NPS-PM-22-193

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Comparative Case Study: Expeditionary Fighting Vehicle and Amphibious Combat Vehicle

June 2022

Maj. Jordan J. Pierce, USMC

Thesis Advisors: Dr. Robert F. Mortlock, Professor
Dr. Deborah E. Gibbons, Associate Professor

Department of Defense Management

Naval Postgraduate School

The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

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ABSTRACT

The Marine Corps Expeditionary Fighting Vehicle (EFV) program cost taxpayers over $3 billion from inception to cancelation. The Amphibious Combat Vehicle (ACV) attempts to replace the Amphibious Assault Vehicle (AAV) and pick up where the EFV left off. A program comparison can be used to learn from previous management mistakes and prevent failures of this magnitude. By analyzing the two amphibious vehicle programs, I assess pertinent successes and failures against the model with available program management tools, including decision science principles. This report compares key junctures in both programs' life cycles and offers recommendations for future amphibious combat vehicle acquisition. The conclusion reveals that unbalanced cost and schedule increases overpowered the EFV performance goal, leading to cancelation. As a result, the ACV reveals less performance but at a lower cost in comparison. Through research, acquisition professionals can better understand the importance of oversight, find solutions, and effectively equip themselves to manage major defense weapon systems.

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ABOUT THE AUTHOR

Maj Jordan Pierce is an AH-1 and TH-57 helicopter instructor pilot. He was commissioned through the NROTC program at Purdue University, where he received his Bachelor of Science. After receiving his wings, he served with HMLA-367 "Scarface" at MCB Kaneohe Bay, HI and deployed twice on the 31st Marine Expeditionary Unit. His second tour was with HMLAT-303 "Atlas," instructing in the AH-1Z. He currently instructs Naval flight students aboard NAS Whiting Field in the TH-57 and serves as the Operations Officer for Marine Aviation Training Support Group 21. After graduation from the Naval Postgraduate School, he will be applying for an aviation acquisition duty station.

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ACKNOWLEDGMENTS

I would like to thank my NPS advisors, Dr. Mortlock and Dr. Gibbons. They provided me with expert guidance, insightful resources, and the latitude to explore this topic while on the distance learning journey. I am incredibly grateful for their time and advice.

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Prepared for the Naval Postgraduate School, Monterey, CA 93943.

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LIST OF ACRONYMS AND ABBREVIATIONS

A2/AD	Anti-Access/Area Denial
AAA	Advanced Amphibious Assault
AAF	Adaptive Acquisition Framework
AAV	Assault Amphibious Vehicle
AAAV	Advanced Amphibious Assault Vehicle
ACAT	Acquisition Category
ACV	Amphibious Combat Vehicle
ADM	Acquisition Decision Memorandum
AoA	Analysis of Alternatives
APB	Acquisition Program Baseline
APUC	Average Procurement Unit Cost
AVM	Adaptive Vehicle Make
CAPE	Cost Assessment and Program Evaluation
CBA	Capability Based Assessment
CDD	Capabilities Development Document
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CEE	Combat Essential Equipment
CE/D	Concept Exploration/Definition
CRS	Congressional Research Service
CMC	Commandant of the Marine Corps
CPAF	Cost-Plus Award Fee
CPFF	Cost-Plus Fixed Fee
DAE	Defense Acquisition Executive
DAG	Defense Acquisition Guidebook
DAMIR	Defense Acquisition Management Information Retrieval
DARPA	Defense Advanced Research Projects Agency
DAS	Defense Acquisition System
DOD	Department of Defense
DON	Department of the Navy

DoS	Days of Supply
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, Facilities, and Policy
DSS	DOD Decision Support System
EFV	Expeditionary Fighting Vehicle
EMD	Engineering and Manufacturing Development
EVMS	Earned Value Management System
FFRDC	Federally Funded Research and Development Center
FANG	Fast, Adaptable, Next-Generation Ground
FOC	Full Operational Capability
FoV	Family of Vehicles
FRP	Full-Rate Production
FPI	Fixed Price Incentive
GAO	Government Accountability Office
GDLS	General Dynamics, or General Dynamics Land Systems
HWS	High Water Speed
IDIQ	Indefinite Delivery Indefinite Quantity
IP	Intellectual Property
IPMR	Integrated Program Management Report
IOC	Initial Operational Capability
IOT&E	Initial Operational Test and Evaluation
JCIDS	Joint Capabilities Integration and Development System
JFEO	Joint Forcible Entry Operations
KP	Knowledge Point
KPP	Key Performance Parameters
KSA	Key System Attribute
LRIP	Low-Rate Initial Production
LRP	Low-Rate Production
LVA	Landing Vehicle, Assault
LVTP	Landing Vehicle, Tracked, Personnel
LVT(X)	Landing Vehicle Tracked (Experimental)
MEB	Marine Expeditionary Brigade
MCCDC	Marine Corps Combat Development Command

MCDP	Marine Corps Doctrinal Publication
MCPP	Marine Corps Planning Process
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MILCON	Military Construction
MOE	Measures of Effectiveness
MOP	Measures of Performance
MPC	Marine Personnel Carrier
MS	Milestone
MSA	Material Solutions Analysis
MTBOMF	Mean Time Between Operational Mission Failures
NBC	Nuclear, Biological, Chemical
NDAA	National Defense Authorization Act
NM	Nautical Miles
O&S	Operations and Sustainment
OA	Operational Assessment
ORM	Operational Risk Management
OTH	Over-the-Horizon
P&D	Production and Development
PAUC	Program Acquisition Unit Cost
PDRR	Program Definition and Risk Reduction Phase
PIIT	Platform Integration Information Table
PM	Program Manager
PMO	Program Management Office
PPBE	Planning, Programming, Budgeting, and Execution
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
RACI	Responsible, Accountable, Consulted, Informed
RFI	Request for Information
RFP	Request for Proposal
SAIC	Science Applications International Corporation
SASC	Senate Armed Services Committee
SDD	System Development and Demonstration

SECNAV	Secretary of the Navy
SLEP	Service Life Extension Program
STSC	Software Technology Support Center
SWH	Significant Wave Height
TMMR	Technology Maturation and Risk Reduction
TPM	Technical Performance Metric
UARC	University-Affiliated Research Center
USMC	United States Marine Corps

I. INTRODUCTION

A. MARINE CORPS' AMPHIBIOUS MISSION

The Marine Corps prides itself on upholding the title of America's expeditionary force-in-readiness. While expeditionary missions change with each conflict, the Corps remains flexible and strives to maintain an elevated level of readiness to respond quickly should one arise. Amphibious operations are one of the essential capabilities surrounding the Corps' expeditionary nature. Marine Corps Doctrinal Publication (MCDP) 3, *Expeditionary Operations*, states that "the capstone operating concept for Marine Corps expeditionary operations is *Operational Maneuver from the Sea*" (Department of the Navy [DON], 2018, p. 89). Since its inception, the ability to conduct ship to shore operations has defined the Corps. Through the passing of the National Security Act of 1947, Congress codified the amphibious mission and gave the Marine Corps discretion as to how to accomplish them:

