993: 77; Suit, 1991: 9; Morrocco; 1991a: 38). Superior technology is a deterrent to war, and if deterrence fails technology provides the means to offset numerical disadvantage in forces and to minimize loss of life (AFPD 10-6, 1993: 1). However, technology is not useful unless it is developed into combat capability (Kent, 1988: 1). One area of technology that gained recognition as being key to combat success in Desert Shield/Storm was the application of airpower (Toffler and Toffler, 1993: 106; Mann, 1991: 20; Gold, 1994: 21). Strengths in night attack and smart bombs were instrumental to the success of airpower in Desert Shield/Storm (Morrocco, 1991a: 38; Morrocco, 1991b: 52). Three multi-role fighter aircraft, the F-15E, F-16, and F/A-18, possessed the advanced avionics and precision guidance capabilities to attack targets at night with smart bombs (Morrocco, 1991a, 38; Morrocco, 1991a: 66). Technological advances in armament and avionics have the potential to increase combat capability (Kent, 1988: 1; Stanley, 1980: 1). This research is a preliminary study looking at different alternatives for maintaining the DOD's strength in fighter aircraft by capitalizing on recent advances in armament and avionics.

General Issue

The annual defense budget has dropped 34 percent in real terms from a 1988 peak and is projected to fall by a total of 41 percent by 1998 (Loh, 1994: 1). This trend of decreased defense funding threatens the United States aircraft industrial base and the capability of the DOD to meet future challenges (Morrocco, 1994a: 48, Correll, 1991: 52, Morrocco, 1994b: 66). The reduction in funding has been particularly hard on the aerospace industry.

DOD procurement of fighter and other military aircraft is down significantly; in 1995, 127 military aircraft will be procured, down from 900 in 1985 (Rich and Dews, 1986: 22; Morrocco, 1994a: 48). Decreased acquisition means conflicts in the next twenty years will be fought with existing weapon systems (Ferris and Jackson, 1994: 52; Heberling, 1994: 248). Existing weapon systems will become obsolete and ineffective over time without system upgrades and technology insertions. Therefore, reduced acquisition of new systems requires that upgrading weapon systems already in inventory must become part of DOD acquisition strategy (Conver, 1993: 51; Rich and Dews 1986: 24). System upgrades modernize the combat capability of platforms, and support the industrial base (Conver, 1993: 48; Morrocco, 1994a: 48; Heberling, 1994: 245).

A trend toward extending the inventory life of fighter aircraft requires modernization programs to avoid obsolescence and maintain combat effectiveness (Rich and Dews, 1986: 22). The House of Representatives Appropriation Committee (HAC) has directed the DOD to report on plans to modernize existing multi-role fighter aircraft and maintain the national capability to produce these aircraft (House of Representatives, 1993: 175). Technology advances in navigation and guidance, plus funding for smart bomb programs based on inertial guidance, provide an opportunity to take action on the HAC directive. This action would increase the capability of DOD multi-role fighter aircraft by increasing the ability of such aircraft to carry inertially guided smart bombs.

Specific Problem

Three smart bomb programs based on inertial guidance technology will be available around the year 2000. They are the Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) (Fulghum, 1994a: 22; Fulghum, 1994b: 46; King, 1994). All three smart bombs require a smart interface with the employing aircraft, an interface that is not at all fighter weapon stations. The F-15E, F-16, and F/A-18 are the first fighter aircraft in the DOD inventory prioritized for integration of inertially guided smart bombs (Fulghum, 1994a: 22; Fulghum, 1994b: 46). The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Research Hypothesis and Questions

The research hypothesis is that the recommended alternative will be a joint program or one that is the same for each aircraft. Joint programs can provide significant reductions in both development and procurement costs, and lead to higher compatibility and interoperability (Conrow and others, 1983: 21; Department of Air Force AFDD-40, 1994: 7). A RAND study's recommendation for improving the military acquisition process cited increasing early coordination among services as a better approach to meeting future challenges (Rich and Dews, 1986: 51). Admiral William Owens, the vice chairman of the Joint Chiefs of Staff states, "it is essential for the military to buy only the weapons it needs and to avoid duplication" (Matthews, 1994: 34). A joint program is hypothesized as a better solution, because it will meet the needs of more than one service and allow lower unit costs through larger purchase economies. Selecting a recommended alternative and testing the research hypothesis requires answering seven research questions.

The seven research questions are:

1) What is the impact of smart bombs on warfare?

2) What aircraft support is required for the next generation of smart bombs?

3) What is the present DOD fighter capability to support smart bombs?

4) What alternatives exist for addressing fighter smart bomb capability?

5) What DOD guidance exists for evaluating alternative solutions?

6) What decision criteria are used to evaluate the identified alternatives?

7) Considering the decision criteria, what alternative is recommended?

A formalized study is used to answer the seven research questions. The research methodology follows four phases and is described in Chapter III. The foundation for beginning the research is laid by establishing assumptions and limitations.

Research Assumptions and Limitations

Several assumptions and limiting factors scope the research problem. The impact of the assumptions and limitations on the research is discussed in Chapter IV.

The primary research assumptions are:

1) All known feasible solutions are considered.

2) The weighting of decision criteria is representative.

3) The focus is on potential, not necessarily planned capability.

4) Only one-half of the potential aircraft will require retrofit of smart bomb racks.

5) That new smart bomb racks would not be procured for the F/A-18's, and existing BRU-33A/A racks would be modified with smart electronics.

All alternative solutions found by the researcher and known by contacted experts were reviewed. Further advances in technology may occur that will develop alternatives that are not considered in this research. The weighting of decision criteria is based on the Delphi technique, a method of gathering a group of experts' judgments (Brown, 1968: 1). The Delphi technique is further discussed in Chapter II. The inherent capability to expand each aircraft's ability to carry smart bombs is used in the research, and may not be representative of the planned development of an aircraft's capability. For example, there is no defined requirement for F-15E carriage of the 1,000 lb. version of JDAM, although the aircraft has the undeveloped capability to carry the store. Likewise, it is not feasible that every F-15E, F-16, and F/A-18 have a smart bomb rack, because some of the missions the aircraft perform are not compatible with a smart bomb rack. In addition, F/A-18 aircraft already use BRU-33A/A bomb racks that could be modified into BRU-55 smart bomb racks. Therefore, the cost for the F/A-18 for the BRU-55 alternative assumes no additional bomb rack hardware will be procured.

The primary research limitations are:

1) Exact cost figures could not be obtained for each alternative due to their theoretical nature.

2) Cost estimates are for the development and retrofit of an alternative only.

3) Alternatives requiring modification of weapons are not considered.

4) Only alternatives for 1,000 lb. class weapons are considered.

5) Only alternatives for the F-15E, F-16, and F/A-18 are considered.

6) There is no defined requirement for carriage of additional smart bombs on DOD fighter aircraft.

7) Except for the F-16, the impact of external fuel tank carriage on the number of available weapon stations with a smart interface is not considered.

8) The F/A-18 technical information was not independently reviewed by a F/A-18 expert, and F/A-18 cost information is based on the combined high and low cost estimate values for the F-15E and F-16 cost estimates respectfully.

Cost information for each feasible alternative is only representative of actual cost to allow comparison of the alternatives. Life cycle costs are not developed, because not enough is known about all the alternatives to quantify support costs. Including changes to weapon design would not allow direct comparison of different alternatives, because the weapon design would not be baselined across the alternatives. Only 1,000 lb. class weapons are considered, because that is the only single common weight class for JDAM, JSOW, and WCMD. Selection of the F-15E, F-16, and F/A-18 aircraft is based on their status as the top three DOD operational, multi-role, night capable, fighter aircraft prioritized for integration of inertially guided weapons. Without a defined requirement no formal performance measures for the alternatives exist. Definition of weapon system requirements is a continuing concern in DOD acquisition (Kent, 1988: 8; Rich and Dews, 1986: 31; Davis, 1994: 44). Carriage of external fuel tanks is dependent on the mission profile and would be part of the defined requirement. The requirement for additional smart bomb carriage is only defined for the F-16. Therefore, the F-16 is the only aircraft where external fuel tank carriage is considered. The F/A-18 technical and cost information will not be as reliable as the information for the F-15E and F-16, because it was not independently reviewed.

Summary

This chapter states the research problem, hypothesis, and goal of the research effort. Changing technology and declining defense budgets require the DOD to optimize the combat capability of existing weapon systems. An alternative for addressing the DOD's fighter aircraft smart bomb capability is recommended from the results of a formal study. This research identifies and evaluates alternative methods for addressing DOD capability to employ inertially guided smart bombs in combat.

Overview of Thesis

The thesis is divided into five chapters. Chapter I introduced the research problem, hypothesis, and goal. Chapter II is a literature review. This chapter answers the first five research questions by identifying background information, and potential alternatives. A foundation is also laid for answering the sixth and seventh research questions. Chapter III describes the methodology used to answer the research questions. The Analytical Hierarchy Process (AHP), a multiple criteria decision support tool developed by Saaty, is used to recommend an alternative and to perform sensitivity analysis (Saaty, 1980; Wind and Saaty, 1980). A multiple criteria decision making problem has multiple alternatives and decision criteria (Tabucanon, 1988: 5). The AHP allows the use of both quantitative and qualitative decision criteria. A decision support software package, Expert Choice, is used to perform the complex computations and sensitivity analysis of the AHP (Decision Support Software, 1993). Expert Choice allows systematic consideration of alternatives for multiple criteria decision making problems (Battin and Bender, 1992: 68). Chapter IV provides the results and evaluates the sensitivity of the recommended alternative to changes. Chapter V reviews the thesis, evaluates the impact of the research assumptions and limitations, summarizes the research questions and findings, and presents research conclusions and recommendations.

II. Literature Review

Introduction of Topics

In Chapter I the research issue and investigative questions were introduced, and an overview of the thesis was provided. In this chapter the first five research questions are answered and a foundation is established for answering the last two research questions. The research questions are:

1) What is the impact of smart bombs on warfare?

2) What aircraft support is required for the next generation of smart bombs?

3) What is the present DOD fighter capability to support smart bombs?

4) What alternatives exist for addressing fighter smart bomb capability?

5) What DOD guidance exists for evaluating alternative solutions?

6) What decision criteria are used to evaluate the identified alternatives?

7) Considering the decision criteria, what alternative is recommended?

At the end of this chapter, conclusions are drawn from the information found from the investigation of the research questions.

Information in this chapter is very detailed, and repetition occurs among related categories. The information is organized in categories for two reasons. First, experts in each area are able to verify the information easier when it is self contained. Second, once verified, organizing the information by category provides easy reference to required information. If less detail is desired, the main points of the answer for each research question are summarized before beginning discussion of the next research question.

What is the impact of smart bombs on warfare?

In their review of changes in modern warfare and the world economy, Alvin and Heidi Toffler say the most important change in war since the Vietnam conflict is the development of smart bombs (Toffler and Toffler, 1993: 11). When the Tofflers discuss important trends in warfare, two apply to smart bombs. The first applicable trend is the growing importance of knowledge and information. A revolution placing knowledge at the core of military power was demonstrated in Desert Shield/Storm (Toffler and Toffler, 1993: 70). The two Joint Surveillance and Target Attack Radar System (J-STARS) aircraft flew 49 sorties during Desert Storm and identified over 1,000 targets (Toffler and Toffler, 1993: 71). Maj. Gen. Thomas S. Swalm of the Air Force is quoted by the Tofflers as saying, "aircraft directed by J-STARS had a 90 percent success rate in finding targets on the first pass" (Toffler and Toffler, 1993: 71). The ability to accurately locate targets from platforms such as J-STARS allows for a higher success in employing smart bombs. The second applicable trend is that improved technology requires fewer resources. Smart bombs using advanced technology can destroy targets in one attack (Toffler and Toffler, 1993: 73). This is significant change because:

> As recently as the Vietnam War American pilots flew 800 sorties and lost ten planes in an unsuccessful attempt to knock out the Thanh Hoa bridge. Later four F-4's armed with some of the earliest smart bombs did the job in a single pass. Today one F-117, flying a single sortie and dropping one bomb, can accomplish what it took B-17 bombers flying 4,500 sorties and dropping 9,000 bombs to do during World War II, or 95 sorties and 190 bombs during Vietnam.
> (Toffler and Toffler, 1993: 73)

Better accuracy requires fewer sorties and fewer sorties improve survivability, because aircraft exposure to threats is minimized (Stiles, 1989: 1).

The actual advances in accuracy have been made in weapon delivery modes and guidance. Previously bombs were delivered on predetermined ballistic paths. F-15E, F-16, and F/A-18 aircraft now use continuously computed impact point (CCIP) delivery modes that allow unguided weapons to be delivered with approximately 100 foot accuracy (Morrocco, 1991c: 52). An improvement over the 150 to 200 feet average accuracy for weapons delivered during the Vietnam conflict (Morrocco, 1991c: 52). Laser or optically guided bombs during Desert Storm had an accuracy within one to two feet (Morrocco, 1991c: 52). However, there are two limiting factors for these advanced guidance systems: they require support after launch, and bad weather degrades their performance.

Both limitations affect the survivability and effectiveness of aircraft. Laser guided weapons require that the target be illuminated by a laser until the bomb hits the target. Optically guided weapons require constant radio data link communication with the launch aircraft to update the selected target impact point. The radio data link can be jammed and requires that the launch aircraft maintain line of sight with the weapon. Additionally, laser illumination and data link line of sight may require an aircraft to remain in high threat target areas until the bomb hits its target. Also, the weather during Desert Storm was twice as bad as forecast and that caused some aircraft to return without finding their targets (Morrocco, 1991a: 38). Concerns about the limitations of current smart bombs, and advances in technology have led to the development of new weapons.

The next generation of smart bombs is inertially guided. Initial inertially guided weapons are designed for an accuracy of 30 to 40 feet (Fulghum, 1994a: 22; Fulghum, 1994b: 46). Although the predicted accuracy of an inertially guided weapon is less than the accuracy for a laser or optically guided weapon, an inertially guided weapon has two distinct advantages. First, inertially guided weapons will not require support from an aircraft after launch, so the launch aircraft can leave or avoid high threat areas. Second, inertial guidance is not affected by adverse weather.

Summary. Limitations of current laser and optically guided smart bombs have led to the development of inertially guided smart bombs. Advances in bomb guidance and delivery modes have decreased the number of aircraft sorties required to destroy selected targets and have increased survivability.

What aircraft support is required for the next generation of smart bombs?

Inertially guided smart bombs rely on Inertial Navigation Systems (INS) for guidance, and in some cases the INS is aided with a Global Positioning System (GPS) (Fulghum, 1994a: 22). Inertial Navigation Systems provide information on position based on relative movement from a starting point. The GPS compensates for drift in INS position information by receiving updates from GPS satellites. The 24 GPS satellites provide both position and velocity information by triangulation (Nordwall, 1993: 57). Combined, an INS/GPS system provides very accurate position and guidance information. The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology.

JDAM is an INS/GPS tail kit that can be combined with existing dumb bombs (Fulghum, 1994a: 22). The dumb bombs include: the BLU-110, a 1,000 lb. unitary warhead; the MK-84, a 2,000 lb. unitary warhead; and the BLU-109, a penetrating 2,000 lb. warhead (Fulghum, 1994a: 22). The combined tail kit and bomb form an adverse weather smart bomb that will autonomously guide to a selected location.

JSOW is a new 1,000 lb. bomb body with deploying wings for gliding up to 40 miles (Fulghum, 1994b, 46). The JSOW is guided by INS/GPS and can carry a variety of weapons including: 500-1000 lb. unitary warheads, general purpose submunitions, or smart anti-tank weapons (Fulghum, 1994b: 46).

WCMD is an INS kit that is attached to existing 1,000 lb. class cluster munitions including the CBU-87, CBU-89, and CBU-97 (King, 1994). The WCMD allows accurate employment of cluster bombs from higher altitudes by correcting for the effects of wind on weapon ballistics.

A limitation of these smart bombs is that they require additional support from launch aircraft. Inertially guided smart bomb requirements include mechanical, electrical, and logical interfaces with a launch aircraft. The mechanical interface is the actual physical interaction between the aircraft and weapon. The electrical interface defines the type of electrical power supplied to the weapon from the aircraft before launch. The logical interface defines the format and content of information passed between the aircraft and weapon. A discussion of the requirements for each type of support follows.

Mechanical Interface. The mechanical interface required for inertially guided smart bombs includes the physical fit and weight limits of the aircraft weapon station, pylon, bomb rack, and weapon umbilical (F-15A-E. . .Guide: 1994, 19). Aircraft weapon stations are locations where weapons can be loaded, and are the points where a suspension pylon can be connected to the fuselage or wing. Each weapon station has a structural limit for the amount of weight that can be suspended at that point. Pylons provide the necessary clearance between the weapon and aircraft. Bomb racks fit within pylons and allow weapons to be connected to the aircraft. MIL-STD-8591 sets forth general structural and mechanical design criteria for airborne store and bomb rack designs (MIL-STD-8591, 1990).

Weapon umbilicals provide a conduit for communication between the aircraft platform and smart bomb electronics, and confirm weapon separation from the aircraft. Inertially guided smart bombs require umbilicals compatible with MIL-STD-1760 connectors (F-15A-E. . .Guide, 1994: 24). For a similar example in the home, this means that a three prong electrical plug requires a three prong electrical socket. More sophisticated weapon development led to MIL-STD-1760, because the amount of data and the rate of data exchanged increased, and a standard increased interoperability while lowering support costs (Byrd, 1995). MIL-STD-1760 is a standard electrical/logical interface between an aircraft and a compatible store. The standard defines requirements for power lines, low and high bandwidth lines, and a digital data bus. The wiring is incorporated into a standard connector on the weapon umbilical between the aircraft and the store (MIL-STD-1760, 1992).