> The United States Marine Corps, within the Department of the Navy, shall include land combat and service forces and such aviation as may be organic therein. The Marine Corps shall be organized, trained, and equipped to provide fleet marine forces of combined arms, together with supporting air components, for service with the fleet in *the seizure or defense of advanced naval bases* [emphasis added] and for the conduct of such land operations as may be essential to the prosecution of a naval campaign. It shall be the duty of the Marine Corps to develop, in coordination with the Army and the Air Force, those phases of *amphibious operations* [emphasis added] which pertain to the tactics, technique, and equipment employed by landing forces. In addition, the Marine Corps shall provide detachments and organizations for service on armed vessels of the Navy, shall provide security detachments for the protection of naval property at naval stations and bases, and shall perform such other duties as the President may direct: Provided, that such additional duties shall not detract from or interfere with the operations for which the Marine Corps is primarily organized. The Marine Corps shall be responsible, in accordance with integrated joint mobilization plans, for the expansion of peacetime components of the Marine Corps to meet the needs of war. (Marine Corps University [MCU], 2021)

Additionally, 10 U.S.C. § 5063 assigns the composition and functions of the Marine Corps, lawfully requiring that "the Marine Corps will be organized, trained and equipped to provide an amphibious and land operations capability to *seize advanced naval bases* and to conduct naval land campaigns" (MCU, 2021).

B. INTERPRETATION

The Marine Corps answers the call by continuing to procure and maintain a fleet of amphibious vehicles. The Corps upholds an extensive and expensive history of operating these vehicles in combat stemming from the Philippines, World War II, Vietnam, and Korea. Since 1971 the Marine Corps has employed the Assault Amphibious Vehicle (AAV), officially named the AAV-7A1. The amphibious nature of these vehicles creates costly operation and repair cycles. A 2020 report to Congress stated that "the AAV has become increasingly difficult to operate, maintain, and sustain … [its] *two-mile* ship-to-shore range is viewed by many as a significant survivability issue not only for the vehicle itself but also for naval amphibious forces" (Feickert, 2020, p. 2). Despite these facts, the Corps understands this capability as worth the risk. However, throughout the years, political, public, and military officials have shown opposition to certain aspects of Marine Corps doctrine and, consequently, the relevance of amphibious vehicles. For example, in 1957, Brigadier General Krulak wrote a letter to the Commandant of the Marine Corps (CMC), General Pate, stating that "the United States does not need a Marine Corps. However, for good reasons which completely transcend cold logic, the United States wants a Marine Corps" (Denny, 2021). In 2019, the current CMC, General Berger, released his planning guidance, citing the current threats facing the Corps:

> Visions of a massed naval armada *nine nautical miles* (NM) [emphasis added] offshore in the South China Sea preparing to launch the landing force in swarms of ACVs, LCUs, and LCACs are *impractical and unreasonable* [emphasis added]. We must accept the realities created by the proliferation of precision long-range fires, mines, and other smart-weapons and seek innovative ways to overcome those threat capabilities. (Berger, 2019, p. 5)

Despite political pressure and challenges associated with the AAV amphibious capability, the Marine Corps continues its lawful and historic mission. Amphibious requirements remain valid. Still, given billions in taxpayer-funded sunk costs surrounding Expeditionary Fighting Vehicle (EFV) development, the Marine Corps continues its Amphibious Combat Vehicle (ACV) pursuit. However, this acquisition effort coincides with radical force design measures within the Marine Corps, underscoring a warfighting shift regarding battlespace, equipment, and force projection. The intent of this research is to positively impact future amphibious combat vehicle acquisition efforts.

C. STAKEHOLDERS

The amphibious capability of the Marine Corps encompasses a variety of stakeholders, including the American taxpayers, Congress, the Joint Chiefs, Navy, and Marine Corps leaders, servicemembers, industry contractors (General Dynamics and BAE), and various research organizations such as the Government Accountability Office (GAO), Congressional Research Service (CRS), and oversight committees. The goals and objectives of each organization do not always align. Competing interests such as jobs, warfighting readiness, cost savings, interoperability, and safety play into the acquisition solution. This research does not focus on each stakeholder in-depth; instead, it correlates stakeholder interactions with program results.

D. SCOPE AND BENEFIT

This research is essential to avoid inefficiencies associated with actual waste and unsupported warfighters resulting from acquisition program cancelations. The report compares and contrasts both programs and observes program evidence of *advantages* and *disadvantages* in four areas: (1) mandatory requirements, (2) the DOD Decision Support System (DSS) model, (3) Program Management (PM) tools, and (4) decision science principles. Through comparative analysis, program management can better understand the impact of decisions. I analyze shifting key performance parameters (KPPs), program baselines, and harmonization with industry. The analysis follows the DOD Decision Support System (DSS) structure specific to the major capability acquisition pathway. Finally, I attempt to analyze organizational behavior through decision science principles. This aspect can enable program managers (PMs) to recognize paradigms and cognitive barriers which can negatively affect a program.

E. ANALYSIS TECHNIQUES

The research incorporates mostly open-source documents, including DOD guidebooks, reports, program submissions, and various books and articles. In addition, I conducted both hard copy and internet searches and accessed specific program data through the Defense Acquisition Management Information Retrieval (DAMIR) system. I use these sources throughout the literature review to establish analysis criteria relevant to the EFV and ACV comparison.

Of note, throughout the report, I am unable to prove causation. However, I show correlation and then make observations. This outside look does not contain all program information, nor does the intent support a fully comprehensive level of research. Too many variables exist inside and outside a PM’s control to analyze all risks to distinguish an absolute correct path forward. Similarly, variability with the programs does not support recommending a concrete prescriptive process, only suggestions.

F. RESEARCH QUESTION

1. How did the EFV and ACV programs compare concerning the following key defense acquisition areas: (1) mandatory requirements, (2) DOD Decision Support System (DSS) model, (3) Program Management (PM) tools, and (4) decision science principles.

This question can be answered in several ways, especially given the variety of mandatory requirements, tools, and specialties. Nevertheless, I acknowledge the volume and interconnectedness of the information. Next, Chapter II lays out each program’s historical background and timelines, leading to the literature review and analysis in Chapter III. Then in Chapter IV, I draw connections applicable to both programs.