Electrical Interface. Smart bombs require electrical support from the aircraft before they become self sufficient on battery power after release from an aircraft (F-15A-E. . .Guide, 1994: 19). Inertially guided smart bombs require an electrical interface that complies with MIL-STD-704. MIL-STD-704 provides voltage and frequency limits and conditions for aircraft electric power (MIL-STD-704, 1991). The standard includes quality requirements for alternating current (AC) and direct current (DC) power. The MIL-STD-704 power lines are combined into the MIL-STD-1760 connector mentioned in the description of the mechanical interface.

Logical Interface. Smart bombs require passing of information between the aircraft and weapon over the weapon umbilical (F-15A-E. . .Guide, 1994: 19). Some of the information passed includes aircraft commands to turn on weapon batteries, weapon status information, and aircraft and target location. Inertially guided smart bombs require a logical interface that is MIL-STD-1760 compatible (Morrocco, 1994c: 78). MIL-STD-1760 defines implementation requirements for the connection between an aircraft and weapons (MIL-STD-1760, 1992). The MIL-STD-1760 connection implementation provides a common interface for the operation and employment of weapons from an aircraft. MIL-STD-1553 is a subset of the 1760 standard and establishes requirements for digital data bus techniques (MIL-STD-1553, 1993). MIL-STD-1553 defines the concept of operation and data format over a specified wiring configuration between the aircraft and weapon.

Summary. JDAM, JSOW, and WCMD are three smart bomb programs under development that use inertial guidance technology. Though each is a different design they require similar mechanical, electrical, and logical support from launch aircraft.

What is the present DOD fighter capability to support smart bombs?

The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and the F/A-18 are multi-mission, night capable, fighter aircraft with advanced avionics and targeting systems (Morrocco, 1991c: 52; Morrocco, 1991a: 38). A discussion of the capability for each aircraft to employ inertially guided smart bombs is contained in the following subsections.

F-15E. The F-15E, produced by McDonnell-Douglas, is a two seat dual role attack/air superiority fighter (Lambert, 1994: 584). A total of 209 F-15E aircraft were produced, with the last Air Force fighter delivered in 1994 (Lambert, 1994: 584). However, due to attrition only 205 F-15E's remain (Thirtle, 1994). The advantages of the F-15E include its night navigation capability, high resolution radar, and ability to carry a wide quantity and variety of weapons (Lambert, 1994: 585; Morrocco, 1991c: 52).

The F-15E has fifteen air-to-ground weapon stations (Lambert, 1994: 586). The weapon stations are located with one under the centerline aircraft fuselage, one under each wing, and six on each side of the aircraft along conformal fuel tanks (CFTs) (Lambert, 1994: 586). The F-15E can carry external fuel tanks on the center fuselage and wing stations (Thirtle, 1994). There are also provisions for additional outboard wing weapon stations. The specific mechanical and electrical/logical interface at each weapon station is discussed in the next two paragraphs.

Mechanical Interface. The mechanical interface of an aircraft consists of four areas: the suspension equipment, weapon station weight limits, the physical connector, and physical fit of the weapon. The F-15E suspension equipment is compatible with MIL-STD-8591 as required by the inertially guided smart bombs (F-15A-E. . .Guide, 1994: 19). F-15E weapon station weight limits at nine times gravity (9g) are: 5,000 lb. for the wing and centerline stations, 3,500 lb. for the center inboard CFT stations, 3,000 lb. for the fore and aft inboard CFT stations, and 1,000 lb. for the outboard CFT stations. (F-15A-E. . .Guide, 1994: 19). This information is summarized in Table 2.1.

Table 2.1: F-15E Air-to-Ground Weapon Stations

Station Location	Weight Limit (lbs. at 9g)	Number of Stations
Wing		
Inboard	5,000	2*
Outboard (Notional)	1,000 (notional)	2 (notional)
Centerline	5,000	1*
CFT Inboard		
Center	3,500	2*
Fore/Aft	3,000	4
CFT Outboard	1,000	6

* Denotes weapon stations with MIL-STD-1760 interface

The F-15E does not have a standard MIL-STD-1760 connector at each weapon station; however, all the required wires are at the wing, centerline, and center, inboard CFT stations (F-15A-E. . .Guide, 1994: 19). A weapon umbilical is required to bring the available wires into a MIL-STD-1760 connector (F-15A-E. . .Guide, 1994: 19). The size and shape of the 1,000 lb. class JDAM, JSOW, and WCMD vary, causing the weapon stations where the stores can physically fit to be different. JDAM and WCMD in the

1,000 lb. class can physically fit on every F-15E weapon station. JSOW can fit on the centerline, wing, and inboard CFT stations. However, either one JSOW can be carried per CFT at the center inboard station, or two JSOW per CFT can be carried with one each at the fore and aft inboard stations.

Electrical and Logical Interface. The F-15E has wiring and power support in accordance with MIL-STD-704, MIL-STD-1553, and MIL-STD-1760 at certain weapons stations (F-15A-E. . .Guide, 1994: 19). The five air-to-ground weapon stations with provisions for a smart interface are: the wing stations, the centerline station, and the center inboard CFT stations (F-15A-E. . .Guide, 1994: 19). The F-15E weapon stations with a smart interface are indicated on Table 2.1.

F-16. The F-16, produced by Lockheed Fort Worth Company, is a single/dual seat multi-role fighter (Lambert, 1994: 566). The production of F-16 aircraft has been divided into different aircraft blocks. Only F-16 aircraft in the Block 40 and 50 series are currently being considered for integration with inertially guided smart bombs (Okuly, 1994). A total of 462 F-16 Block 40 aircraft were produced, and 425 remain in operational inventory (Lambert, 1994: 566; Appleton, 1994). F-16 Block 40 aircraft require retrofit of their pylons to incorporate a MIL-STD-1760 connector (Okuly, 1994). Production of F-16 Block 50 aircraft for the Air Force will continue through 1997 (Clark, 1994). There are 230 F-16 Block 50 aircraft still in operational inventory (Appleton, 1994). The advantages of the F-16 include its night navigation capability and ability to carry a variety of weapons (Lambert, 1994: 566).

The F-16 has five air-to-ground weapon stations (Lambert, 1994: 570). The weapon stations are located with one under the centerline aircraft fuselage, and two under each wing (Lambert, 1994: 570). The inboard wing station and centerline aircraft fuselage stations can carry external fuel tanks (Okuly, 1994). The specific mechanical, and electrical/logical interface at each weapon station is discussed in the following paragraphs.

Mechanical Interface. The mechanical interface of an aircraft consists of four areas: the suspension equipment, weapon station weight limits, physical connector, and physical fit of the weapon. The F-16 suspension equipment is compatible with MIL-STD-8591 as required by inertially guided smart bombs (Clark, 1994). F-16 air-to-ground weapon station weight limits at nine times gravity are: 1,200 lb. for the centerline station, 2,500 lb. for the inboard wing stations, and 2,000 lb. for the center, wing stations (Lambert, 1994: 570). This information is summarized in Table 2.2.

Table 2.2: F-16 Air-to-Ground Weapon Stations

Station Location	Weight Limit (lbs. at 9g)	Number of Stations
Centerline	1,200	1*
Wing		
Inboard	2,500	2*
Center	2,000	2*

* Denotes weapon stations with MIL-STD-1760 interface

The F-16 does not have a standard MIL-STD-1760 connector at each weapon station, so weapon umbilicals are required. The stations where 1,000 lb. class JDAM, JSOW, and WCMD fit on the F-16 are the centerline fuselage station, the inboard wing stations, and the center wing stations. However, the centerline fuselage station and inboard wing station are normally reserved for fuel tanks (Okuly, 1994).

Electrical and Logical Interface. The F-16 has wiring and power support in accordance with MIL-STD-704, MIL-STD-1553, and MIL-STD-1760 at all weapon stations (Okuly, 1994). The F-16 weapon stations with a smart interface are indicated on Table 2.2.

F/A-18. The F/A-18, produced by McDonnell Douglas, is a single/two seat carrier based strike/attack and maritime air superiority fighter (Lambert, 1994: 590). The production of F/A-18 aircraft has been divided into different models. Only F/A-18 aircraft in the C/D and E/F models are being considered for integration with inertially guided smart bombs (Esker, 1994). A total of 168 F/A-18C/D aircraft were produced (Lambert, 1994: 586). A total of 72 F/A-18E/F aircraft will be produced, with production continuing beyond 1995 (Lambert, 1994: 586; Morrocco, 1994a: 48). The advantages of the F/A-18 include a high resolution radar, night attack capability, and its deployability from aircraft carriers to many locations (Lambert, 1994: 586; Suit, 1991: 11).

The F/A-18 has five air-to-ground weapon stations (Lambert, 1994: 589). One weapon station is located under the centerline aircraft fuselage, and two are located under each wing (Lambert, 1994: 589). The F/A-18 can carry external fuel tanks on the centerline and inboard wing stations (Lambert, 1994: 589). The specific mechanical, and electrical/logical interface at each weapon station is discussed in the following paragraphs.

Mechanical Interface. The mechanical interface of an aircraft consists of four areas: the suspension equipment, weapon station weight limits, physical connector, and physical fit of the weapon. The F/A-18 suspension equipment is compatible with MIL-STD-8591 as required by the inertially guided smart bombs. F/A-18 weapon station weight limits at the seven and one half times gravity maneuvering limit are as follows: 2,700 lb. for the centerline station, 2,800 lb. for the inboard wing stations, and 2,400 lb. for the outboard wing stations (Caulfield, 1994). This information is summarized in Table 2.3.

Table 2.3: F/A-18 Air-to-Ground Weapon Stations

Station Location	Weight Limit (lbs. at 7.5g)	Number of Stations
Centerline	2,700	1*
Wing		
Inboard	2,800	2*
Outboard	2,400	2*

* Denotes weapon stations with MIL-STD-1760 interface

The F/A-18 does not have a standard MIL-STD-1760 connector at each weapon station, so weapon umbilicals are required. The 1,000 lb. class JDAM, JSOW, and WCMD fit at all the F/A-18 air-to-ground weapon stations (Esker, 1994).

Electrical and Logical Interface. The F/A-18 has wiring and power support in accordance with MIL-STD-704, MIL-STD-1553, and MIL-STD-1760 at each weapon station (Esker, 1994). The F/A-18 weapon stations with a smart interface are indicated on Table 2.3.

Summary. The F-15E, F-16, and F/A-18 are the first operational DOD fighters prioritized for integration of inertially guided smart bombs. The mechanical, electrical, and logical interfaces of the F-15E, F-16, and F/A-18 are discussed. Both the F-15E and the F/A-18 both have five weapon stations currently capable of carrying 1,000 lb. smart bombs, and the F-16 has two 1,000 lb. smart bomb stations, because external fuel tanks are normally carried on the centerline fuselage and inboard wing stations. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces.

What alternatives exist for addressing fighter smart bomb capability?

All known alternatives for addressing smart bomb capability on fighter aircraft are discussed in this section. Evaluation of the alternatives occurs in Chapter IV. The available alternatives fall into four categories (King, 1994). The first category is to add smart interface wiring to current weapon stations capable of carrying 1,000 lb. smart bombs. The second category is to procure a smart bomb rack that can split the aircraft's smart interface to more than one smart bomb. The third category is to transmit the smart interface to all 1,000 lb. capable stations with a wireless interface. The fourth category is to do nothing and continue with the status quo. Specific alternatives under each category are explained by aircraft in the following subsections.

Additional Wiring. Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. The 1,000 lb. weapon stations without a smart interface and mechanically compatible with inertially guided smart bombs are candidates for additional wiring. For the F-15E, ten CFT stations without a smart interface are candidates for additional wiring. Additional wiring to these ten CFT stations would triple the F-15E's capability to carry 1,000 lb. smart bombs. The modifications required to add MIL-STD-1760 wiring to the F-15E CFTs is detailed in McDonnell Douglas Report Number 92B0481 (McDonnel Douglas, 1992: 1). The undeveloped outboard wing stations on the F-15E are also candidates for additional wiring. Additional wiring is not appropriate for the F-16 or F/A-18, because the stations on those aircraft that can carry the weight of 1,000 lb. smart bombs already have a smart interface. The additional wiring alternatives are summarized in Table 2.4.

Table 2.4: Additional Wiring Alternatives

Aircraft	Number and Location of Stations	Compatible Weapon Type
F-15E	10 CFT 2 CFT 2 Wing Outboard*	JDAM, WCMD JSOW All Three
F-16	Not Applicable	Not Applicable
F/A-18	Not Applicable	Not Applicable

* Denotes notional capability

Smart Bomb Rack. A bomb rack that can carry more than one store is called a multiple ejection rack (MER). There are two MERs that have been developed for taking a single smart interface from an aircraft and multiplexing, or splitting, it to more than one smart bomb. A disadvantage of the MER concept is that they will be carried at the same stations capable of carrying external fuel tanks. The MERs have been developed by modifying existing bomb rack designs for the BRU-33A/A and the TER-9A. It is not feasible to procure smart bomb racks for every aircraft, because not all of the missions performed by the aircraft are compatible with smart bomb rack carriage. Therefore, it is assumed that only 1,100 smart bomb racks, enough for one half of all the potential aircraft, will be procured. All F-15E, F-16, and F/A-18 aircraft would be modified to carry a smart bomb rack; however, smart bomb racks will not procured for every aircraft.

A BRU-33A/A modified to multiplex a smart interface has the designation BRU-55; a BRU-55 is capable of carrying two 1,000 lb. smart bombs (Wright, 1994: 2). Unmodified versions of the BRU-33A/A are already certified on the F/A-18 (Wright, 1994: 2; M. Technologies, 1993a). A BRU-55 could be carried on the wing stations of the F-15E, center wing stations on the F-16, and all stations on the F/A-18. The BRU-55 is compatible with carrying two 1,000 lb. JDAM, JSOW, or WCMD (M. Technologies, 1993a).

A modified TER-9A is capable of carrying three 1,000 lb. smart bombs (Wright, 1994: 2). Unmodified versions of the TER-9A are already certified on the F-16 (Wright, 1994: 2). A smart TER-9A could be carried on the wing stations of the F-15E, center wing stations of the F-16, and the wing stations of the F/A-18. The TER-9A is compatible with carrying three JDAM and WCMD; however, it can carry only one JSOW due to physical fit problems (Roberts, 1992: 1). Additionally, because of the weight limits the F-16 and F/A-18 weapon stations are under 3,000 lbs. (see Tables 2.2 and 2.3) only two JDAM or WCMD could be carried on the TER-9A with the F-16 and F/A-18. These limitations for the TER-9A drive the determination of this alternative to be not feasible. Alternatives for both smart bomb racks are summarized in Table 2.5.

Table 2.5: Smart Bomb Rack Alternatives

Aircraft/Bomb Rack	Number and Location of Stations	Compatible Weapon Type
F-15E		
BRU-55	2 wing (4)*	All Three
TER-9A	2 wing (6)*	JDAM & WCMD
F-16		
BRU-55	2 center wing (4)*	All Three
TER-9A	2 center wing (4)*	JDAM & WCMD
F/A-18		
BRU-55	All 5 (10)*	All Three
TER-9A	4 wing (8)*	JDAM & WCMD

* number in parenthesis is total weapons carried on smart racks

Wireless Interface. The two wireless interface options would use either radio or ultraviolet transmitters to send smart interface signals without wiring. The wireless interface is only an alternative for the F-15E, because the F-16 and F/A-18 already have a smart interface at every weapon station. The advantage of a wireless databus is that smart weapons can continue to be updated with information after separation from an aircraft (Gill, 1994: 5). However, the technology to accomplish transmittal of smart interface signals is still under development and faces several technical challenges (Mills, 1994). The technology may require modification to both the weapons and the aircraft (Mills, 1994). Because of the assumption that alternatives requiring weapon modifications are not considered, this group of alternatives is determined to be not feasible for this study.

Status Quo. The status quo would not change the present capability of the F-15E, F-16, and F/A-18 to employ smart bombs. The present capabilities of DOD fighter aircraft to carry smart bombs are summarized in Tables 2.1, 2.2, and 2.3. Other alternatives are evaluated as a change from the status quo baseline.

Summary. Alternatives for addressing the problem of smart bomb capability on DOD fighter aircraft fall into four categories: additional wiring, smart bomb rack, wireless interface, or continuation of the status quo. Only F-15E additional wiring, the BRU-55 smart bomb rack, and the status quo for each aircraft are determined to be feasible alternatives. Table 2.6 summarizes the information found for each alternative.

Table 2.6 Summary of Alternatives

Category	Aircraft	Alternative	Determination	Reason
Additional Wiring	F-15E	1. CFT	Feasible	Achievable
		2. Outboard Wing	Feasible	Achievable
	F-16	None	Not Feasible	Not required
	F/A-18	None	Not Feasible	Not required
Smart Bomb Rack	F-15E	1. BRU-55	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
	F-16	1. BRU-55	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
	F/A-18	1. BRU-55	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
Wireless Interface	F-15E	CFT	Not Feasible	Requires more development
	F-16	None	Not Feasible	Not required
	F/A-18	None	Not Feasible	Not required
Status Quo	F-15E	No change	Feasible	Present capability
	F-16	No change	Feasible	Present capability
	F/A-18	No change	Feasible	Present capability

What DOD guidance exists for evaluating alternative solutions?

The DOD uses economic analysis to make rational choices among competing alternatives (AFI 65-501, 1994: 1). Economic analysis is required if a total investment of $1 Million, or annual recurring costs of $200,000 will be committed on a program. However, economic analysis is not required if the Office of the Secretary of Defense (OSD) or higher directs a new program, or the cost to perform the analysis is determined to outweigh the benefits of the analysis (AFI 65-501, 1994: 1). There are twelve special analysis cases for economic analysis that have special requirements (AFI 65-601, 1994: 1). They are summarized in Table 2.7 by topic.

Table 2.7: Special Analysis Cases Under Economic Analysis

1) Communications and computer equipment	7) Productivity investment programs
2) Military construction projects	8) Overseas activity analysis
3) Energy projects	9) Private sector development
4) Lease-purchase decisions	10) Acquisition of weapon systems
5) Commercial cost comparisons	11) Mechanized materials handling systems
6) Weapon system warranty cost benefit analysis	12) Program Evaluations

The alternative solutions for providing additional smart bomb capability for DOD fighters are examples of special analysis case ten, acquisition of weapon systems. The special requirement for the economic analysis of weapon system acquisition is a report called a Cost and Operational Effectiveness Analysis, or COEA (DODI 5000.2, 1991: 8-1). No easy checklist exists for assessing COEA for acquisition programs (DODM 5000.2, 1993: 8-2). The documents describing COEA policy and content are summarized in the following subsections.

COEA Policy. Conducting a COEA is fundamental to the acquisition process (DODI 5000.2, 1991: 4-1). Acquisition programs are driven by a requirements generation system. The focus of requirements is to identify deficiencies in current capabilities and opportunities to provide new capabilities (DODI 5000.2, 1991: 4B-3). The role of a COEA is to facilitate the selection of a system concept from reasonable alternatives. A COEA serves three purposes (DODI 5000.2, 1991: 4-E-1). First, a COEA aids decision makers in judging whether any proposed alternatives provide sufficient military benefit over the status quo to justify the cost. Second, a COEA facilitates communication through early identification and discussion of reasonable alternatives. Third, a COEA is a historical record of the alternatives considered and the justification for a decision. The content of a COEA is broken into four sections as explained in DOD Manual 5000.2 section 8.

COEA Contents. A COEA has four sections, and each section has additional parts, when they are applicable. The sections are:

1) Issue identification
2) Alternative identification
3) Alternative analysis
4) Summary of results (DODM 5000.2, 1993: 8-1-1).

Each section of a COEA report is summarized in the following subsections.

COEA Issue Identification. Issue identification may be developed with five underlying areas. First, need identification documents either deficiencies in capability or opportunities to enhance capability with a mission need statement (DODM 5000.2, 1993: 8-2). Second, descriptions of the threat and operational environment establish the conditions a system is expected to perform under (DODM 5000.2, 1993: 8-2). Third, constraints and assumptions limit the set of feasible alternatives (DODM 5000.2, 1993: 8-4). Fourth, the operational concept explains how the system is to be used to accomplish the defined objective (DODM 5000.2, 1993: 8-4). Fifth, functional objectives use quantitative terms to describe the tasks a system needs to perform.

COEA Alternative Identification. Alternative identification is one of the most important steps of a COEA (DODM 5000.2, 1993: 8-5). Six suggestions are provided for identifying alternatives (DODM 5000.2, 1993: 8-5). First, define the status quo for a base of reference. Second, identify a range of alternatives not just variations of the same alternative. Third, define each alternative fully. Fourth, present all reasonable alternatives. Fifth, study the alternatives for additional benefits. Sixth, assure that the capabilities of undeveloped systems are not oversold.

COEA Alternative Analysis. Alternative analysis development represents the basis of the COEA and occurs in the following six areas:

1) Model description

2) Data documentation

3) Measures of Effectiveness, or decision criteria

4) Cost

5) Alternative Analysis

6) Recommendation (DODM 5000.2, 1993: 8-5).

The beginning of the COEA describes any model used to represent decisions or systems. Guidance directs that models should eliminate bias and be kept simple (DODM 5000.2, 1993: 8-6). However, there is no guidance on what types of models should be used.

In the data documentation section the data used in the COEA needs to be documented well, so it can be independently reviewed (AFI 65-601, 1994: 2). The ability to independently review the data in a study adds to the credibility of the study.

The measures of effectiveness, decision criteria, section identifies what qualities are used to evaluate the alternatives. Guidance directs that decision criteria need to relate directly to system performance, and that multiple criteria are preferred over a single criterion (DODM 5000.2, 1993: 8-7, 12). However, no decision criteria are mandated.

The cost section of a COEA is one of the more complex sections. Cost should address the following seven factors:

1) Cost estimation technique

2) Program quantity assumptions used to calculate the estimate

3) Weaknesses in the cost estimate

4) Cost uncertainty upper and lower bounds

5) Sensitivity analysis

6) Comparison of alternatives to the status quo

7) Standardization of cost (DODM 5000.2, 1993: 8-8).

The cost estimation technique used to obtain the estimate is required to be explained (DODM 5000.2, 1993: 8-8). Explanation of the cost estimation technique provides information on the basis of the estimate. Examples of estimation techniques include: parametric, analogy, bottom up, or a combination of techniques (DODM 5000.2, 1993: 8-8).

The quantity of items used in obtaining the cost needs to be identified (DODM 5000.2, 1993: 8-8). Knowing the quantities assumed in a cost estimate allows for identification of a key assumption, the expected production size.

The weaknesses in the cost estimate need to be identified (DODM 5000.2, 1993: 8-8). Identifying the weaknesses of the cost estimate identifies the conditions where the estimate can still be applied.

The upper and lower limits of the cost's uncertainty need to be bounded. Bounding the uncertainty establishes the relevant range of the estimate and identifies the conditions where the estimate is no longer valid.

Sensitivity analysis needs to identify what changes in the cost will affect the solution (DODM 5000.2, 1993: 8-8). Sensitivity analysis assesses the reasonableness of a decision based on estimates by calculating how far reality can differ from an estimate without invalidating the decision (Skousen and others, 1993: 1132). Sensitivity analysis is an important step toward understanding the susceptibility of the recommendation to change, if the cost of the alternatives change.

The cost of each alternative needs to be comparable to the cost of the status quo (DODM 5000.2, 1993: 8-8). Knowing the difference in cost from the status quo allows the cost to alleviate a problem to be easily identified.

Standardization of the cost is required, so alternatives can be compared in kind. Proper standardization of the cost requires both the use of a common measure and an adjustment for the effects of inflation. The cost of each alternative must be stated in terms of a common measure. The Office of Management and Budget (OMB) requires all executive branch budget programs to use Net Present Value (NPV) or cost effectiveness (OMB Circular A-94, 1992: 2). The NPV method compares alternatives based on the difference between discounted cash inflows and outflows, where the alternative with the largest positive NPV is the preferred choice (Skousen and others, 1993: 1123). Cost effectiveness is an analysis of competing alternatives to determine the one with the lowest cost, and can be used instead of NPV when a specific dollar value can not be assigned to benefits (OMB Circular A-94, 1992: 4). Regardless of what measure of cost is used, the effects of inflation on the value of the estimate need to be removed. In other words, the cost of each alternative needs to be shown in current and constant dollars (DODM 5000.2, 1993: 8-1-1).

Alternative analysis in the COEA consists of a three part trade-off analysis (DODM 5000.2, 1993: 8-10). Part one, identifies areas of uncertainty that have the greatest effect on the decision outcome. Part two, explains the effect of changes in the system on military utility. Part three, sets maximum and minimum thresholds for system performance. The COEA's recommendation identifies the preferred alternative and groups it with the other alternatives by relative cost and effectiveness (DODM 500.2, 1993: 8-11). This allows for quick identification of the recommended alternative and comparison to the other alternatives for validation of the recommendation.

COEA Summary of Results. The summary of results clearly explains the criteria used to recommend a decision. This is achieved by identifying the costs and decision criteria values of each alternative, allowing the selection of an alternative to relate directly to established criteria.

Summary. The method of evaluating competing alternatives in the DOD for acquiring weapons systems is called a COEA. A COEA aids decision making, facilitates communication, and provides a historical record. A COEA contains four sections: issue identification, alternative identification, alternative analysis, and summary of results.

What decision criteria are used to evaluate the identified alternatives?

Literature review and analytic study are two methods of identifying decision criteria for selecting an recommended alternative (Keeney, 1976: 35). A literature review finds criteria used in similar problems and criteria suggested by theory. Analytical study considers building on identified objectives to determine relevant criteria. Both methods are used to identify decision criteria for recommending an alternative for increasing DOD fighter aircraft smart bomb capability.

Literature Review. Three areas are summarized through literature review: decision theory, a similar problem, and DOD guidance. The information under each area is described in the following subsections.

Decision Theory. A review of decision theory provides three insights. First, there are no universal decision criteria that can be applied to all problems (Keeney, 1976: 32; Conrow and others, 1982: 60). Second, the key element of decision making is the elimination of potential projects, because of limited capital or other limitations (Hastie, 1974: 2). Third, the limitations to a problem can be both quantitative and qualitative (Battin and Bender, 1992; Saaty, 1980). Quantitative criteria can be represented by numbers easily. The most obvious quantitative criteria are financial. A common financial criterion is cost; cost criteria need to be tied to established cost objectives (Coyle and others, 1992: 500). However, the nature of decision problems requires incorporation of both financial and non-financial criteria (Tubacanon, 1988: 1; Battin and Bender, 1992: 37). For example, productivity, or a measurement of output, is a non-financial criterion (Coyle and others, 1992: 500). Qualitative criteria, on the other hand, are not easily represented by numbers. However, they also need to be considered, because they can affect decision outcomes (AFSC Pub 1, 1991: 3-12). Examples of qualitative criteria may include: effectiveness, the performance of a system in meeting requirements, or risk, a judgment about the probability an alternative can be implemented successfully (Coyle and others, 1992: 457; Stanley, 1980: 1).

Similar Problem. Accumulating experience from other projects is an important step in improving acquisition (Conrow and others, 1982: v). Another weapon that requires a smart interface and that is carried on the F-15, F-16, and F/A-18 is the Advanced Medium Range Air-to-Air Missile, or AMRAAM (Malik, 1982: 2). Review of the cost information on AMRAAM integration shows examples of decision criteria used under similar circumstances. Documentation on the cost of the AMRAAM for the F-15 and F-16 shows the average unit hardware cost based on the number of aircraft and weapon stations is used as a criterion (Yoder, 1982: 2). From the historical comparison the average cost of implementing an alternative for a single weapon station is revealed as a potential decision criterion.

Applicable Guidance. Potential COEA decision criteria are found in Air Force Policy Directive 10-6 and Air Force Instruction 10-601.

Air Force Policy Directive 10-6 identifies three measures of effectiveness for defining requirements (AFPD 10-6, 1993). The first requirement consists of system performance criteria. Examples of system performance parameters include: range, accuracy, payload, and environmental conditions, such as weather (AFPD 10-6, 1993: 3-1-1). The second requirement consists of logistics and readiness criteria. An example of a readiness criterion is the frequency and duration of preventive maintenance (AFPD 10-6, 1993: 3-1-1). The third requirement consists of critical system characteristics. An example of a critical system characteristic is electromagnetic compatibility (EMC) of system electronics. A household description of EMC is a television not being affected by the use of a hairdryer or a blender. Setting specific measures of effectiveness is beyond the scope of this research due to the requirements definition limitation; however, these factors are considered under the risk of each alternative.

Air Force Instruction 10-601 directs consideration of commonality, standardization, and interoperability to avoid duplication. Specifically, the instruction states:

> The Air Force will where practical and cost effective consolidate similar deficiencies of MAJCOMS (major commands) and other Services, because integrated programs that share one common solution contribute to lower unit cost, prevent duplication of effort during program development, and result in improved commonality, standardization, and interoperability of weapons systems. (AFI 10-601, 1994: 7)

Commonality reduces development, procurement, and logistics costs, while improving combat capability (Conrow and others, 1982: 12). Therefore, commonality of an alternative between services and weapon systems is a potential decision criterion.

Analytical Study. An analytical study of the problem using relevant objectives helps make criteria obvious (Keeney, 1976: 35). The research of decision criteria with the objective of addressing DOD fighter aircraft ability to carry inertially guided smart bombs suggests four criteria. First, the average cost for each weapon station added for the alternative recommended needs to be minimized. Second, the alternative recommended needs to be common for each aircraft and weapon. Third, the total additional weapon carriage capability added by the recommended alternative needs to be maximized. Fourth, the risk associated with the ability of an alternative to serve as a long term fix needs to be minimized. Effectiveness criteria also need to be considered; however, the operational requirements for adding smart interfaces are not defined. This is a previously noted limitation of the research.

Summary. The potential decision criteria and their feasibility are summarized in Table 2.8.

Table 2.8: Potential Decision Criteria

Criteria	Determination	Reason
Average Unit Cost	Feasible	Can measure cost/Weapon Station added
Effectiveness	Not Feasible	Requirement not defined
Risk	Feasible	Can measure experts' judgment
Performance	Not Feasible	Requirement not defined
Readiness	Not Feasible	Requirement not defined
Critical Characteristics	Not Feasible	Requirement not defined
Commonality	Feasible	Can measure expert's judgment
Additional Weapon Carriage Capability	Feasible	Can measure increased weapon carriage capability

The final decision criteria and their definitions will be determined by interviews with experts as explained in Chapter III. Now that potential criteria have been identified, a method of structuring the problem objective, decision criteria, and alternatives needs to be identified; one method is to use hierarchies (Keeney, 1976: 41; Wind and Saaty, 1980: 642).

Considering the decision criteria, what alternative is recommended?

Alternative selection in this research uses a decision support tool useful for project selection. The Analytic Hierarchy Process (AHP) is a modeling and measurement method for solving multiple criteria decision making problems (Wind and Saaty, 1980: 641; Saaty, 1980: 2; Battin and Bender, 1992: 17). Project selection problems are multiple criteria decision making problems, because competing criteria and alternatives are evaluated. Applying AHP to a problem follows a series of structured steps and has some distinct advantages. The steps in performing AHP with software, the use of the Delphi technique in obtaining a group response from experts, the advantages of AHP, and the use of AHP as a COEA model are discussed in the following subsections.

Steps in AHP. For the purpose of this research, Expert Choice, a Decision Support Software (DSS) package that uses the AHP, is used to recommend an alternative. The steps of AHP are not complex, but the computations behind selecting an alternative are complex, and Expert Choice performs this task. The computations behind AHP have been identified by Saaty and others (Saaty, 1980; Saaty, 1986; Battin and Bender: 1992).

Expert Choice applies AHP in five steps with several tasks required to complete each step; the steps are:

1) Define the problem and the overall objective.

2) Structure the problem in a hierarchy.

3) Gather relational data for the decision criteria.

4) Enter the hierarchy and relational data into a software model.

5) Solve the model and perform sensitivity analysis (DSS, 1993).

Step 1 requires stating the objective and defining the problem the objective intends to solve. Step 1 was accomplished in Chapter I, when the problem was developed and the objective of increasing smart bomb capability was established.

In step 2, the problem is structured in a hierarchy with the overall objective placed at the top, decision criteria and other relevant information placed in subsequent levels, and the alternatives for solving the problem listed at the lowest level (Wind and Saaty, 1980: 646).

Relational data in step 3 can take two forms: quantitative relationships inherent in the data, or expert's weightings of qualitative relationships (Battin and Bender, 1992: 18). AHP uses a nine point scale in performing pairwise comparison of qualitative data (Wind and Saaty, 1980: 644). Experts evaluate hierarchy elements in a pairwise fashion from the bottom up (Wind and Saaty, 1980: 642). Expert evaluations can be accomplished using the Delphi technique (Saaty, 1980: 68).

The Delphi technique allows the judgment of experts to be applied in decision making by obtaining a group response from a panel of experts (Brown, 1968: 2-3). Direct confrontation and debate is replaced with a series of carefully planned individual data collections using either questionnaires or interviews where experts provide reasons for their responses (Brown, 1968: 3). Data collection is interspersed with feedback derived from previous group responses, so responses can be critiqued by fellow experts (Brown, 1968: 3). The Delphi technique emphasizes informed judgment and limits the influence of any expert by providing anonymity of responses (Brown, 1968: 3). Another advantage of the Delphi technique is that it may be refined to meet the objective of a given problem associated with obtaining expert opinion (Brown, 1968: 6).

The first step in applying the Delphi technique is selecting a group of experts (Brown, 1968: 4). After selection of the experts the first of four data collections is performed. The first data collection asks all respondents to record their estimates for established questions (Brown, 1968: 4). Information from these responses furnishes central tendency measures used to provide feedback for the second data collection.

The second data collection asks the experts to revise their previous estimate and provide the reasons and factors considered in obtaining their answer (Brown, 1968: 5). Information from the second set of responses furnishes central tendency measures, reasons for high and low responses, and feedback for the third data collection (Brown, 1968: 5).

The third data collection asks the experts to critique the reasons for previous responses and specify which arguments were unconvincing and why (Brown, 1968: 6). Information from the third set of responses furnishes reasons for and against high and low responses, and provides feedback for the final data collection.

The fourth data collection provides feedback from the results of the third data collection and asks experts to provide final estimates for answers to the questions (Brown, 1968: 6). The median of the final responses is then used to represent the group's response (Brown, 1968: 6).

In step 4, the hierarchy developed in step 2 is entered into Expert Choice as a decision model. Steps 2 through 4 are accomplished in Chapter III and IV. In step 5, Expert Choice solves the model and sensitivity analysis is performed. Sensitivity analysis determines the impact changing data in the model has on the solution (Knowles, 1989: 18). Step 5 is accomplished in Chapter IV.