II. PROGRAM BACKGROUNDS AND TIMELINES

The predecessor program to the EFV, the AAV, started in the early 1970s. In the late 1980s, the AAV reached the end of its service life and required updates. Thus, the *Advanced* Amphibious Assault Vehicle (AAAV) program was born. The EFV grew out of the AAAV program and continued until its cancelation in early 2011. The tools and processes used throughout this acquisition attempt spanned over 40 years, costing the taxpayer over $3 billion. In 2008, the House Oversight Committee summarized the program:

> The Marine Corps envisioned that the EFV would have a broader range and greater fighting capabilities than its predecessor. The new vehicle would be able to transport up to 18 combat-ready Marines at high speeds on both land and sea, have advanced communications capabilities, provide increased armored protection against rocket-propelled grenades and improvised explosive devices, and deliver lethal firepower up to 2,000 meters. (United States House of Representatives Committee on Oversight and Government Reform, Majority Staff [U.S. House], 2008, p. 1)

A. EXPEDITIONARY FIGHTING VEHICLE TIMELINE

The EFV timeline lists key dates, actions, and events throughout the program's life cycle, starting with predecessor vehicles through cancelation. The program never exited the System Development and Demonstration (SDD) phase to achieve a MS III decision. Overall, the program underwent four significant audits. Relatedly, the PMO re-baselined the program five separate times. Following the deficient performance of the last audit in 2008, canceling the program became a real possibility. Finally, in 2011, Secretary of Defense (SECDEF) Gates canceled the EFV. Table 1 reveals the critical decision points, milestones, and phases associated with the EFV program before cancelation.

Table 1. EFV Timeline

Year, Month	Action	Model Phase Milestone (MS)
1972	LVTP-7 (AAV) produced and introduced to the USMC. • AAV Initial Operational Capability (IOC). • Planned service life of ten years.	Predecessor
1982	LVTP-7 (AAV) Service Life Extension Program (SLEP) renamed the AAV-7A1.	Predecessor
1985	Landing Vehicle Tracked, Experimental (LVT[X]) low water speed vehicle program canceled.	Predecessor
1987	AAV ship-to-shore Mission Area Analysis.	Predecessor
1988	AAAV PMO start based upon Mission Needs Statement (MNS) in submission contained in 1988 POM.	CE/D (*MSA*) Pre-MS I (*A*)
1989	Landing Vehicle, Assault (LVA) high water speed (HWS) amphibian program canceled.	Predecessor
1990	General Dynamics Land Systems (GDLS) awarded AAAV contract, beating out BAE. • Only full and open competition held.	CD/V (*MSA*) Pre-MS II (*A*)
1995	Analysis of Alternatives (AoA) complete. • AAAV receives "model defense program" accolades.	
1995, Mar	Conceptual Acquisition Program Baseline (APB) signed; MS I decision.	MS I (*A*)
1995, Jun	General Dynamics (GDLS) Program Definition and Risk Reduction Phase (PDRR) award; official program start.	PDDR (*TMRR*) MS I (*A*)
1998, May	AAAV program awarded the David Packer Excellence in Acquisition Award for significant cost reductions.	
1996, Jun	AAAV program awards GDLS contract for development; again, considered a model acquisition program.	
2000	AAAV program awarded Defense Standardization Program award for medium caliber gun system.	
2000, Dec	Initial development APB established. • PDRR phase end. • SDD phase start. o Knowledge Point (KP) 1 benchmark. • 84% of drawings completed.	SDD 1 (*EMD 1*) MS II (*B*)
2001, Jan	Critical Design Review (CDR) conducted; one month after baseline APB established.	Mid-MS C decision point.
2001, Feb	AAAV program awards GDLS Cost-Plus Award Fee (CPAF) contract for $712 million; completion planned for October 2003 (contract definitized in July 2001).	
2002, Nov	USMC extends SDD phase and updates the AAAV program (APB Change 1).	SDD 2 (*EMD 2*) MS II (*B*)
2002, Dec	AAAV program audit by USMC and Air Force Software Technology Support Center (STSC) showed poor results.	First audit.

Year, Month	Action	Model Phase Milestone (MS)
	• Decision to accelerate development phase. • Test-fix-test approach. • Poor communication between government and contract officials.	
2003, Mar	USMC extends SDD phase and updates EFV program for a second time (APB Change 2), and renames the AAAV the EFV program.	SDD 3 (*EMD 3*) MS II (*B*)
2003, Oct	Original planned completion of first SDD phase (approximately 3 years).	
2004, Sep	Bow flap and hydraulics prototype failures. Survivability concerns surrounding IED threat.	
2004, Oct	Bow flap and hydraulics prototype failures.	
2004, Dec	Hull Electronics Unit (HEU) prototype failures.	
2005, Mar	USMC extends SDD phase and updates EFV program for the third time (APB Change 3).	SDD 4 (*EMD 4*) MS II (*B*)
2005, Dec	Nunn–McCurdy Breach (Significant). • Program Acquisition Unit Cost (PAUC) increase of 33.69%.	
2006	Operational Assessment (OA) showed poor results • Ambitious schedule showed EFV immaturity. • Poor reliability regarding Mean Time Between Operational Failures (MTBOF). • Completed only two of 14 mission profiles.	Second audit. MS C decision point.
2006, Sep	Original planned IOC from July 2001 SDD award.	
2006, Dec	EFV program audit by the Assistant Secretary of the Navy for Research, Development & Acquisition (OASN RD&A) showed poor results: • Inadequate SE processes. • Inadequate program management. • Poor reliability (MTBOF). EFV units reduced from 1,013 to 573. Nunn–McCurdy Act Breach (Critical): • PAUC increase of 112.90%. • Average Procurement Unit Cost (APUC) increase of 56.79%.	Third audit.
2007, Feb	Congress notified of the Nunn–McCurdy breach.	
2007, Feb	Navy announces it must relax EFV performance requirements. • Combat-loaded EFV unable to get on–plane.	
2007, Mar	USMC modifies the original SDD contract with GDLS to redesign the vehicle. • IOC pushed to 2015.	