Advantages of AHP. The AHP has distinct advantages. The main advantage of AHP is its flexibility gained from two characteristics. First, a hierarchy as a structure can be tailored to fit individual needs and decision problems (Wind and Saaty, 1980: 642). Second, AHP allows experts to establish the weights for the decision criteria, so both quantitative and qualitative criteria can be included (Wind and Saaty, 1980: 643; Battin and Bender, 1992: 19). The second advantage of AHP is that it follows a structured process and documents the data used, so that it can be independently reviewed.

Application of AHP within a COEA. AHP represents a type of model that can be applied to support decision making. As identified earlier, guidance on COEAs does not direct what type of model be used; it only directs that the model used needs to be explained. Use of AHP as a model for selecting among weapon system alternatives within a COEA meets the requirements for a COEA. First, the identified steps and use of a hierarchy in AHP allows the model to be explained. Second, AHP can accept multiple decision criteria and allows alternatives to be evaluated using both quantitative and qualitative criteria. Third, AHP software performs sensitivity analysis of the model. Fourth, AHP is flexible enough to apply to the demands of different project selections. The application of AHP within a COEA is further shown by comparison of where the content of a COEA and AHP steps coincide (Table 2.9).

Table 2.9: COEA Content and Related AHP Steps

COEA Content	Related AHP Steps
1) Issue Identification	1) State objective and define problem
2) Alternative Identification	2) Structure problem in a hierarchy
3) Alternative Analysis	3) Gather data for the decision criteria 4) Enter hierarchy and data
4) Summary of Results	5) Solve model and perform sensitivity analysis

<u>Summary.</u> AHP is a modeling and measurement method for solving multiple criteria decision making problems that meets the needs of a COEA. Use of the Delphi technique with AHP allows a group response to be obtained from a panel of experts. AHP is used to select the recommended alternative.

Literature Review Analysis/Conclusions

The findings of the literature review fall into seven areas. First, the importance of smart bombs in warfare is from two trends: the importance of knowledge and the impact of technology advancements. Second, the next generation of inertially guided smart bombs have specific interface requirements. Third, the F-15E, F-16, and F/A-18 are important aircraft platforms for inertially guided smart bombs, and they possess the potential to carry more inertially guided smart bombs. However, carrying additional inertially guided smart bombs requires additional smart interfaces. Fourth, only three feasible alternatives for addressing the smart bomb capability issue on the F-15E, F-16, and F/A-18 exist. Fifth, the DOD guidance on project selection by conducting a COEA is described. Sixth, literature review and analytical study identify four potential decision criteria. Seventh, the AHP model of structuring decision problems in a hierarchy meets the needs of a COEA, allows collection of a group response from experts, and is used to recommend an alternative.

III. Methodology

Overview

Previous chapters have identified the research issue and required background information. This chapter describes the research methodology. A formal study with four phases answered the research questions and collected data. Model formulation and validation within the research design depended upon a series of described interviews.

Research Design

A formalized study was used to answer the research questions. The methodology was conducted in four phases as depicted in Figure 3.1. The first phase involved forming a foundation for the research. The foundation was laid by gathering background information by literature review, interviews, and analytical study. The second phase involved model formulation. The AHP was selected to model the decision criteria and alternatives, because its structuring of decision problems in a hierarchy meets the needs of a COEA, and it allows collection of a group response from experts. The third phase involved validating the model. Model validation was provided by the input of DOD experts. The fourth phase involved solving the model and performing sensitivity analysis. A more detailed description of each phase follows.

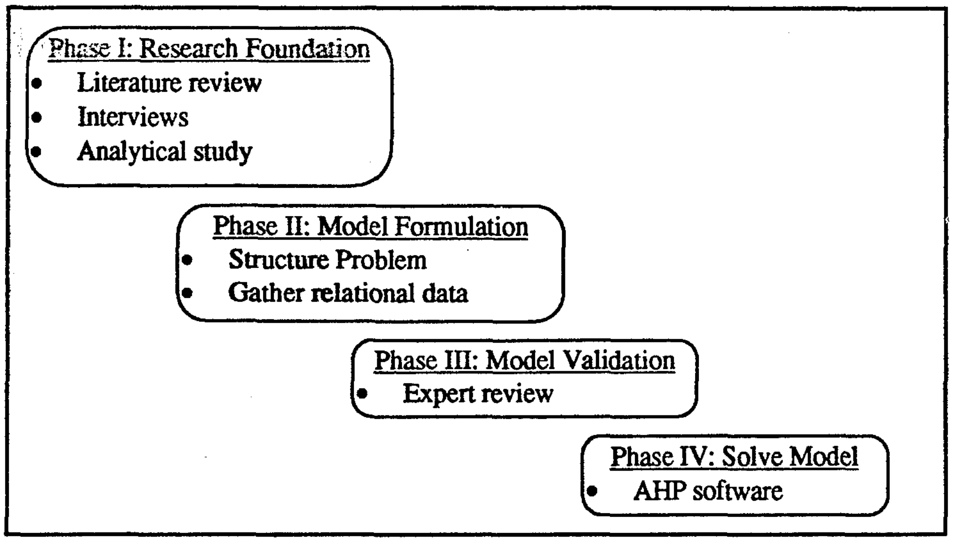


Figure 3.1: Research Design Phases

Phase I. The method of collecting background information for establishing a foundation for the research varied for each research question. Research questions one, two, and five were answered by a review of relevant literature. Research questions three and four were answered by literature review and interviews with experts for technical background information. Research question six was answered in two parts. The first part was conducted with a literature review and an analytical study to identify potential decision criteria (see Table 2.8). Later, a pilot interview was used to establish the final decision criteria and their definitions, to validate technical information, and to limit the alternatives to the most feasible in each category. Research question seven was answered by conducting a literature review to identify the model used in the analysis, and by conducting a series of interviews with experts to gather relational data needed to solve the model.

Phase II. The method of model formulation follows steps two and three of the AHP. The steps include structuring the problem in a hierarchy and gathering relational data for the decision criteria. After the decision criteria were finalized and defined by a pilot interview, a research problem hierarchy was built and a series of interviews were conducted to gather data on the relationships between the quantitative and qualitative decision criteria. The hierarchy built to model the research problem is shown in Figure 3.2.

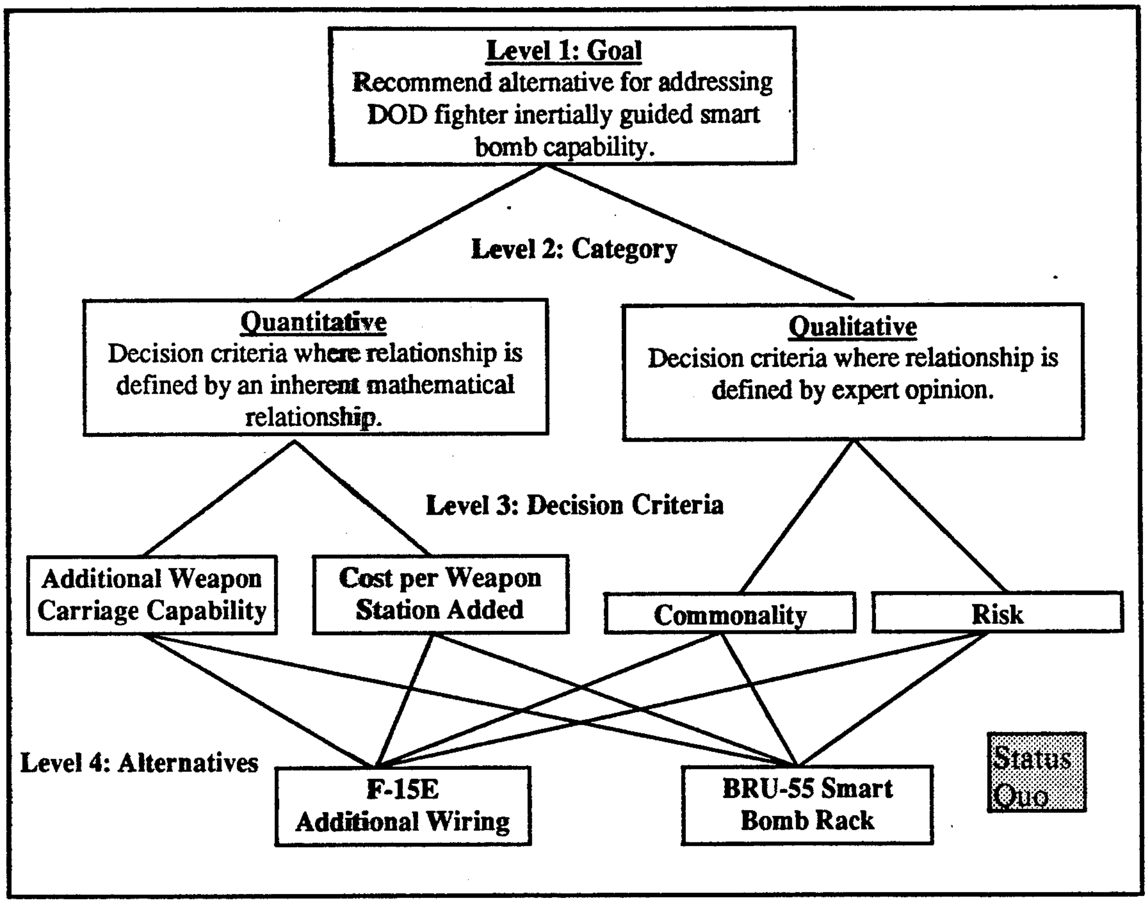


Figure 3.2: Research Problem Hierarchy

The status quo is separate from the rest of the hierarchy to avoid violating the AHP axiom of expectations. The axiom of expectations implies that when one alternative is equivalent to another it should be removed, because it does not add to the choice set (Hacker and Vargas, 1987: 1386). For the qualitative criteria, the F-15E additional wiring alternative is equivalent to the status quo. Therefore, each alternative is compared against the status quo, which provides a common reference for each alternative and criterion. This does not have an impact on the AHP model developed, because the data are ratio scale in AHP (Hacker and Vargas, 1987: 1383; Saaty, 1986: 844). Ratio scale numbers follow the transitive property that if A is equal to B and B is equal to C, then A is equal to C (Bush and Obreanu, 1965: 8; Saaty, 1980: 73). Additionally, ratio comparisons follow the Archimedean property that any two positive numbers are comparable, because their ratio is finite (Hacker and Vargas, 1987: 1305). The transitive and Archimedean properties allow the F-15E and BRU-55 alternatives to be compared directly, because the binary relationships established in the hierarchy are not violated.

The relationship between decision criteria depended on their category. Quantitative weightings were determined by mathematical relationship. Qualitative weightings were determined from the mean response of experts on the nine point scale used in AHP (Wind and Saaty, 1980). The mean response to each criterion came from four iterative interviews with experts based on the Delphi technique (Saaty, 1980: 68; Brown, 1968: 4). The actual data and transformations are described in Chapter IV.

Phase III. The model was validated by the iterative nature of the Delphi technique to find descriptive statistics for a group of experts' responses. The central tendency of responses was validated in the fourth iteration of the interviews that asked the experts to perform a final weighting of the decision criteria and alternatives used in the model, after results from previous interview iterations were provided.

Phase IV. The model was solved by applying steps four and five of the AHP. The steps involve entering the hierarchy and relational data into a software model, solving the model, and performing sensitivity analysis. The AHP software used in this research was Expert Choice, and it was only used to solve the model and perform sensitivity analysis.

The Interviews

Questions six and seven were answered through a series of interviews based on the Delphi technique. Potential participants were identified from prior working relationships of the researcher as a program manager for F-15E weapon integration. Participants were selected based on their willingness to participate and familiarity with fighter aircraft, inertially guided smart bombs, and proposed alternatives. Interviews were conducted with a total of three participants with one from the F-15 System Program Office (SPO), the F-16 SPO, and the Pentagon. The number of interviewees was considered adequate because of the small population of experts familiar with the research issues and potential solutions. Interviews were used so that experts could establish the criteria weights by making pairwise comparisons.

A series of five interviews was conducted with the content refined from the Delphi technique explained in Chapter II. A pilot interview confirmed the decision criteria, alternatives used in the model, and aircraft technical information. Table 3.1 lists the purpose of each interview.

Table 3.1: Purpose of Interviews

Pilot Interview	Finalize decision criteria, and their definitions Finalize alternatives considered Verify aircraft technical information
First Interview	Establish relative priority of decision criteria Gather cost information on BRU-55
Second Interview	Perform pairwise comparison of decision criteria and alternatives Gather aircraft cost information on alternatives
Third Interview	Critique rationale given for previous pairwise comparisons
Fourth Interview	Gather final pairwise comparisons

The pilot interview included only the aircraft experts who are the most familiar with issues associated with integrating systems onto aircraft platforms. The first interview assigned preliminary criteria priority, and was conducted with all three experts. The second interview (1) requested aircraft experts to determine alternative cost information; (2) requested all experts to provide pairwise comparison of the decision criteria and alternatives as compared to the status quo; and (3) requested all experts to explain the rationale for their weighting of the criteria. The third interview provided all three experts feedback on previous comparisons, and asked the experts to critique the rationale for the high and low weightings of pairwise comparisons. The final interview provided all three experts an opportunity to review the arguments for and against the pairwise comparison weightings, and asked the experts to perform a final pairwise comparison. A description of the content of each interview follows:

Pilot Interview. The pilot interview was conducted to establish the final decision criteria and their definitions, to limit the alternatives considered to the most feasible in each category, and to confirm aircraft technical information documented in the literature review. The pilot interview is a refinement from the Delphi technique; however, it was required to establish a common reference point for the remaining data collection interviews. The content of the pilot interview is shown in Appendix A.

First Interview. The first interview was designed to describe the research problem objective and method, and to establish the relative priority of the decision criteria. The actual content of the first interview is shown in Appendix B. In the first interview experts were asked to provide initial rankings of decision criteria based on relative importance; no pairwise comparisons were made. In addition, the bomb rack expert was asked to provide BRU-55 hardware costs; so future aircraft cost estimates could be based on standardized information.

Second Interview. The second interview was designed to describe current research progress and to gather information needed to complete the research effort. The second interview is contained in Appendix C. Experts were asked to provide pairwise comparison of decision criteria and alternatives in relation to the status quo. In addition, experts provided an explanation of the reason for their criteria weightings. Aircraft experts were also asked to provide cost information for alternatives under consideration for their aircraft. F/A-18 cost information is based on the low and high cost values for the F-16 and F-15E respectively.

Third Interview. The third interview was designed to describe the progress of the research and refine information previously gathered. The third interview is contained in Appendix D. After results were provided from previous criteria weightings, experts were asked to critique the rationale for high and low pairwise comparison weightings of the decision criteria and alternatives.

Fourth Interview. In the fourth interview, experts were asked to review the results from previous interviews and perform a final pairwise comparison of the decision criteria and alternatives. The fourth interview is contained in Appendix E. The results of the final pairwise comparison were used as the group's response. The results were then transformed into ratios and entered into Expert Choice, a decision support tool for recommending an alternative. Chapter IV contains results of the research.

Summary

The methodology of this thesis followed the steps of a formal study. The process began by identifying the research issue. After the research issue and required background information were developed, alternative solutions were identified and assessed for feasibility. Next, relational data gathered on the decision criteria and alternative solutions was transformed into ratio comparisons at each level of the hierarchy. Finally, the ratios were entered into a software model that recommended an alternative for increasing fighter aircraft capability for smart bombs based on qualitative and quantitative decision criteria. Chapter IV describes the research results.

IV. Results

Overview

In this chapter, the research results are provided in quantitative, qualitative, and analysis sections. Quantitative data was collected by literature review and interviews. Qualitative data was collected only by interviews using the Delphi technique. Analysis was performed using the AHP decision support software Expert Choice. This chapter concludes with a discussion of the recommended alternative for addressing DOD multi-role fighter aircraft smart bomb capability.

Quantitative

The pairwise comparison of the alternatives was determined by mathematical relationships. Data was collected through review of relevant literature or with interviews.

The cost per weapon station of the F-15E additional wiring alternative was determined by dividing the $43 million total estimated cost (from appendix G) by the 2,050 increase in the number of available smart weapon stations (205 F-15E aircraft times the ten additional smart stations as shown in Table 2.4) for a value of approximately $21,000 per weapon station. The cost per weapon station for the BRU-55 alternative was determined by finding the cost per weapon station for each aircraft and then taking a weighted average. All aircraft cost estimates are shown in Appendix G, and they represent the delta development cost of the alternative from the status quo. The computations for each aircraft are shown in Table 4.1. The equation for finding the BRU-55 cost per weapon station (CWS) is shown below:

$$\underline{CWS} = \underline{TCAT/[(0.5)(N)(w)]} \quad (1)$$

where:

CWS = Cost per weapon station (dollars)

TCAT = Total cost by aircraft type (dollars)

N = Number of aircraft for each type (number of aircraft)

w = Additional weapon carriage capability (number of weapons by aircraft)

Table 4.1: BRU-55 Cost Per Weapon Station by Aircraft

Aircraft	CWS computation	Result
F-16 Block 40	45.5M/[(.5)(425)(2)]	$107,059
F-16 Block 50	34.0M/[(.5)(230)(2)]	$147,826
F-15E	41.0M/[(.5)(205)(2)]	$200,000
F/A-18C/D	22.6M/[(.5)(168)(5)]	$ 53,809
F/A-18E/F	18.2M/[(.5)(72)(5)]	$101,111

The computations behind the weighted average BRU-55 cost per weapon station are shown in Table 4.2.

Table 4.2: Average BRU-55 Cost Per Weapon Station

Aircraft	Half operational aircraft inventory	Results Table 4.1	Weighted cost
F-16 Block 40	212.5	$107,059	22,750,037
F-16 Block 50	115	$147,826	16,999,990
F-15E	102.5	$200,000	20,500,000
F/A-18C/D	84	$ 53,809	4,519,956
F/A-18E/F	36	$101,111	3,639,996
Totals	550		68,409,979
	Weighted Average	68,409,979/550	$124,382

For the purposes of the research, the BRU-55 cost per weapon station used will be the weighted average in Table 4.2 rounded to the nearest thousand, or $124,000.

The additional weapon carriage capability is found by following a four step process:

1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon from information in Tables 2.4 and 2.5.

2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.

3) Multiplying step 2 by the total number of that aircraft type.

4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Using this process the F-15E additional wiring alternative results in a total additional weapon carriage capability of 4,510 smart weapons. The computations for the additional wiring additional weapon carriage capability are shown in Table 4.3.

Table 4.3: Additional Wiring Additional Weapon Carriage Computations

Aircraft	Additional JDAM	Additional JSOW	Additional WCMD	Total Additional	Number aircraft	Total added Capability
F-15E	10	2	10	22	205	4510

The additional weapon carriage capability of the BRU-55 alternative is 4,374 and the supporting computations are shown in Table 4.4.

Table 4.4: BRU-55 Additional Weapon Carriage Computations

Aircraft	Additional JDAM	Additional JSOW	Additional WCMD	Total Additional	Half Number aircraft	Added Capability
F-15E	2	2	2	6	102	612
F-16 (both)	2	2	2	6	327	1962
F/A-18 (both)	5	5	5	15	120	1800
Totals	9	9	9	27	549	4374

Quantitative pairwise comparisons between the alternatives are found by computing the ratios of the individual criteria to the criteria totals. The cost of the BRU-55 alternative comprises 85.5 percent of the combined cost of the alternatives. The F-15E additional wiring alternative comprises 50.8 percent of the combined additional weapon carriage capability. Table 4.5 shows the values used in determining the cost per weapon station and additional weapon carriage capability ratio values.

Table 4.5: Ratios and Associated Values

Cost		**BRU-55**	**F-15E**	**Total**
	Value	$124,382	$21,000	$145,382
	Ratio	.855	.145	1
Additional Carriage				
	Value	4,374	4,510	8,884
	Ratio	.492	.508	1

Qualitative

The qualitative pairwise comparisons include expert weighting of each alternative against the two qualitative criteria and the criteria themselves. The qualitative data was gathered through a series of five interviews described in Chapter III.

The Interviews. A pilot interview with F-15E and F-16 experts and a series of four interviews with three DOD experts was conducted to validate background information, and gather cost and qualitative comparison data. The experts possessed an average of eight years of related experience in their fields and all were familiar with at least four of the seven weapon systems related to the research problem. The results of each interview are described in the following paragraphs.

Pilot Interview. The pilot interview established a common reference point for the remaining interviews. Four decision criteria were determined to be relevant and measurable to the research problem. The final decision criteria are shown in Table 4.6.

Table 4.6: Final Decision Criteria

Quantitative	Qualitative
1) Cost/Weapon Station Added	1) Commonality
2) Additional Weapon Carriage Capability	2) Risk

The pilot interview also established definitions for each of the final decision criterion.

Cost per weapon station added was defined by aircraft as the total additional development and retrofit cost from the status quo baseline in current year dollars for each alternative. The cost per weapon station is the cost of an alternative for each aircraft divided by the additional number of weapon stations the alternative will provide on that aircraft. Cost per weapon station allows a method of comparing the cost of each alternative on an aircraft. A weighted average based on the cost per weapon station added and the number of each aircraft type will be used to compare alternatives between the F-15E, F-16, and F/A-18. Costs were provided by the respective aircraft expert through interviews, except for the F/A-18 as discussed in Chapter I.

Additional weapon carriage capability was defined as the cumulative number of the additional weapon carriage an alternative will provide above current capability for each weapon type (JDAM, JSOW, and WCMD). It is found in four steps:

1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon as shown in Tables 2.4 and 2.5.

2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.

3) Multiplying step 2 by the total number of that aircraft type.

4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Additional weapon carriage capability provides a measure of the overall increase in MIL-STD-1760 combat capability provided by an alternative.

Commonality was defined as a qualitative judgment that compares an alternative's ability to serve as a common solution for increasing weapon carriage capability for each aircraft and weapon type. Commonality prevents duplication of development effort, results in improved standardization and interoperability, and reduces procurement and logistics life cycle costs. Judgments are based on the respective 9-point scale in Appendix B, and measure the amount of increased commonality, if any, an alternative has over the status quo.

Risk was defined as a qualitative judgment that compares alternatives based on their ability to serve as a long term fix. The concept of risk is a judgment based on factors that include: the level of complexity of an alternative, the level of technological development for an alternative, and the ability of an alternative to meet measures of effectiveness anticipated by the expert. For example, an alternative an expert judges to have the ability to survive in the expected environment or to require less maintenance has less risk than another alternative. Judgments are based on the respective 9-point scale in Appendix B where higher values represent the amount of increased risk, if any, an alternative has over the status quo.

Along with establishing criteria definitions, the aircraft experts confirmed the accuracy of aircraft technical information contained in Chapter II. The F-15E expert also limited the most feasible additional wiring alternative to the F-15E CFTs.

First Interview. The first interview established the relative priority of the decision criteria to each other and collected BRU-55 cost information needed to complete aircraft cost estimates. No pairwise comparisons were made, establishing the relative priority of the hierarchy elements ensured a common reference for future pairwise comparisons. All three experts agreed that quantitative criteria are more important than qualitative criteria. For the quantitative criteria, two of the three experts indicated that cost was more important than additional weapon carriage capability. Commonality was unanimously chosen as having more importance than risk.

The cost of the BRU-55 bomb rack was obtained from a BRU-55 expert and does not represent DOD officially approved values. However, the values form a range that is representative of the actual anticipated cost for developing and procuring the 1,100 bomb racks that would be required to implement the BRU-55 alternative in the opinion of the BRU-55 expert. The expected unit cost for a BRU-55 is contained in Table 4.7.

Table 4.7: BRU-55 Expected Cost

Cost (in thousands)	Description
$60	BRU-33 with two bomb racks
$10	Strong back, and fore/aft fairings for BRU-33
$18	BRU-55 "smart" electronics and wiring
$88	Total

Additionally, in the opinion of the BRU-55 expert, the potential range in the BRU-55 cost could vary between $60,000 and $95,000 for each smart bomb rack. The BRU-55 cost estimate is based on contractor and government data. The contents and results of the first interview are shown in Appendix B.

Second Interview. The second interview assigned weightings between the criteria and alternatives, determined the relative weightings for the qualitative criteria, and obtained F-15E and F-16 cost information for appropriate alternatives from the respective aircraft experts. The content, results, and appropriate definitions for the second interview are shown in Appendix C. All three experts indicated that quantitative criteria had a strong importance, or a numerical value of five, over qualitative criteria. With respect to the quantitative criteria two of the three experts indicated that cost per weapon station added was of a strong or greater importance, or a numerical value of seven or higher, than the additional weapon carriage capability. With respect to the qualitative criteria, commonality was determined to have a demonstrated importance over risk. Two of the three experts rated the risk of the BRU-55 alternative as equal to the status quo with the other expert rating it with strong risk, because of potential store certification issues. The risk of the F-15E additional wiring alternative is of equal risk with the status quo, because it is only an extension of the current smart interface used. The commonality of the F-15E additional wiring alternative was determined to have equal commonality with the status quo for the same reason. The commonality of the BRU-55 alternative was determined to be a demonstrated improvement over the status quo by all three experts. The actual weightings given by the experts are provided in Table 4.8, and explanations of the weights are given in Appendix C.

Table 4.8: Initial Expert Weightings of Criteria and Alternatives

Criterion	Expert 1	Expert 2	Expert 3
BRU-55 commonality	7	8	7
F-15E wiring commonality	1	1	1
BRU-55 risk	1	6	1
F-15E wiring risk	1	1	1
Commonality to risk	7	5	7
Cost to capability	7	1/7	7
Quantitative to qualitative	5	5	5

The cost estimates provided by the F-16 and F-15E experts respectively do not represent DOD officially approved values. However, the values form a range that is representative of the anticipated costs of the alternatives in the opinion of the respective experts. The F-16 Block 40 aircraft cost estimate for the BRU-55 is $45.5 million, with a low of $43 million and a high of $50 million. The F-16 Block 50 aircraft cost estimate for the BRU-55 is $34 million, with a low of $26 million and a high of $36 million. The F-15E BRU-55 estimate is $41 million, with a low of $39 million and a high of $47 million. The F-15E additional wiring estimate is $43 million, with a low of $41 million and a high of $49.5 million. Estimates of the F/A-18 BRU-55 costs were based on analogies to the F-16 and F-15E. The cost of the BRU-55 alternative used for the F/A-18C/D is $22.6 million. The cost used for the F/A-18E/F BRU-55 alternative is $18.2 million. Additional detail for the aircraft cost estimates is contained in Appendix G.

Third Interview. In this interview, experts were asked to critique the high and low pairwise comparison weightings in an effort to persuade or to justify weightings to the other experts. Of the seven pairwise comparisons made, only two had significant differences and three showed consensus. Only the two weightings with significant differences solicited additional comments from the experts.

The risk of the BRU-55 alternative as compared to the status quo was the first weighting that had significant differences. Two of the three experts rated the BRU-55 of equal risk with the status quo, while a third rated it with a higher risk value of six that equates to strong or demonstrated higher risk. The reason given for the BRU-55 having low risk is that it has low technical risk, because it is a small development effort. High risk for the BRU-55 was justified by concerns over integrating the BRU-55 on aircraft and potential problems with flutter, memory of avionics, and interface timing requirements.

The relative importance of the quantitative criteria was the second area of disagreement between the experts. Two of the three experts identified the cost per weapon station as having demonstrated importance over the additional weapon carriage capability. The reasoning behind the cost of a program having more importance was that if a program is too costly it will be canceled. The reasoning behind additional weapon carriage capability having more importance was that requirements drive programs and if a justified need exists the funds will be found to meet that requirement.

Fourth Interview. In the fourth interview, the range and mean pairwise comparison weightings were provided with the reasons given to justify the low and high weightings. After being provided with this additional information, the experts were asked to perform final pairwise comparisons. The final pairwise comparison resulted in an increase in consensus from three to four weightings and a decrease in the range of disagreement on the other weightings. The low, mean, and high value for each of the weightings is provided in Table 4.9.

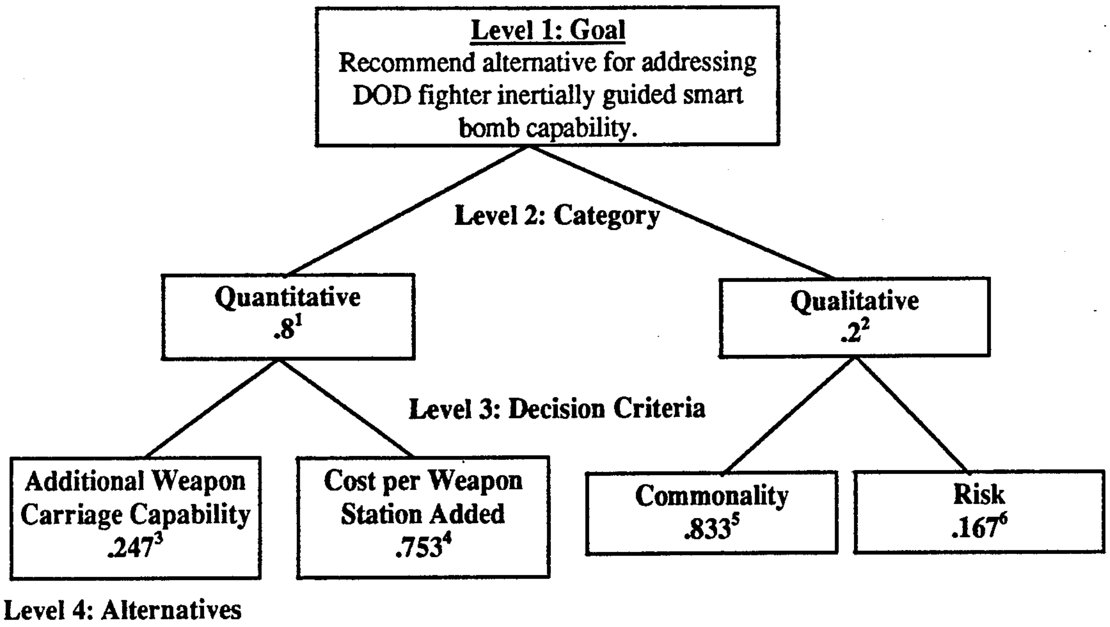
Table 4.9: Descriptive Statistics on Final Expert Weightings

Criterion	Low weighting	Mean	High weighting
BRU-55 commonality	7	7.33	8
F-15E wiring commonality	1	1	1
BRU-55 risk	1	3.33	6
F-15E wiring risk	1	1	1
Commonality to risk	6	6	6
Cost to capability	1/7	4.05	7
Quantitative to qualitative	5	5	5

Summary. The series of four interviews was essential in obtaining and validating data for comparing the two feasible alternatives with the established decision criteria. The transformation of the gathered data into pairwise comparisons that could be entered into a hierarchical model is discussed in the next section.

Analysis

The quantitative and qualitative information gathered was transformed into ratios for each level of the hierarchy, and then entered into the developed Expert Choice software model. The quantitative ratios were found by summing the result for each alternative for the respective criterion and dividing the individual values by the total value. Qualitative ratios were found by inverting the mean numerical value of the expert pairwise comparison. The resulting value was used for the criteria given the lower relative priority in the first interview. The ratio value of the criteria with the higher relative priority was found by determining the reciprocal of the associated lower priority criteria (Saaty, 1982: 78). This ensured the sum of the ratios was one. The resulting ratios were entered into Expert Choice with the data comparison method. In each case, the sum of the ratios at each intersection of the hierarchy is one. The Expert Choice model with weightings is shown in Figure 4.1; footnotes identify the source of the weightings.



	Additional Weapon Carriage Capability	Cost per Weapon Station Added	Commonality	Risk
F-15E	.508[7]	.855[8]	.136[9]	.7[10]
BRU-55	.492[11]	.145[12]	.864[13]	.3[14]

Figure 4.1: Model with Weightings

1. Reciprocal of inverted mean final expert weighting from Table 4.9
2. Inverted mean final expert weighting, 5, from Table 4.9
3. Reciprocal of inverted mean final expert weighting from Table 4.9
4. Inverted mean final expert weighting, 4.05, from Table 4.9
5. Reciprocal of inverted mean final expert weighting from Table 4.9
6. Inverted mean final weighting, 6, from Table 4.9
7. From Table 4.5
8. From Table 4.5
9. Inverted mean final expert weighting, 7.33, from Table 4.9
10. Reciprocal of inverted mean final expert weighting from Table 4.9
11. From Table 4.5
12. From Table 4.5
13. Reciprocal of inverted mean final expert weighting from Table 4.9
14. Inverted mean final expert weighting, 3.33, from Table 4.9

The values in Figure 4.1 for the F-15E additional wiring and BRU-55 alternatives are inverted for the cost and risk criterion, because low values are considered good for these criteria and the model assumes high numbers are better.

Results. Looking at the level 4 alternatives in Figure 4.1 shows that the data provides the F-15E additional wiring alternative with higher ratios than the BRU-55 smart bomb rack under each criterion except commonality. Solving the model using Expert Choice in the distributive mode results in the F-15E additional wiring alternative being recommended over the BRU-55 smart bomb rack alternative by a weighting of .661 to .339. The distributive mode applies, because it is used for prioritizing alternatives where the criterion values for the alternatives are different (Decision Support Software, 1993: 63). The results are shown in Table 4.10. The inconsistency ratio is zero, because inconsistency ratios are not given when data is entered using the data method.

Table 4.10: Model Results

Alternative	Rating
F-15E	.661
BRU-55	.339

Overall inconsistency index = 0.00

Sensitivity Analysis. Further manipulation of Expert Choice shows that the following criterion values, when the others are held constant, result in indifference points where either alternative would be preferable: equal or .5 weightings for the level 3 quantitative criteria, and equal or .5 weightings for the level 2 criteria categories. This means that the BRU-55 would be the preferred solution, if qualitative criteria had relative priority over quantitative criteria or additional weapon carriage capability had relative priority over cost per weapon station added. Additionally, the model is insensitive to changes in the level 3 qualitative criteria, or use of the ideal solution mode. Actual Expert Choice output is contained in Appendix H.

Considering the data collected, even in the best case the cost of the BRU-55 alternative per weapon station is anticipated to be higher than the cost of the F-15E alternative; therefore, it is unrealistic to anticipate equal weighting of the level 3 quantitative criteria. Equal weighting of the level 2 quantitative and qualitative criteria categories is not suggested by the results, because a consensus existed among the experts that quantitative criteria had a strong importance over qualitative criteria. However, the interaction between the criteria can be complex, and recommending the F-15E additional wiring alternative as a solution assumes that quantitative criteria are more important than qualitative criteria in regard to this decision.