Year, Month	Action	Model Phase Milestone (MS)
	• Full Operational Capability (FOC) pushed to 2025.	
2007, Jun	USMC decides to repeat the SDD process. New acquisition decision memorandum (ADM) and CPAF contract signed. • SDD phase completion updated to 2011 completion.	
2007, Aug	USMC officially rebaselines the EFV program and updates the program for the fourth time (APB Change 4) from the 1993 base year. • Known as SDD-2 in the DOD Earned Value Management–Central Repository (EVM-CR).	SDD 5 (*EMD 5*) MS II (*B*)
2007, Dec	USMC awards GDLS over $60 million in award fees to date.	
2008, Aug	USMC awards GDLS a second SDD contract for seven new prototypes.	
2008, Dec	CDR conducted for a second time. KP 1 achieved again: • 94% of system design models releasable. • Critical technologies are mature and stable. • KP 2 not achieved.	
2008	EFV program audit by the Defense Contract Management Agency (DCMA) showed poor results: • Poor program management, including oversight and adherence to the schedule. • Not using GAO EVMS best practices.	Fourth audit. Mid-MS C decision point.
2009, Apr	SECDEF Gates questions the EFV program and amphibious operations while addressing the Naval War College.	Cancelation decision point.
2009, Dec	DAMIR Selected Acquisition Report (SAR) reveals an in-process APB revision (SDD 6).	
2010, Mar	USMC estimates $185 million to terminate the EFV program.	Cancelation decision point.
2010, Jun	Congressional Sustainable Defense Task Force recommends canceling the EFV program.	Cancelation decision point.
2010, Aug	SECDEF Gates orders a review of the future role of the USMC.	Cancelation decision point.
2010, Oct	USMC admits EFV must show improved reliability testing, or they will consider cancelation.	Cancelation decision point.
2011, Jan	SECDEF cancels the EFV program based on recommendations from the Secretary of the Navy (SECNAV) and CMC. • SECNAV does not question the future amphibious assault mission.	Cancelation.

Year, Month	Action	Model Phase Milestone (MS)
	• GDLS recommends scaling back to 200 EFV units for $6 billion savings (not awarded). • USMC uses Fiscal Year (FY) 2010 and FY2011 money to cover termination costs. No FY2012 money requested.	
2011, Feb	USMC issues Requests for Information (RFIs) to industry for New Amphibious Vehicle (NAV) capability.	
2011, Nov	Second official planned completion date of the EFV SDD phase (approximately 8 years behind schedule).	

Adapted from Johnson (1998, p. 2-16), Adams (1999, p. 20, 22, 159), Bailey (2003, p. 46), DAMIR (2022), DOT&E (2001, p. IV-1–IV-4, 2006, p. 123–124, 2007, p. 119–120), EVM-CR (2022), Feickert (2011), GAO (2010a), U.S. House (2008).

B. AMPHIBIOUS COMBAT VEHICLE TIMELINE

Following the cancelation of the EFV, the DOD did not prioritize a Marine Corps amphibious vehicle at first, opting to push forward with a less capable Marine Personnel Carrier (MPC). The MPC was a previous Marine Corps armored personnel vehicle program with a reduced inland, *shore-to-shore*, waterway amphibious capability. In February 2011, the Marine Corps released multiple Requests for Information (RFIs) to industry, requesting a similar yet increased amphibious vehicle capability (Feickert, 2011, p. 9). Initially, this capability remained nameless. Fearing amphibious redundancy, the Marine Corps transitioned the MPC into the ACV. At the time, Gen Amos, CMC, stated that the Corps was “committed to fielding the ACV within 4 years” (Feickert, 2011, p. 9). This schedule proved ambitious from the start, even by modern-day standards.

Interestingly, the new proposed amphibious vehicle attempted to leverage the Defense Advanced Research Projects Agency’s (DARPA’s) Fast Adaptable Next-Generation Ground (FANG) vehicle competitions and initiatives, a part of the Adaptive Vehicle Make (AVM) portfolio. However, in 2014, DARPA AVM technologies transitioned oversight of this initiative to the DOD Manufacturing Technology (ManTech) and Digital Manufacturing and Design Innovation Institute (DMDII; Defense Advanced Research Projects Agency [DARPA], 2014). Eventually, DARPA canceled all future competitions and initiatives associated with FANG, which slowed the Corps’ amphibious capabilities initiatives. However, the Marine Corps did capitalize on existing amphibious knowledge and decided to push forward with the ACV based on a modified BAE–Iveco SuperAV design partnership. Like the EFV timeline, Table 2 lists key dates, actions, and events throughout the ACV's life cycle, which remains ongoing.

Table 2. ACV Timeline

Year, Month	Action	Model Phase Milestone (MS)
2011, Feb	USMC issued RFIs to industry for a New Amphibious Vehicle (NAV) capability.	Material Solution Analysis (MSA) Pre-MS A
2011, May	MPC PM transferred from PM Light Armored Vehicle (LAV) to PM Advanced Amphibious Assault (AAA). • USMC Program Executive Office (PEO) remains PEO Land Systems.	Predecessor program.
2011, Sep	"Cost Assessment and Program Evaluation (CAPE) presents five options for a new amphibious capability: 1. Continue the canceled EFV (about $18 million/unit). 2. Develop a new amphibious vehicle (NAV). 3. Develop a new land-mission-focused vehicle to be transported from ship to shore via another watercraft. 4. Make upgrades to the legacy AAVs to address identified gaps in the vehicle's survivability. 5. Make upgrades to the legacy AAVs to address other capability gaps such as water and land mobility, networking, and lethality" (GAO, 2012, p. 146) BAE–Iveco announces participation in the MPC program.	MSA decision point.
2011, Oct	MPC Initial Capabilities Document (ICD) completed.	Predecessor
2011, Nov	MPC AoA initiation. President Obama initiates the Pivot to the Pacific strategy.	Predecessor
2011, Dec	MPC ADM signed.	MS A (MPC) Predecessor
2012, Jun	MPC AoA complete. Validated requirements for: • Over-the-Horizon (OTH), self-deployable, survivable, amphibious vehicle. • HWS not addressed.	Predecessor
2013, Jan	USMC HWS study was initiated. DARPA begins FANG challenges.	Industry engagement.
2013, Mar	DOD begins budget cuts due to sequestration.	
2013, Jun	Previous USMC MPC program canceled due to budgetary pressures; focus moves towards: • ACV HWS requirement.	*Cancelation decision point.*

Year, Month	Action	Model Phase Milestone (MS)
	• Joint Light Tactical Vehicle (JLTV) options.	
2013, Jul	HWS ACV user workshop to determine tradeable capabilities.	Industry engagement.
2014, Jan	HWS study briefed to USMC leadership.	
2014, Feb	DARPA drops AVM portfolio to other DOD agencies.	
2014, Mar	USMC revives MPC amphibious capability with new ACV program. • ACV 1.1 wheeled variant (204 vehicles). • ACV 1.2 tracked variant (470 vehicles). • ACV 2.0 HWS-capable variant (unit number unknown).	Technology Maturation and Risk Reduction (TMMR) MS A decision.
2014, Mar	ACV 1.1 draft request for proposal (RFP) released to industry. Original competition included five contractors: • Lockheed Martin, BAE Systems, GDLS, Science Applications International Corporation (SAIC), and Advanced Defense Vehicle Systems.	
2014, Nov	ACV 1.1 updated draft RFP released to industry.	
2015, Mar	Capability development document (CDD) version 5.0 approved by the JROC. ACV 1.1 final RFP released to industry.	
2015, Aug	Office of Naval Research (ONR) held a Focus Area Forum: Expeditionary and Irregular Warfare for Amphibious High–Water Speed Challenge. • HWS problem posed to industry (ACV 2.0).	Industry engagement.
2015, Nov	USMC down-selects two contractors to build 16 prototypes each for testing. Contract awards: • BAE, $103.8 million. • SAIC, $121.5 million.	EMD MS B decision.
2015, Dec	GDLS protests award.	Industry protest.
2016, Mar	GAO denies GDLS's protest.	Industry protest.
2016, May	Development APB signed.	
2016, Jul	MDA signs Preliminary Design Review (PDR) and CDR.	
2017, Mar	Engineering and Manufacturing Development (EMD) testing begins.	
2017, Dec	USMC final down-selects; RFPs sent to BAE and SAIC.	
2018, Jan	OA conducted to inform selection.	MS C decision-point.
2018, Apr	GAO annual report provides recommendations to USMC: • Not enter LRIP until MRL of 8. • Not enter FRP until MRL of 9. USMC chose to proceed and mitigate the risk.	