Conclusion

The F-15E additional wiring alternative is recommended as the solution to address DOD multi-role fighter smart bomb capability. The results of the research do not support the hypothesis that the alternative that provides a common solution would be recommended. This study demonstrates that joint acquisition programs do not necessarily result in lower cost solutions, and that the increased cost of a joint program may outweigh potential gains in compatibility. Joint acquisition programs should not be viewed as a panacea to current challenges--all feasible alternative solutions to a problem need to be considered.

V. Conclusions and Recommendations

Overview

This chapter reviews the thesis, evaluates the impact of assumptions and limitations, summarizes the research questions and findings, and presents research conclusions and recommendations. After summarizing the thesis research, the thesis concludes with suggestions for further research.

Summary of Previous Chapters

Chapter I introduced the issue and significance of the research problem. The general issue was the decrease in defense funding is extending the inventory life of DOD fighter aircraft, and that modernization programs are required to avoid obsolescence and maintain combat effectiveness. The specific research problem is that existing DOD multi-role fighter aircraft could carry more inertially guided smart bombs if they had more smart interfaces.

Chapter II laid the foundation for the rest of the thesis by answering research questions one through five. The first finding indicates that advances in bomb guidance have decreased the number of aircraft sorties required to destroy selected targets and have increased survivability. Second, the specific mechanical, electrical, and logical support requirements of inertially guided smart bombs were outlined. Research on the third question resulted in identifying four potential alternatives that were later reduced to two feasible alternatives. Fourth, the method of evaluating competing alternatives in the DOD for acquiring weapon systems, a COEA, was described. The chapter also outlined the use of AHP within the requirements of a COEA. Finally, four feasible decision criteria were identified out of eight potential decision criteria.

Chapter III outlined the methodology of the research effort. A formal study was conducted in four phases to collect required data, form a model, and recommend an alternative for addressing DOD multi-role fighter smart bomb capability. Interviews based on the Delphi technique were combined with AHP to gather data, formulate a hierarchical model, and validate model weightings. The hierarchical model with weightings was entered into Expert Choice, an AHP based software program, so the model could be solved and sensitivity analysis performed.

Chapter IV described the quantitative and qualitative data collected in the research effort, and how it was transformed into hierarchical model weightings. The model was then solved and sensitivity analysis performed. This chapter answered research questions six and seven. Definitions for the four feasible decision criteria were finalized in the pilot interview, and the model was solved to recommend an alternative. The F-15E additional wiring solution was recommended, in contradiction to the research hypothesis that a joint program would be recommended.

Impact of Assumptions and Limitations

The research was bounded by thirteen assumptions and limitations listed in Chapter I. All technology with known applications to the research problem were included as potential alternatives. In the future, new technology may become available, or current alternatives deemed infeasible may become viable. If this occurs, the research will need to be revisited. The model weightings were carefully gathered from knowledgeable and experienced experts, and are appropriate for the current environment. Continued policy or budgetary changes could impact model weightings. The absence of a defined requirement was a significant condition that drove several assumptions on smart bomb rack procurement quantities and aircraft configurations, and limited the number of feasible decision criteria. If an actual requirement materializes that is different from what was assumed by the research, another evaluation of alternatives will be required. The lack of a defined requirement also limited the ability of experts to complete cost estimates for the entire life cycle of alternatives.

Cost estimates were limited to each alternative's development cost as subject to other assumptions and limitations. For example, limiting research to specific weapon types bounded the research problem; however, implementation of the recommended alternative would have additional applications to other weapons. The research was also confined to the F-15E, F-16, and F/A-18; however, they include the current DOD fighter aircraft facing needed modernization. F/A-18 information was not independently verified by an expert, and the F/A-18 cost estimates are the only ones not developed by an expert associated with the impacted aircraft. Overall, the research is representative of current conditions and the largest threat to the research's validity from the assumptions and limitations is the potential for a defined requirement to vary from the assumed conditions.

Research Questions and Findings

The following sections restate the seven research questions, and provide a summary of the answers found.

What is the impact of smart bombs on warfare?

Limitations of current laser and optically guided smart bombs have led to the development of inertially guided bombs. Advances in bomb guidance and delivery modes have decreased the number of aircraft sorties required to destroy selected targets and have increased aircraft survivability.

What aircraft support is required for the next generation of smart bombs?

JDAM, JSOW, and WCMD are three smart bomb programs under development that use inertial guidance technology. Though each is a different design they require similar mechanical, electrical, and logical support from launch aircraft.

What is the present DOD fighter capability to support smart bombs?

The F-15E, F-16, and F/A-18 are the first operational DOD fighters prioritized for integration of inertially guided smart bombs. The specific interface capabilities of each aircraft are described in Chapter II. However, it is shown that the F-15E, F-16, and F/A-18 could carry more smart bombs, if they had more smart interfaces.

What alternatives exist for addressing fighter smart bomb capability?

Alternatives for addressing the problem of smart bomb capability on DOD fighter aircraft fall into four categories: additional wiring, smart bomb rack, wireless interface, or continuing the status quo. Only F-15E additional wiring, the BRU-55 smart bomb rack, and the status quo were determined to be feasible.

What DOD guidance exists for evaluating alternative solutions?

The method of evaluating competing alternatives in the DOD for acquiring weapon systems is called a COEA. A COEA aids decision making, facilitates communication, and provides a historical record.

What decision criteria are used to evaluate the identified alternatives?

Four decision criteria, cost per weapon station, additional weapon carriage capability, risk, and commonality, were used to evaluate the feasible alternatives. The criteria are defined in Chapter IV.

Considering the decision criteria, what alternative is recommended?

The AHP and the associated software Expert Choice were used to select the recommended alternative. The recommended alternative is F-15E additional wiring. If increasing the capability of DOD multi-role fighter aircraft is a valid requirement, the CFTs of all F-15E aircraft should be modified for additional MIL-STD-1760 wiring. Modifying the CFTs of an F-15E will allow every F-15E to carry three times as many 1,000 lb. inertially guided smart bombs than current capability, at approximately one fifth the cost of other solutions. The 2,050 increase in weapon stations with a smart interface results in a 3,075 smart bomb carriage capability, on the F-15E, that is comparable to the current 3,535 smart bomb capability of all existing F-15E, F-16, and F/A-18 aircraft combined.

Conclusions

Joint acquisition programs do not necessarily result in lower cost solutions, and the increased cost of a joint program may outweigh potential gains in compatibility. Joint acquisition programs should not be viewed as a panacea to meeting requirements. All feasible alternative solutions to a problem need to be considered.

The research has shown that AHP and Expert Choice are an effective way to compare acquisition programs within the guidelines of a COEA. AHP allows collection of expert opinion, comparison of alternatives on both quantitative and qualitative criteria, and structuring of problems in easily understood hierarchies. Expert Choice performs the complex math behind AHP, identifies recommended alternatives, and performs sensitivity analysis. Expert Choice also provides experts and decision makers with the ability to see the impact of changes to models immediately. Current hard copy COEA reports are not as flexible.

Recommendations

This research has demonstrated that AHP and Expert Choice can be applied to decisions requiring selection of an alternative for meeting DOD needs within required guidelines. The decision model and software are easy to use and could be used by managers and analysts to evaluate acquisition program alternatives. A strength of AHP is that it can be structured to compare different alternatives on the same criteria by collecting expert opinion on quantitative and qualitative criteria. The Air Force and DOD should consider using AHP and Expert Choice in performing COEA reports, because it has wide application and provides a dynamic end product.

Suggestions for Further Research

While performing this research, two areas suggested opportunities for further research.

First, the definition of weapon system requirements is an unresolved issue in DOD acquisition. This was reflected in the research limitation that an additional smart bomb carriage requirement has not been defined. Previous research has also identified definition of requirements as a concern in DOD acquisition (Kent, 1988: 8; Rich and Dews, 1986: 31; Davis, 1994: 44). Additional research could examine the current DOD requirement based planning system with the goal of recommending improvements.

Second, the dramatic improvement in smart bomb carriage capability by increasing the number of F-15E weapon stations with a smart interface suggests the F-15C may offer an inherent capability to make similar gains in capability by adding smart interfaces to F-15C aircraft. Avionics upgrades to the F-15C and decreased workload requirements of inertially guided smart bombs may make integration and carriage of inertially guided smart bombs on the F-15C feasible. Additional research could examine the feasibility and cost of upgrading F-15C aircraft to employ inertially guided smart bombs.

Appendix A. Pilot Interview

Problem

The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology. The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Progress

A comprehensive literature review of the problem has been completed. A series of four interviews will be used after this pilot interview to gather the additional information needed to solve the problem by applying a decision support tool. This pilot interview establishes the final decision criteria and their definitions, limits alternatives considered to the most feasible in each category, and confirms aircraft technical information documented in the literature review.

Research Assumptions and Limitations

Several assumptions and limiting factors scope the research problem. The impact of the assumptions and limitations on the research is discussed in Chapter IV.

The primary research assumptions are:

1) All known feasible solutions are considered

2) The weighting of decision criteria is representative

3) The focus is on potential, not necessarily planned capability

4) Only one-half of the potential aircraft will require retrofit of smart bomb racks

5) That new smart bomb racks would be procured for the F/A-18's, or that existing BRU-33A/A racks would not be modified

All alternative solutions found by the researcher and known by contacted experts were reviewed. Further advances technology may occur that will develop alternatives that are not considered in this research. The weighting of decision criteria is based on the Delphi technique, a method of gathering experts' judgments (Brown, 1968: 1). The Delphi technique is further discussed in Chapter II. The inherent capability to expand each aircraft's ability to carry smart bombs is used in the research, and may not be representative of the planned development of an aircraft's capability. For example, there is no defined requirement for F-15E carriage of the 1,000 lb. version of JDAM, although the aircraft has the undeveloped capability to carry the store. It is not feasible that every F-15E, F-16, and F/A-18 have a smart bomb rack, because some of the missions the aircraft perform are not compatible with a smart bomb rack. Procurement of new bomb racks is assumed for the F/A-18 to maintain consistency of the cost across the model.

The primary research limitations are:

1) Exact cost figures could not be obtained for each alternative due to their theoretical nature

2) Cost estimates are for the development and retrofit of an alternative only

3) Alternatives requiring modification of weapons are not considered

4) Only alternatives for 1,000 lb. class weapons are considered

5) Only alternatives for the F-15E, F-16, and F/A-18 are considered

6) There is no defined requirement for carriage of additional smart bombs on DOD fighter aircraft

7) Except for the F-16, the impact of external fuel tank carriage on the number of available weapon stations with a smart interface is not considered

8) The F/A-18 technical information was not independently reviewed by a F/A-18 expert, and F/A-18 cost information is based on the combined high and low cost estimate values for the F-15E and F-16 cost estimates respectfully

Cost information for each feasible alternative is only representative of actual cost to allow comparison of the alternatives. Life cycle costs are not developed, because not enough is known about all the alternatives to quantify support costs. Including changes to weapon design would not allow direct comparison of different alternatives, because the weapon design would not be baselined across the alternatives. Only 1,000 lb. class weapons are considered, because that is the only single common weight class for JDAM, JSOW, and WCMD. Selection of the F-15E, F-16, and F/A-18 aircraft is based on their status as the top three DOD operational, multi-role, night capable, fighter aircraft prioritized for integration of inertially guided weapons. Without a defined requirement no formal performance measures for the alternatives exist. Definition of weapon system requirements is a continuing concern in DOD acquisition (Kent, 1988: 8; Rich and Dews, 1986: 31). The requirement for additional smart bomb carriage is only defined for the F-

16. Therefore, the F-16 is the only aircraft where external fuel tank carriage is considered. The F/A-18 technical and cost information will not be as reliable as the information for the F-15E and F-16, because it was not independently reviewed.

Interview

The interview questions gather information needed to complete the research. Definitions of key terms are provided in each section as required. Please remember the identified research limitations, when answering the measurement questions. Responses to the interview will be kept anonymous.

1. A review of related literature has identified four potential decision criteria for identifying an optimal alternative for increasing DOD fighter aircraft smart bomb capability. The criteria fall into either quantitative or qualitative categories. The quantitative criteria are cost per weapon station added and additional weapon carriage capability. The qualitative criteria are commonality and risk. Are the definitions of these four decision criteria adequate? The criteria are defined below:

A. **Cost Per Weapon Station Added:** The cost is the total additional development and retrofit cost from the status quo baseline in current year dollars by aircraft for each alternative. The cost per weapon station is the cost of an alternative for each aircraft divided by the additional number of weapon stations the alternative will provide on that aircraft. Cost per weapon station added allows a method of comparing the cost of each alternative on an aircraft. A weighted average based on the cost per weapon station added and the number of each aircraft type will be used to compare alternatives between the F-15E, F-16, and F/A-18.

B. **Additional Weapon Carriage Capability:** Additional weapon carriage capability is a cumulative number of the additional weapon carriage an alternative will provide above current capability for each weapon type (JDAM, JSOW, and WCMD). It is found in four steps:

> 1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon.
>
> 2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.
>
> 3) Multiplying step 2 by the total number of that aircraft type.
>
> 4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Additional weapon carriage capability provides a measure of the overall increase in MIL-STD-1760 combat capability provided by an alternative.

C. **Commonality:** Commonality is a qualitative judgment that compares an alternative's ability to serve as a common solution for increasing weapon carriage capability for each aircraft and weapon type. Commonality prevents duplication of development effort, results in improved standardization and interoperability, and reduces procurement and logistics life cycle costs. Judgments are based on the following 9-point scale, and measure the amount of increased commonality, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives contribute equally to commonality
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

D. **Risk:** Risk is a qualitative judgment that compares alternatives based on their ability to serve as a long term fix. The concept of risk is a judgment based on factors that include: the level of complexity of an alternative, the level of technological development for an alternative, and the ability of an alternative to meet measures of effectiveness anticipated by the expert. For example, an alternative an expert judges to have the ability to survive in the expected environment or to require less maintenance has less risk than another alternative. Judgments are based on the following 9-point scale, where the higher the value the more risk associated with the alternative, and represents the amount of increased risk, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives have equal risk
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

2. Would you recommend considering additional criteria, if so how would you define them?

None of the aircraft experts recommended additional criteria, after considering the research assumptions and limitations.

3. Confirmation of literature review

A) The available alternatives for addressing smart bomb capability on fighter aircraft fall into four categories: install additional wiring, procure a smart bomb rack, install a wireless interface, or continue with the status quo. Following is a table of all alternatives by category and aircraft. Please answer two questions. First, is the determination of each alternative accurate for your system? Second (F-15E Only), if there are more than one alternative for your aircraft in a category, in your judgment which is the most feasible based on the four decision criteria identified above?

Table A.1: Summary of Alternatives

Category	Aircraft	Alternative	Determination	Reason
Additional Wiring	F-15E	1. CFT	Most Feasible	Achievable
		2. Outboard Wing	Least Feasible	Achievable
	F-16	None	Not Feasible	Not required
	F/A-18	None	Not Feasible	Not required
Smart Bomb Rack	F-15E	1. BRU-33A/A	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
	F-16	1. BRU-33A/A	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
	F/A-18	1. BRU-33A/A	Feasible	Achievable
		2. TER-9A	Not Feasible	N/A for all weapons
Wireless Interface	F-15E	CFT	Not Feasible	Requires more development
	F-16	None	Not Feasible	Not required
	F/A-18	None	Not Feasible	Not required
Status Quo	F-15E	No change	Feasible	Present capability
	F-16	No change	Feasible	Present capability
	F/A-18	No change	Feasible	Present capability

B) Please confirm the aircraft information and alternative information pertaining to your aircraft in the Literature Review (Note: a copy of Chapter II was provided).

Conclusion

Thank you for your participation. The next interview requests alternative cost information, initial ranking of decision criteria, and rationale for criteria rankings.

Appendix B. First Interview

Problem

The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology. The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Progress

A comprehensive literature review of the problem has been completed. A series of four interviews will be used to gather the additional information needed to solve the problem by applying a decision support tool. This is the first of four interviews. This interview asks experts to provide initial rankings of four identified decision criteria. Bomb rack experts are also asked to provide BRU-55 hardware costs; so future aircraft cost estimates are based on standardized information.

Interview

The interview questions gather information needed to complete the research, and are divided into two parts. Part A is for all experts; Part B is for BRU-55 experts. Definitions of key terms are provided in each section as required. Responses to the interview will be kept anonymous. Responses that can not be assigned specific values need to be representative of actual information. Responses are considered representative if a specified and realistic range of values is determined to contain the actual or anticipated value.

Part A: All respondents

A review of related literature and a pilot interview with aircraft experts have identified four decision criteria for recommending an alternative for increasing DOD fighter aircraft smart bomb capability. The criteria fall into either quantitative or qualitative categories. The quantitative criteria are cost per weapon station added and additional weapon carriage capability. The qualitative criteria are commonality and risk. The criteria are defined below, and understanding the definitions is needed to answer the remaining questions.

A. **Cost Per Weapon Station Added:** The cost is the total additional development and retrofit cost from the status quo baseline in current year dollars by aircraft for each alternative. The cost per weapon station is the cost of an alternative for each aircraft divided by the additional number of weapon stations the alternative will provide on that aircraft. Cost per weapon station added allows a method of comparing the cost of each alternative on an aircraft. A weighted average based on the cost per weapon station added and the number of each aircraft type will be used to compare alternatives between the F-15E, F-16, and F/A-18.

B. **Additional Weapon Carriage Capability:** Additional weapon carriage capability is a cumulative number of the additional weapon carriage an alternative will provide above current capability for each weapon type (JDAM, JSOW, and WCMD). It is found in four steps:

1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon.

2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.

3) Multiplying step 2 by the total number of that aircraft type.

4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Additional weapon carriage capability provides a measure of the overall increase in MIL-STD-1760 combat capability provided by an alternative.

C. **Commonality:** Commonality is a qualitative judgment that compares an alternative's ability to serve as a common solution for increasing weapon carriage capability for each aircraft and weapon type. Commonality prevents duplication of development effort, results in improved standardization and interoperability, and reduces procurement and logistics life cycle costs. Judgments are based on the following 9-point scale, and measure the amount of increased commonality, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives contribute equally to commonality
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

D. **Risk:** Risk is a qualitative judgment that compares alternatives based on their ability to serve as a long term fix. The concept of risk is a judgment based on factors that include: the level of complexity of an alternative, the level of technological development for an alternative, and the ability of an alternative to meet measures of effectiveness anticipated by the expert. For example, an alternative an expert judges to have the ability to survive in the expected environment or to require less maintenance has less risk than another alternative. Judgments are based on the following 9-point scale, where the higher the value the more risk associated with the alternative, and represents the amount of increased risk, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives have equal risk
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

1. Based on your opinion will the Quantitative or Qualitative criteria be more important and why?

Expert 1: Quantitative, because of cost considerations
Expert 2: Qualitative, because the common solution will have the lowest cost
Expert 3: Quantitative, because of cost

2. Based on your opinion which quantitative criteria is the most important?

____ Cost per weapon station

____ Number of Additional Stations

Reason (Please Specify):

Expert 1: Cost, because of budget limitations
Expert 2: Additional stations, because if important enough they will find the money
Expert 3: Cost, because of limited budget

3. Based on your opinion which qualitative criteria is the most important?

____ Commonality

____ Risk

Reason (Please Specify):

Expert 1: Commonality, because of increased interoperability and decreased cost
Expert 2: Commonality, because of decreased cost
Expert 3: Commonality, because of advantages to commonality and that risk is low

Part B: BRU-55 Experts

1. BRU-55 Expert: What do you anticipate the average cost of a BRU-55 to be in FY95 constant dollars?

The bomb rack is expected to cost between $75,000 to $95,000 dollars per bomb rack with an expected cost of $88,000 per bomb rack based on a buy of 1,000 bomb racks. The cost is broken out as follows:

	$60,000	Cost of one BRU-33 with two bomb racks
	$10,000	Cost of one strong back with front and aft fairings (some Navy surplus)
	$15,000-$20,000	Cost of Electronics
Total	$88,000 approximately	

Conclusion

Thank you for your participation. The next interview requests alternative cost information, initial weighting of decision criteria, and rationale for criteria weightings.

Appendix C. Second Interview

Problem

The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology. The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Progress

A comprehensive literature review of the problem has been completed. The first in a series of four interviews has assigned preliminary rankings of the decision criteria. This is the second of four interviews. This interview requests pairwise comparison of decision criteria and rationale, and that alternative cost information be provided by aircraft experts.

Interview

The interview is divided into identification and measurement sections. Questions in the identification section are used to determine the area of specialty for the respondent. Measurement questions gather information needed to complete the research, and are divided into two parts. Part A is for all experts; Part B is for aircraft experts. Definitions of key terms are attached. Responses to the interview will be kept anonymous. Responses that can not be assigned specific values need to be representative of actual information. Responses are considered representative if a specified and realistic range of values is determined to contain the actual or anticipated value.

Identification Questions

1. What weapon systems are you familiar with? (check all that apply)

____ F-15E	____ JDAM
____ F-16	____ JSOW
____ F/A-18	____ WCMD

____ Other (Please specify) ______________________________

Expert 1: F-15E, JDAM, JSOW, and WCMD
Expert 2: F-16, JDAM, JSOW, and WCMD
Expert 3: JDAM, JSOW, WCMD, and BRU-55

2. How many years of experience do you have in acquisition related activities?

Expert 1: 4 years
Expert 2: 10 years
Expert 3: 10 years

Measurement Questions

Part A: All respondents

1. (Two Parts) Please fill in the below pairwise comparison matrix to evaluate each alternative against the status quo for each of the qualitative criteria. Definitions and the measurement scale are attached.

A) Commonality

Alternative's Commonality	Status Quo
BRU-55	

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

What reason did you use in assigning the weighting?

Expert 1: Score 7; BRU-55 is common and the status quo is not
Expert 2: Score 8; Commonality is the only reason for new programs
Expert 3: Score 7; because a common solution across three aircraft is a significant improvement over the status quo

Alternative's Commonality	F-15E Additional Wiring
Status Quo	

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

What reason did you use in assigning the weighting?

Expert 1: Score 1; they are the same
Expert 2: Score 1; additional wiring is only an extension of the status quo
Expert 3: Score 1; additional wiring is the same as the status quo

B) Risk

Alternative's Risk	Status Quo
BRU-55	

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

What reason did you use in assigning the weighting?

Expert 1: Score 1; the BRU-55 is low risk
Expert 2: Score 6; certifying existing stores on the BRU-55 is an unresolved issue
Expert 3: Score 1; both are well developed technologies

Alternative's Risk	F-15E Additional Wiring
Status Quo	

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

What reason did you use in assigning the weighting?

Expert 1: Score 1; they are the same
Expert 2: Score 1; additional wiring is only an extension of the status quo
Expert 3: Score 1; the status quo and additional wiring are the same

2. Please fill in the below pairwise comparison matrix for the relative importance of the qualitative criteria. Definitions and the measurement scales are attached.

Criterion	Risk
Commonality	

What reason did you use in assigning the weighting?

Expert 1: Score 7; commonality has a much larger impact than risk
Expert 2: Score 5; all new programs are common
Expert 3: Score 7; both alternatives are developed and risk is low

3. Please fill in the below pairwise comparison matrix for the relative importance of the quantitative criteria. The actual quantitative decision criteria values for each alternative will be defined by mathematical relationship from related information. Definitions and the measurement scale are attached.

Criterion	# Add. Stat
Cost/Wpn Station Added	

What reason did you use in assigning the weighting?

Expert 1: Score 5; affordability of programs is needed to obtain funding
Expert 2: Score 1/7: Additional carriage capability is a valid requirement and the money will be found
Expert 3: Score 7; Cost is significant in determining whether a program is funded

4. Please fill out a pairwise comparison matrix on the relative importance of quantitative and qualitative criteria. The definitions and the measurement scales are attached.

Criterion	Qualitative
Quantitative	

What reason did you use in assigning the weighting?

Expert 1: Score 5; Quantitative measures are more easily explained and understood
Expert 2: Score 5; What can be counted counts
Expert 3: Score 5; Things that can be measured like cost have a stronger influence

Part B: Aircraft Respondents

1. What is the cost to implement each alternative? The following guidelines should be used to develop the cost estimate:

1) The cost is a total program cost in current year dollars for the alternative as its development and retrofit cost is different from the status quo.
2) The cost estimate should identify the expected cost with lower and upper bounds
3) Assume the cost of a single in FY95 constant dollars BRU-55 bomb rack is $88,000.

Conclusion

Thank you for your participation. The next interview provides the results of this interview and requests that you perform a second weighting of decision criteria, and rationale for criteria weightings.

Criteria Definitions

A. Cost Per Weapon Station Added: The cost is the total additional development and retrofit cost from the status quo baseline in current year dollars by aircraft for each alternative. The cost per weapon station is the cost of an alternative for each aircraft divided by the additional number of weapon stations the alternative will provide on that aircraft. Cost per weapon station added allows a method of comparing the cost of each alternative on an aircraft. A weighted average based on the cost per weapon station added and the number of each aircraft type will be used to compare alternatives between the F-15E, F-16, and F/A-18.

B. Additional Weapon Carriage Capability: Additional weapon carriage capability is a cumulative number of the additional weapon carriage an alternative will provide above current capability for each weapon type (JDAM, JSOW, and WCMD). It is found in four steps:

1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon.

2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.

3) Multiplying step 2 by the total number of that aircraft type.

4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Additional weapon carriage capability provides a measure of the overall increase in MIL-STD-1760 combat capability provided by an alternative.

C. Commonality: Commonality is a qualitative judgment that compares an alternative's ability to serve as a common solution for increasing weapon carriage capability for each aircraft and weapon type. Commonality prevents duplication of development effort, results in improved standardization and interoperability, and reduces procurement and logistics life cycle costs. Judgments are based on the following 9-point scale, and measure the amount of increased commonality, if any, an alternative has over the status quo.

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9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

D. **Risk:** Risk is a qualitative judgment that compares alternatives based on their ability to serve as a long term fix. The concept of risk is a judgment based on factors that include: the level of complexity of an alternative, the level of technological development for an alternative, and the ability of an alternative to meet measures of effectiveness anticipated by the expert. For example, an alternative an expert judges to have the ability to survive in the expected environment or to require less maintenance has less risk than another alternative. Judgments are based on the following 9-point scale, where the higher the value the more risk associated with the alternative, and represents the amount of increased risk, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives have equal risk
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

Appendix D. Third Interview

Problem

The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology. The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Progress

A comprehensive literature review of the problem has been completed. Two out of four interviews are complete and a comparison of the alternatives and decision criteria have been performed. Additionally, cost information has been requested for alternatives for the F-15E and F-16. This is the third of four interviews. This interview requests a critique of the reasons given for the pairwise comparisons in the last interview.

Interview

The interview questions gather information needed to complete the research. Definitions of key terms are attached.

Part A: All respondents

1. (Two Parts) After looking at the results from the last interview and related explanations, please critique the reasons given for the high and low pairwise comparisons. Definitions are and measurement scales are attached.

A) Commonality

Alternative's Commonality	Low BRU-55	High BRU-55
Status Quo	7	8

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

Rationale given for low and high weightings:

The BRU-55 is a significant improvement over the status quo.

Critique of low and high weighting:

None

Alternative's Commonality	Low F-15E Additional Wiring	High F-15E Additional Wiring
Status Quo	1	1

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

Rationale for low and high weighting:

Additional wiring is only an extension of the status quo

Critique of low and high weighting:

None

B) Risk

Alternative's Risk	Low BRU-55	High BRU-55
Status Quo	1	6

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

Rationale for low and high weighting:

Low: The BRU-55 is low risk development
High: The BRU-55 has additional risk because of certification issues with existing stores

Critique of low and high weighting:

Low: The BRU-55 is low development risk and any increase in risk would be associated with cost
High: Development risk is low; however, integration risk on aircraft with memory limitations, flutter concerns, and so on is high

Alternative's Risk	Low F-15E Additional Wiring	High F-15E Additional Wiring
Status Quo	1	1

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

Rationale for low and high weighting:

They are technically the same

Critique of low and high weighting:

None

2. Please critique the reasons given for the high and low pairwise comparisons of the qualitative criteria. Definitions are and measurement scales are attached.

Criterion	Low Risk	High Risk
Commonality	5	7

Rationale for low and high weighting:

Commonality is important and risk is relatively low for either alternative

Critique of high and low weighting:

None

3. Please critique the reasons given for the high and low pairwise comparisons of the quantitative criteria. Definitions are and measurement scales are attached.
The actual quantitative decision criteria values for each alternative will be defined by mathematical relationship from related information.

Criterion	Low Add. Weapon	High Add. Weapon
Cost/ Wpn Station	1/7	7

Rationale for low and high weighting:

Low: Cost is not as important, because if it is a valid requirement the funds will be found
High: Affordability drives program selection

Critique of low and high weighting:

Low: Requirements drive program selection
High: If a program is too costly it will be canceled

4. Please critique the reasons given for the low and high pairwise comparisons given on the relative importance of quantitative and qualitative criteria. The measurement scale is attached.

Criterion	Low Qual.	High Qual.
Quantitative	5	5

Rationale for low and high weighting:

Quantitative criteria are normally more important than qualitative criteria

Critique of low and high weighting:

None

Conclusion

Thank you for your participation. The next interview is the last interview and it asks that your review and approve the gathered information as representative of the actual information.

Criteria Definitions

A. Cost Per Weapon Station Added: The cost is the total additional development and retrofit cost from the status quo baseline in current year dollars by aircraft for each alternative. The cost per weapon station is the cost of an alternative for each aircraft divided by the additional number of weapon stations the alternative will provide on that aircraft. Cost per weapon station added allows a method of comparing the cost of each alternative on an aircraft. A weighted average based on the cost per weapon station added and the number of each aircraft type will be used to compare alternatives between the F-15E, F-16, and F/A-18.

B. Additional Weapon Carriage Capability: Additional weapon carriage capability is a cumulative number of the additional weapon carriage an alternative will provide above current capability for each weapon type (JDAM, JSOW, and WCMD). It is found in four steps:

1) Determining the number of additional weapons carried by the alternative for each aircraft and weapon.

2) Summing the additional JDAM, JSOW, and WCMD carried with an alternative into a total number of additional weapons carried by aircraft.

3) Multiplying step 2 by the total number of that aircraft type.

4) Summing the result for each aircraft type into an overall total of the number of additional weapon carriage capability by alternative.

Additional weapon carriage capability provides a measure of the overall increase in MIL-STD-1760 combat capability provided by an alternative.

C. Commonality: Commonality is a qualitative judgment that compares an alternative's ability to serve as a common solution for increasing weapon carriage capability for each aircraft and weapon type. Commonality prevents duplication of development effort, results in improved standardization and interoperability, and reduces procurement and logistics life cycle costs. Judgments are based on the following 9-point scale, and measure the amount of increased commonality, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives contribute equally to commonality
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

D. **Risk:** Risk is a qualitative judgment that compares alternatives based on their ability to serve as a long term fix. The concept of risk is a judgment based on factors that include: the level of complexity of an alternative, the level of technological development for an alternative, and the ability of an alternative to meet measures of effectiveness anticipated by the expert. For example, an alternative an expert judges to have the ability to survive in the expected environment or to require less maintenance has less risk than another alternative. Judgments are based on the following 9-point scale, where the higher the value the more risk associated with the alternative, and represents the amount of increased risk, if any, an alternative has over the status quo.

Intensity of Importance	Definition	Explanation
1	Equal Importance	The alternatives have equal risk
3	Weak Importance of one over another	Experience and judgment slightly favor one alternative over another
5	Essential or Strong Importance	Experience and judgment strongly favor one alternative over another
7	Demonstrated Importance	An alternative is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one alternative over another is the highest possible
2,4,6,8	Intermediate values between the two adjacent judgments	Use when the distinction is not clear

Appendix E. Fourth Interview

Problem

The Joint Direct Attack Munition (JDAM), the Joint Stand-Off Weapon (JSOW), and the Wind Corrected Munition Dispenser (WCMD) are three smart bomb programs under development that use inertial guidance technology. The F-15E, F-16, and F/A-18 are the first operational fighter aircraft prioritized for the integration of inertially guided smart bombs. The F-15E, F-16, and F/A-18 could carry more inertial smart bombs if they had more smart interfaces. The goal of this research is to recommend an alternative for addressing the capability of DOD multi-role fighter aircraft to employ inertially guided smart bombs.

Progress

A comprehensive review of the problem has been completed. This is the last interview and it contains a summary of all the previous results for your review. This interview requests that your review the previous decision criteria weights and rationale, and perform a final pairwise comparison that will be used as the group's response.

Interview

Perform one final weighting of each decision criteria after reviewing arguments for and against high and low weightings. Responses to the interview will be kept anonymous.

1. (Two Parts) Alternative comparison against the status quo for each of the qualitative criteria.

A) Commonality

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

Previous Weightings

Alternative's Commonality	Low BRU-55	Mean BRU-55	High BRU-55
Status Quo	7	7.33	8

Reasons behind the weightings:

The BRU-55 is a significant improvement over the status quo.

Final Weightings

Expert 1: 7
Expert 2: 8
Expert 3: 7

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

Previous Weightings

Alternative's Commonality	Low F-15 Wiring	Mean F-15E Wiring	High F-15E Wiring
Status Quo	1	1	1

Reasons behind the weightings:

Additional wiring is only an extension of the status quo.

Final Weighting

Expert 1: 1
Expert 2: 1
Expert 3: 1

B) Risk

BRU-55: A BRU-55 is a BRU-33A/A modified to multiplex a smart interface and is capable of carrying two 1,000 lb. smart bombs.

Previous Weighting

Alternative's Risk	Low BRU-55	Mean BRU-55	High BRU-55
Status Quo	1	2.67	6

Reasons behind the weightings:

The BRU-55 has low development risk; however, implementation risk is increased because of potential memory limitations from software requirements.

Final Weighting

Expert 1: 3
Expert 2: 6
Expert 3: 1

Additional Wiring: Additional wiring would extend the present method of supplying a smart interface to weapon stations to more weapon stations. Ten F-15E CFT stations without a smart interface are candidates for additional wiring.

Previous Weighting

Alternative's Risk	Low F-15E Wiring	Mean F-15E Wiring	High F-15E Wiring
Status Quo	1	1	1

Reasons behind the weightings:

The status quo and additional wiring are technically the same.

Final Weighting

Expert 1: 1
Expert 2: 1
Expert 3: 1

2. Comparison matrix for the relative importance of the qualitative criteria. Definitions and are provided below and the measurement scale is attached.

Previous Weighting

Criterion	Low Risk	Mean Risk	High Risk
Commonality	5	6.33	7

Reasons behind the weightings:

Commonality is important and risk is relatively low for either alternative.

Final Weighting

Expert 1: 6
Expert 2: 6
Expert 3: 6

3. Comparison matrix for the relative importance of the quantitative criteria. Definitions and the measurement scales are attached. The actual quantitative decision criteria values for each alternative as defined by mathematical relationship from related information.