Year, Month	Action	Model Phase Milestone (MS)
2018, Jun	MDA signs ADM commencing ACV 1.1 LRIP: • USMC selects BAE–Iveco Defense Vehicles to produce 30 ACV-Ps, $198 million award. • USMC cancels the AAV SLEP upgrade.	Production and Development (P&D) MS C decision.
2018, Dec	Director, Operational Test and Evaluation (DOT&E) annual report notes low reliability (27% of planned growth), specifically with suspension and steering.	
2019, Apr	Following USMC testimony at the Senate Armed Service Committee (SASC), ACV 1.1 and 1.2 increments are combined into a single ACV variant to replace all AAVs. • USMC cites satisfactory water mobility and that ACV 1.1 meets 1.2 requirements.	Increment combination. MS C decision point.
2019, Oct	ACV LRIP lot awarded 30 ACV-Cs, $119.9 million award.	P&D
2019, Jun	BAE contract modification for future variants: • ACV-C and ACV-30 development, +$67 million.	
2020, Mar	USMC announces force design 2030 initiatives, including: • Reducing amphibious vehicle companies from six to four.	FRPD decision point.
2020, Aug	AAV sinks off San Clemente Island, CA: • Seven Marines and one Sailor killed. • USMC temporarily suspends AAV deployments and water-borne missions.	FRPD decision point.
2020, Nov–Dec	ACV 1.1 reaches IOC (APB Change 1): • Costs increase. • Unit quantities increase (204 to 632). ACV 1.1 FRPD: • BAE to produce 36 ACV-P vehicles, for $184 million. • Projected to grow to 72 vehicles in early 2021 and then 80 annually for 5 years (472 total).	P&D, Operations and Sustainment (O&S)
2021, Jan	BAE IDIQ support contract, $77M.	
2021, Feb	BAE contract option exercised: • +36 ACV-Ps, $184 million (72 total).	
2021, Sep	USMC suspends ACV water-borne operations due to towing mechanism problem.	FOC decision point.
2021, Dec	USMC permanently suspends AAVs from water-borne missions.	FOC decision point.
2021, Dec	BAE second lot contract modification: • Additional +33 ACV vehicles, $169.3 million.	

Year, Month	Action	Model Phase Milestone (MS)
2025	Tentative USMC ACV 2.0 HWS decision point.	New MS A decision point.

Adapted from Burrow (2014b, p. 2), DARPA (2011, p. 11, 2014), Eckstein (2014, 2015, 2019), GAO (2012, 2022), Feickert (2020, 2021), Freedberg Jr. (2014b), GAO (2012, p. 146), Judson (2020), Lee (2019), Mullins (2019), Sicard (2014), Srivastava (2019), Trevithick (2018), USMC (2012, 2014), DAMIR (2022).

After reviewing the timeline, one sees the tumultuous amphibious landscape of Marine Corps acquisition. The AAV, which has been in service for 50 years, was only planned to have a service life of 10 years (Adams, p. 20, 1999). Therefore, it's taken the Marine Corps through one canceled low water speed vehicle (LVT[X]), two HWS vehicles (LVA, EFV), and over 40 years to field the low water speed ACV. Overall, the attempted EFV acquisition lasted 23 years. The ACV captures 8 years to date, not including MPC years. Next, Chapter III includes the literature review to identify those criteria for analysis.

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III. LITERATURE REVIEW AND CRITERIA SELECTION

Chapter III looks at the three distinct sections of the decision support systems (DSS) to determine specific criteria for comparing the EFV and ACV programs. Again, I consider only a portion of the acquisition environment when choosing criteria for analyzing the program's *advantage* or *disadvantage.*

A. MANDATORY REQUIREMENTS

In this section, I chose to review four critical areas where the programs differed: (1) the Acquisition Program Baseline (APB), (2) the Selected Acquisition Report (SAR), (3) the Nunn-McCurdy Act and associated breaches, and (4) market research.

When enacted by the legislature, statutes are laws that must be adhered to while procuring government military equipment. These laws are the highest mandated guidelines government decision-makers must follow. Without these boundaries, the acquisition system remains open to cost overruns and undue influence. Similarly, regulations, or established rules, also govern DOD acquisitions. Both statutes and regulations help drive program expectations from inception to retirement by setting overarching constraints.

DOD Instruction (DODI) 5000.85 categorizes the EFV and ACV programs as acquisition category (ACAT) I programs based on their dollar value. Specifically, ACAT ID for the EFV and ACAT IC for the ACV. Figure 1 details the dollar thresholds associated with each ACAT I program.

ACAT	Reason for ACAT Designation	Decision Authority

ACAT I	• MDAP[1] (Section 2430 of Title 10, U.S.C.)
	  ○ Dollar value for all increments of the program: estimated by the DAE to require an eventual total expenditure for research, development, and test and evaluation of more than $525 million in Fiscal Year (FY) 2020 constant dollars or, for procurement, of more than $3.065 billion in FY 2020 constant dollars
	  ○ MDA designation
	• MDA designation as special interest[3]
		ACAT ID: DAE
		ACAT IB: SAE[2]
		ACAT IC: Head of the DoD Component or, if delegated, the CAE

Figure 1. ACAT I Description and Decision Authorities. Source: Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD[A&S], 2021).

The lettered "D" distinction after the "I" gives Milestone Decision Authority (MDA) to the Defense Acquisition Executive (DAE), while "C" enables the component to decide. The *U.S. Code* (U.S.C.) currently mandates 54 conditions for ACAT ID and IC programs, not including service-specific requirements. This research does not account for every statute and regulation, only those I found significant to decision-makers within the EFV and ACV programs. Table 3 details an overview of each program. The DOD classifies both programs as Major Defense Acquisition Programs (MDAPs).

Table 3. EFV and ACV Family of Vehicles (FoV) Program Overview. Adapted from Defense Acquisition Visibility Environment (DAVE 2022a, 2022b).