Previous Weighting

Criterion	Low Add. Weapon	Mean Add. Weapon	High Add. Weapon
Cost/ Wpn Station	1/7	4.04	7

Reasons behind the weightings:

Low: The driving force in this decision is carrying 4 and not 2 weapons not the cost

High: Affordability drives program selection

Final Weighting

Expert 1: 7
Expert 2: 1/7
Expert 3: 5

4. Comparison matrix on the relative importance of quantitative and qualitative criteria.

The measurement scale is attached.

Previous Weighting

Criterion	Low Qual.	High Qual.	Final Weighting
Quantitative	5	5	5

Reasons behind the weightings:

Quantitative criteria are generally more important than qualitative criteria.

Final Weighting

Expert 1: 5
Expert 2: 5
Expert 3: 5

Conclusion

Thank you for your participation. Results will be consolidated into an AFIT thesis. Please provide a POC's address, and telephone and FAX numbers if you desire an executive summary of the results.

Appendix F. Acronym List

AC	Alternating Current
AHP	Analytical Hierarachy Process
CFT	Conformal Fuel Tank
COEA	Cost and Operational Effectiveness Analysis
CWS	Cost per weapon station
DC	Direct Current
DOD	Department of Defense
DSS	Decision Support System
EMC	Electromagnetic Compatibility
GPS	Global Positioning System
HAC	House of Representatives Appropriation Committee
INS	Inertial Navigation System
J-STARS	Joint Surveillance and Target Attack Radar System
JDAM	Joint Direct Attack Munition
JSOW	Joint Stand-Off Weapon
M	Million
MajCom	Major Command
MER	Multiple Ejection Rack
N	Number of aircraft for each type
N/A	Not Applicable
NPV	Net Present Value
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
SPO	System Program Office
TCAT	Total cost by aircraft type
w	Additional weapon carriage
WCMD	Wind Corrected Munition Dispenser

Appendix G. Cost Background

Definition of Terms

Software - cost of developing and testing operational flight program (OFP)
Hardware - cost to procure two BRU-55 for one half of applicable aircraft
Test - cost to perform system test and evaluation
Logistics - costs associated with data and support equipment
Other - costs associated with engineering change orders and mission support
Non-recurring - costs associated with system development and test
Recurring - costs associated with production of retrofit kits
Non-hardware - any cost not associated with BRU-55 hardware

F-16 Block 40 BRU-55

Area	Estimated Cost (in millions)	Methodology
Software	3	analogy to similar estimate
Hardware	38	one half 425 aircraft X (2)$88K
Test	1.5	analogy to similar estimate
Logistics	1	analogy to similar estimate
Other	2	Based on 5% rate other costs
Total	$45.5	

F-16 Block 50 BRU-55

Area	Estimated Cost (in millions)	Methodology
Software	5	analogy to similar estimate
Hardware	21	one half 230 aircraft X (2)$88K
Test	4	analogy to similar estimate
Logistics	2	analogy to similar estimate
Other	2	Based on 5% rate other costs
Total	$34	

F-15E BRU-55

Area	Estimated Cost (in millions)	Methodology
Software	6	analogy to similar estimate
Hardware	18	one half 205 aircraft X (2)$88K
Test	13	analogy to similar estimate
Logistics	2	analogy to similar estimate
Other	2	Based on 5% rate other costs
Total	$41	

F-15E Additional Wiring

Area	Estimated Cost (in millions)	Methodology
Non-recurring	31	review of contractor estimate
Recurring	12	review of contractor estimate
Total	$43	

F/A-18C/D BRU-55

F/A-18 costs are estimated from the low F-16 non-hardware costs and the high F-15E non-hardware costs. Additionally, F/A-18 hardware costs are based only on the $18,000 expected cost of the BRU-55 smart electronics, because the Navy already uses the BRU-33 on the F/A-18.

Area	Estimated Cost (in millions)	Methodology
Non-hardware	15	Average of F-16 and F-15E
Hardware	7.6	one half 168 aircraft X(5)$18K
Total	$22.6	

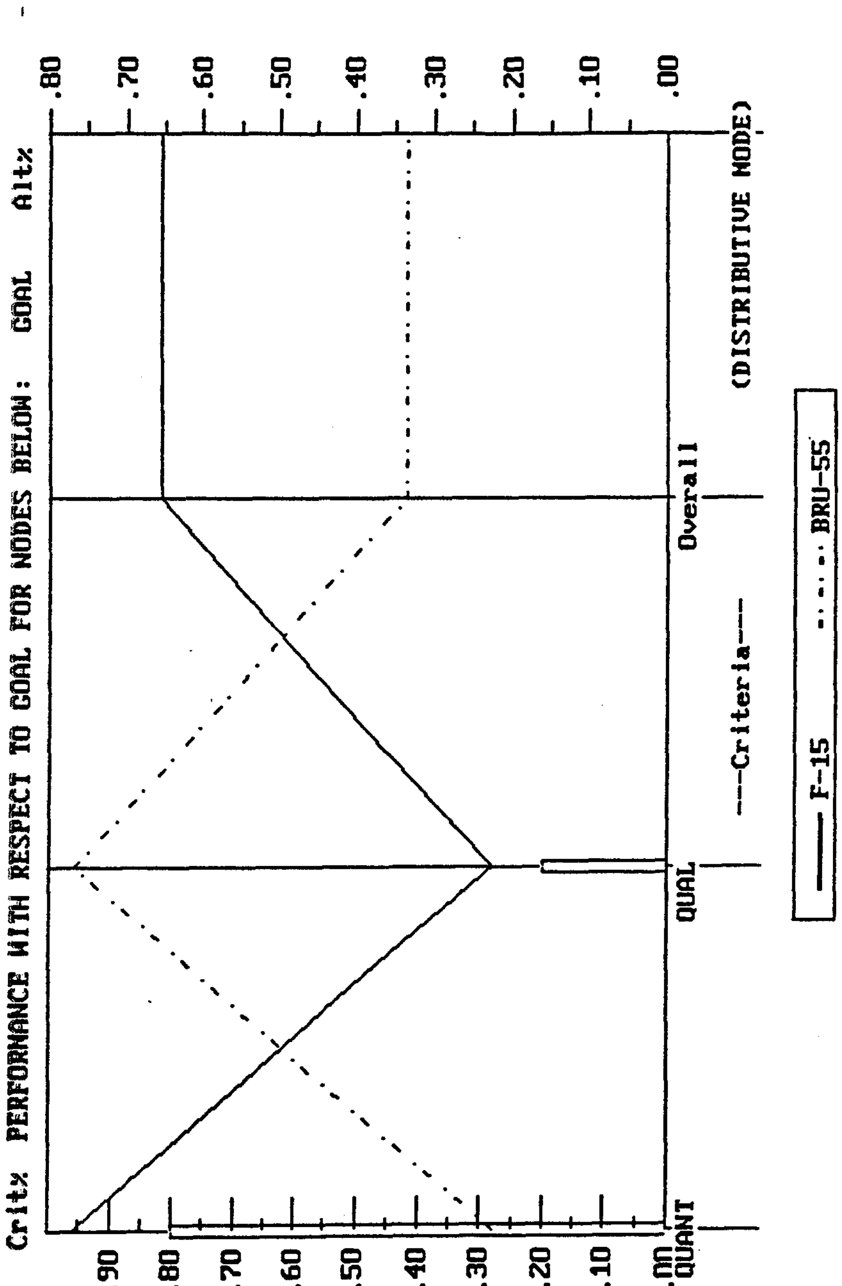
F/A-18E/F BRU-55

Area	Estimated Cost (in millions)	Methodology
Non-hardware	15	Average of F-16 and F-15E
Hardware	3.2	one half 72 aircraft X(5)$18K
Total	$18.2	

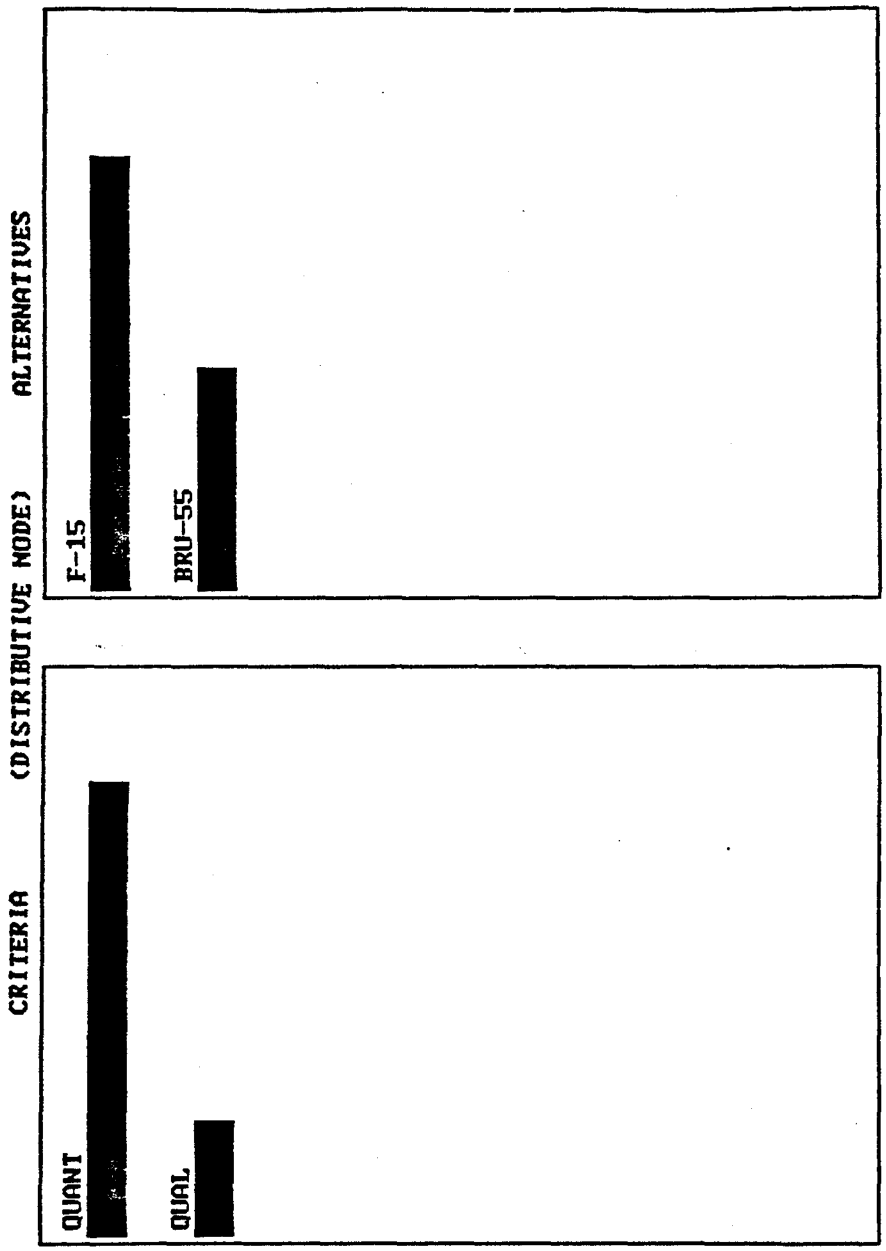
Appendix H. Expert Choice Output

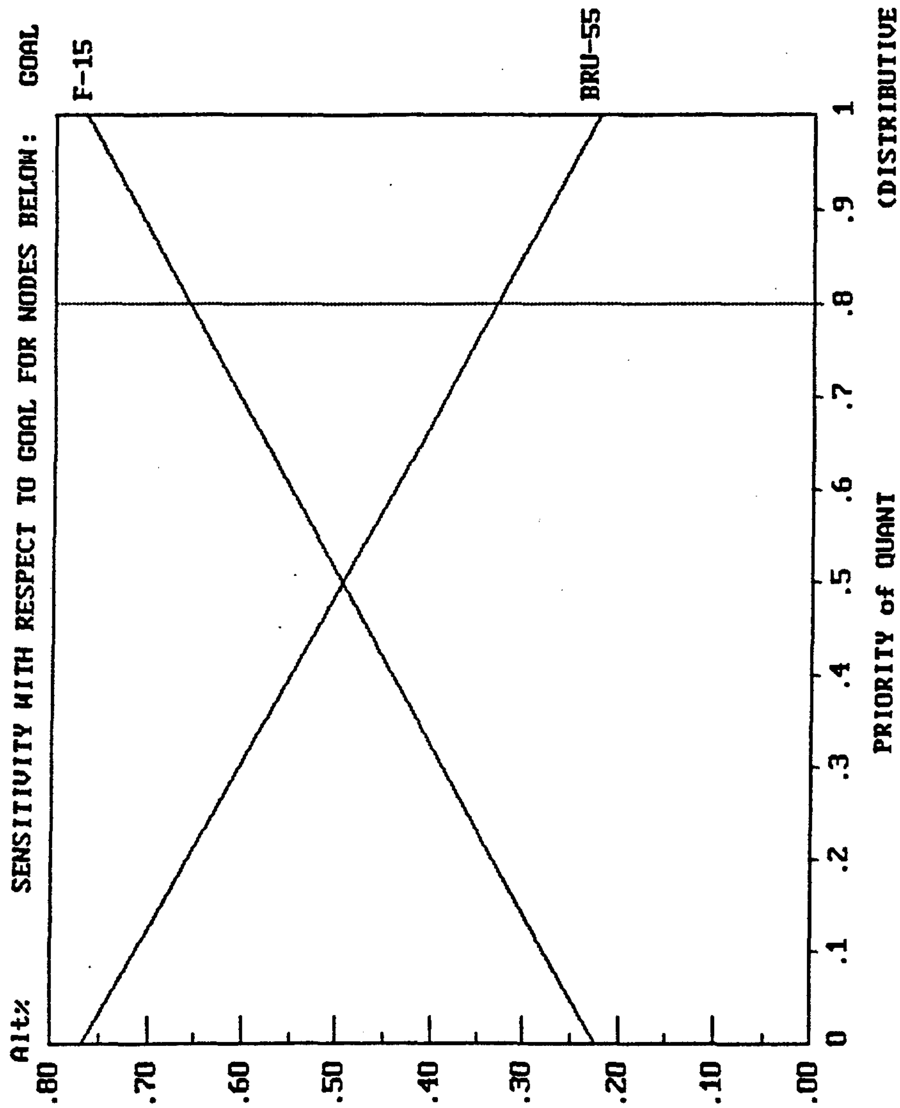
```
                                  best alternative
     Sorted Details for Synthesis of Leaf Nodes with respect to   GOAL
                                  DISTRIBUTIVE MODE

LEVEL 1           LEVEL 2            LEVEL 3             LEVEL 4        LEVEL 5
-------           -------            -------             -------        -------
QUANT    =0.800
.                 COST      =0.602
.                 .                  F-15     =0.515
.                 .                  BRU-55   =0.087
.                 AWCC      =0.198
.                 .                  F-15     =0.100
.                 .                  BRU-55   =0.097
QUAL     =0.200
.                 COMMONAL  =0.167
.                 .                  BRU-55   =0.144
.                 .                  F-15     =0.023
.                 RISK      =0.033
.                 .                  F-15     =0.023
.                 .                  BRU-55   =0.010
```



Crit%
PERFORMANCE WITH RESPECT TO GOAL FOR NODES BELOW: GOAL
Alt%
.90
.80
.70
.60
.50
.40
.30
.20
.10
.00
QUANT
QUAL
Overall
---Criteria---
(DISTRIBUTIVE MODE)
F-15
BRU-55


CRITERIA (DISTRIBUTIVE NODE) ALTERNATIVES
QUANT
QUAL
F-15
BRU-55


SENSITIVITY WITH RESPECT TO GOAL FOR NODES BELOW: GOAL
Alt%
.80
.70
.60
.50
.40
.30
.20
.10
.00
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1
PRIORITY of QUANT
(DISTRIBUTIVE NODE)
F-15
BRU-55

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Vita

Captain David R. King was born on 15 May, 1968, in Deadwood, South Dakota. He graduated from Snake River High School in Blackfoot, Idaho in 1986. In 1990, he graduated from the Air Force Academy in Colorado Springs, Colorado with a Bachelor of Science degree in Management and Behavioral Science. Upon graduation from the Air Force Academy, he was commissioned and served his first tour of duty at Wright-Patterson AFB, Ohio. He began as a Test Manager for the F-15 System Program Office where he directed the testing of air-to-ground weapons until October 1992. He was then given program management responsibilities for thirteen F-15E air-to-ground weapon acquisition programs. Some of the programs he managed included the JDAM, JSOW, and WCMD. His next assignment was to the Air Force Institute of Technology, in May 1994. After AFIT, Captain King will return to the F-15 System Program Office at Robins AFB, Georgia.

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This study examined potential alternatives and decision criteria for inclusion in a Cost and Operational Effectiveness Analysis to recommend an alternative for addressing existing DOD multi-role fighter capability to employ inertially guided smart bombs. A survey of literature and interviews with experts were used to collect required information. An Analytical Hierarchy Process (AHP) decision model was developed for two feasible alternatives and four relevant decision criteria with two each in quantitative and qualitative categories. Data on both the quantitative and qualitative decision criteria were collected to evaluate the alternatives. This study concluded that the F-15E additional wiring alternative is the recommended solution for addressing DOD multi-role fighter aircraft inertially guided smart bomb capability, and that acquisition decisions need to carefully consider all feasible alternatives. Additionally, the Air Force and DOD should consider formally adopting AHP and the software Expert Choice in analysis of multiple criteria decision making problems.

14. SUBJECT TERMS
Economic Analysis, Cost Models, Fighter Aircraft, Smart Weapons, Military Capabilities Airpower, Military Modernization, Defense Planning, Military Procurement, Delphi Techniques

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