Short Name	Lead Component	PEO	Acquisition Status	Acquisition Type	ACAT	Program Number
EFV	Navy	N/A	Terminated	MDAP	ID	515
ACV FoV	Navy	PEO LS	Active	MDAP	IC	472

1. Acquisition Program Baseline Data

The PM operating concept involves operating within the triple constraint of cost, schedule, and performance, which form the basis for the APB. Therefore, the APB reflects the PM's goals (Defense Acquisition University [DAU], 2013, p. 13). Since 1988, U.S.C. has mandated APBs, which allow the PMO to monitor and react to a program's constraints while documenting breaches. A RAND conducted in 1997 concluded that "the APB process provides acquisition decision-makers with a necessary management tool for reviewing programs and documenting changes as events occur. It is difficult to use the frequency of baseline breaches or duration of those breaches as measures of overall DOD acquisition program success" (Drezner & Krop, 1997, p. 59). Therefore, although I assess the number of APBs produced within a program, I use it to gauge transformation within the program related to uncertainty and complexity instead of focusing merely on baseline breaches. RAND continues, stating that "each program has unique characteristics, both in terms of technology and the political and economic aspects of the acquisition process, and these characteristics are the real determinants of program performance" (Drezner & Krop, 1997, p. 60). These determinants will be analyzed in the PM tools section. Again, APB submissions point toward a potential for increased complexity, poor communication, or poor organization within a program. In a 1997 study, RAND conducted a "rough estimate" and found that approximately 56% of the factors affecting a program are within DOD's control (Drezner & Krop, p. 62). Of that 56%, 16% of those factors relate to internal DOD restructuring efforts associated with the program rebaseline, or APB (Drezner & Krop, 1997, p. 63). Therefore, approximately 28% (16/56) of the program factors under DOD control relate to restructuring efforts, highlighting the significance of the APB. The APB data of both programs will be gauged for overall change and its effect.

2. Selected Acquisition Report Data

Like APBs, Selected Acquisition Reports (SARs) provide decision-makers with essential program information during the life cycle. PMs submit SARs annually and include current program data and progress updates. Primarily, SARs report the current program status, archive the length of the program, and annotate the PM of the program at the time. In addition, SARs highlight shifting requirements over time, reveal APB breaches, and point toward leadership turnover, which can all contribute to levels of uncertainty.

3. Nunn-McCurdy Breaches

In terms of the triple constraint, cost determines the program's category (ACAT). Based on the DOD Authorization Act of 1983, Congress mandated DOD to report cost overruns of certain thresholds (Schwartz, 2010, Summary). In this regard, SARs indicate if a program is approaching a potential Nunn–McCurdy breach. Two Nunn–McCurdy breaches can occur, significant or critical. A significant breach occurs when the larger PAUC or APUC exceeds 15% over the *current* baseline estimate or 30% over the *original* baseline estimate. A critical breach occurs when the cost increases 25% or more over the *current* baseline estimate or *50%* over the *original* baseline estimate (Schwartz & O'Connor, 2016, Summary).

> Of note, APUC refers only to the total procurement cost divided by the number of units procured. PAUC is a greater number accounting for the total cost of procurement, including Research, Development, Test and Evaluation (RDT&E), Military Construction (MILCON), and Operations

and Sustainment (O&S) monies divided by the number of units procured. (Schwartz & O'Connor, 2016, Summary)

Therefore, I look to find the number of Nunn–McCurdy breaches, which point towards complexity. The report does not analyze pre-award negotiations concerning cost. I only attempt to analyze decisions post-award dollar figures.

4. Market Research

In addition to the APB and SAR data, I analyze market research dictated by Federal Acquisition Regulations (FAR) Part 10. Both government and open sources enable me to determine if the service conducted studies or held industry days and workshops before program initiation. Table 4 summarizes four vital areas that I analyze based on established mandatory requirements. Of note, many more standards are placed upon the PMOs; therefore, these criteria do not capture the entire statutory and regulatory spectrum.

Table 4. EFV/ACV Analysis Criteria: Mandatory Management Requirements

	COMPARISON	
Mandatory Requirements	**EFV**	**ACV**
Acquisition Program Baseline Data Change	*TBD*	*TBD*
Selected Acquisition Report Change	*TBD*	*TBD*
Nunn-McCurdy Breaches	*TBD*	*TBD*
Level of Market Research and Effect on Program	*TBD*	*TBD*

Applicable Statutes: 10 U.S.C. § 2435, Baseline Description, 10 U.S.C. § 2220, Performance-Based Management Acquisitions, 10 U.S.C. § 2432, Selected Acquisition Reports (SARs), 10 U.S.C. § 2433, Nunn–McCurdy Act, 10 U.S.C. § 2374a, Prizes for Advanced Technology Achievements. Applicable Regulation: FAR Part 10, Market Research.

B. DOD DECISION SUPPORT SYSTEM

Currently, acquisition professionals work within a decision support system (DSS) that combines Joint Capability Integration and Development System (JCDIS), Planning, Programming, Budget, and Execution (PPBE), and the Defense Acquisition System (DAS; Advisory Panel on Streamlining and Codifying Acquisition Regulations, 2019). When combined, these subsystems form "Big A" acquisition. Each subsystem, however, is complex, each using unique information, sources, and metrics while working in unison.

Leaders must operate objectively and subjectively within each subsystem due to differences in their environments, statutes, rules, norms, and behaviors. Figure 2 reveals the interconnectedness within the "Big A" acquisition system.

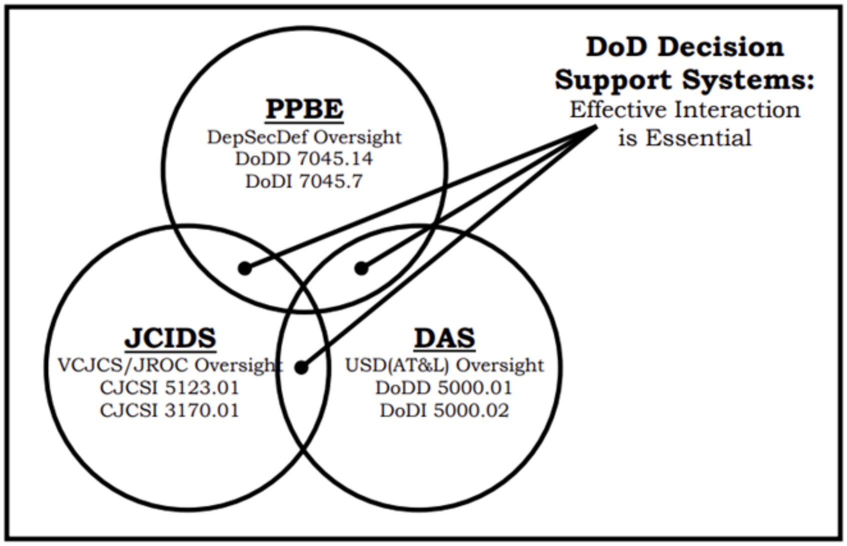

Figure 2. DSS Critical Interacting Processes. Source: Chairman of the Joint Chiefs of Staff [CJCS] (2012a, p. A-5).

1. Joint Capabilities Integration and Development System

The EFV program started as the AAAV program in 1988. Since then, the Joint Capabilities Integration and Development System (JCIDS), the DOD's requirements validation process, has transformed. JCIDS includes various activities, reviews, boards, and functions. Figure 3 illustrates a 2018 JCIDS view chart with different process interactions and competing priorities at work. The figure incorporates the two remaining "Big A" elements and highlights six additional requirements areas.

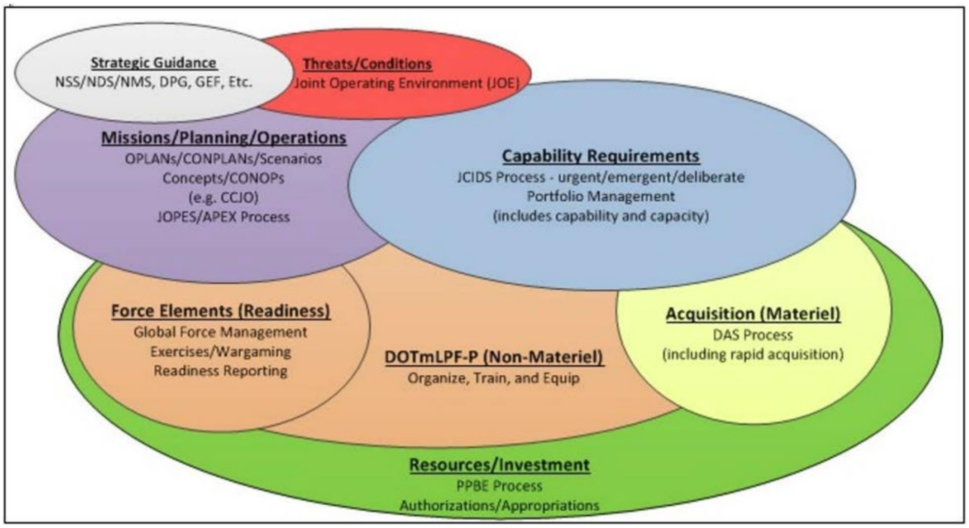

Figure 3. JCIDS Process Interactions. Source: CJCS (2018, p. D-4).

In the most current 2021 JCIDS publication, the capability-mission analysis highlights the unique and ever-growing set of interrelated tasks. These tasks span multiple processes, dependencies, and stakeholders (see Figure 4).

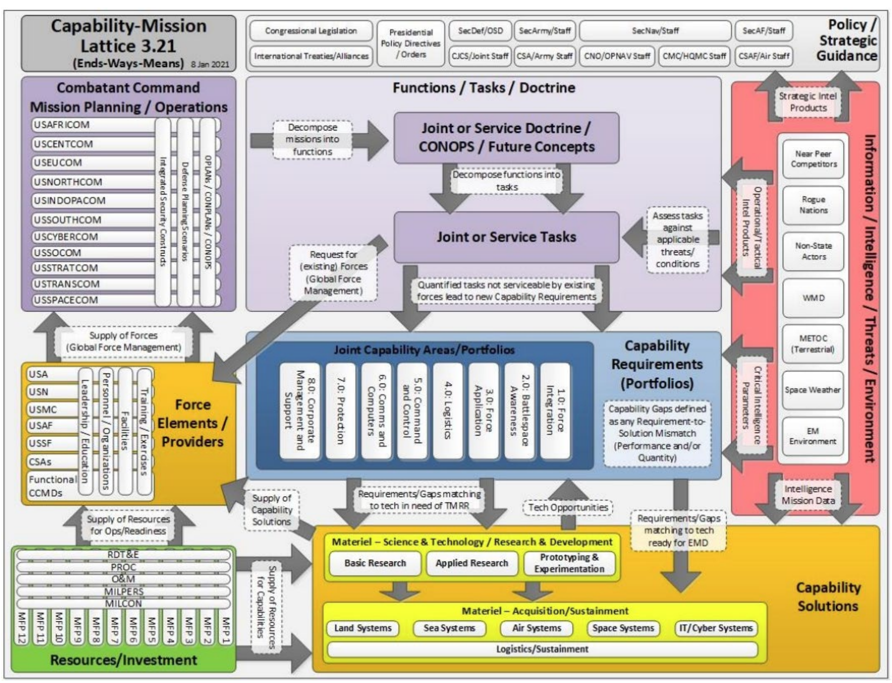

Figure 4. JCIDS Capability-Mission Lattice. Source: CJCS (2021, p. C-5).

Figures 3 and 4 show how extensive the JCIDS process can be when determining requirements. During deliberation, the Joint Requirements Oversight Council (JROC) validates the requirements for the PM to include them in the APB as KPPs. This research compares and analyzes EFV and ACV requirements, including all changes contained in various APB changes. Additionally, as depicted in the gray circle in Figure 3, national strategic guidance flows-down into requirements, which can cause uncertainty and impact program performance. As such, I analyze the number of changes to high-level guiding documents, such as the National Defense Strategy (NDS), during each life cycle. Table 5 summarizes these criteria, highlighting a level of uncertainty within the programs.

Table 5. EFV/ACV Analysis Criteria: Joint Capability Integration and Development System

DOD Decision Support System	**COMPARISON**	
Joint Capability Integration and Development System	**EFV**	**ACV**
Effect of Changes in Key Performance Parameters	*TBD*	*TBD*
Effect of Changes in Strategic Guidance	*TBD*	*TBD*

2. Defense Acquisition System: "Little A" Acquisition

The EFV program began under the precursor to the current DODI 5000.02. However, it is important to note that the AAAV/EFV ACAT ID managers used a life cycle consisting of different milestones. For example, as shown in Figure 5, the earlier flow consisted of MS 0 (mission needs determination), I (concept selection and results), II (full-scale development approval), III (full-rate production approval), IV (logistics readiness and support), and V (major upgrade or system replacement; Office of Technology Assessment [OTA], 1990b, p. 55-57). Today, the ACV adheres to the current DODI 5000.85 and its three associated milestones: A, B, and C (Office of the Under Secretary of Defense for Acquisition and Sustainment [OUSD(A&S)], 2021, p. 12-18).

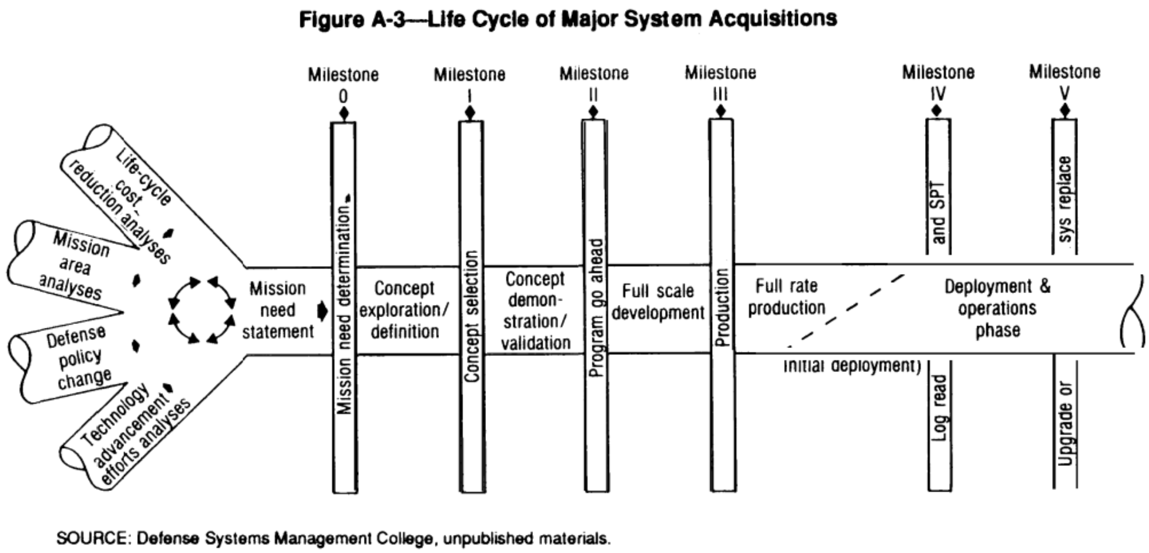

Figure 5. Historical Life cycle of Major System Acquisitions. Source: OTA (1990a, p. 14).

The EFV acquisition phases overlapped with its milestones, consisting of concept exploration/definition (CE/D), concept demonstration/validation (CD/V), full-scale development, full-rate production, and deployment and operations (General Accounting Office, 1982, p. 3). Currently, the ACV program adheres to the updated DOD phases: MSA, TMMR, EMD, P&D, and O&S (DAU, 2020). Figure 6 merges both milestones and phases. Importantly, each major capability acquisition must meet specific exit criteria before attaining a milestone benchmark. Figure 7 details the distinct decision points (in yellow) within a program life cycle.

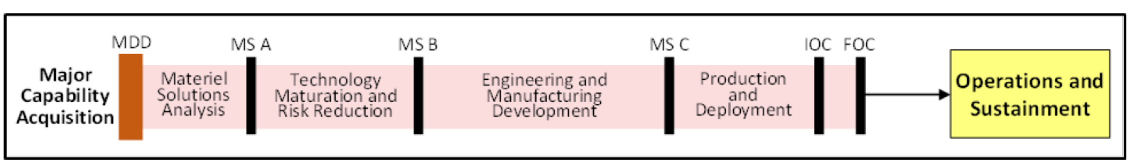

Figure 6. Major Capability Acquisition Pathway. Source: OUSD (A&S, 2020, p. 13).

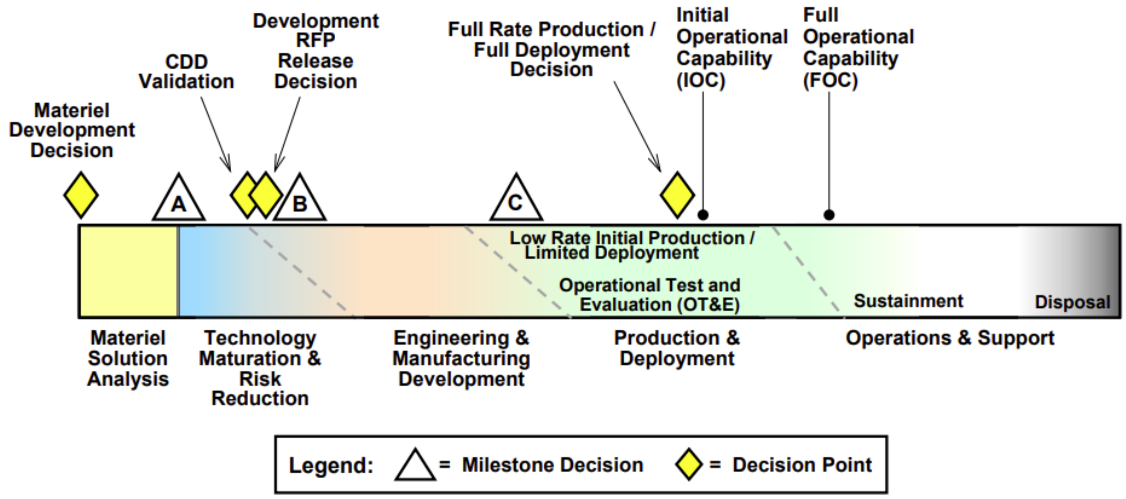

Figure 7. Major Capability Acquisition Model. Source: OUSD (A&S, 2021, p. 10).

Before the ACV program started, some critics viewed the defense acquisition system as flawed, including the DOD itself (Erwin, 2010). In response, the DOD implemented the Operation of the Adaptive Acquisition Framework (AAF) on January 23, 2020. The goal was to provide more flexibility to PMs. Neither the EFV nor the ACV programs started under the new framework.

I analyze both programs' schedule history concerning their major capability acquisition approach. Missed schedules are commonly detrimental to a program and drive-up total cost. Similarly, if costs increase, the quantity of units tends to decrease as an offset, reducing warfighter performance in the field. Therefore, I analyze each program's historical cost data in conjunction with its schedule data. Both programs adhere to the major capability pathway, and the ACV PMO utilized an *incremental approach* when developing different variants. This approach is analyzed to determine the impact on overall performance. Table 6 summarizes these criteria.

Table 6. EFV/ACV Analysis Criteria: Defense Acquisition System

DOD Decision Support System	**COMPARISON**	
Defense Acquisition System: Little "A"	**EFV**	**ACV**
Acquisition Approach	*TBD*	*TBD*
Schedule Change	*TBD*	*TBD*
Change to the Number of Units	*TBD*	*TBD*

3. Planning, Programming, Budgeting, and Execution

PPBE process resources and funds all DOD programs. This report looks at the PPBE model through an execution lens only. I did not access past programming objective memorandum (POM) documentation outside the APB submissions. This report focuses on executed dollars within the EFV and ACV programs.

Since the EFV program began in 1988, there has been a gradual increase in government regulations through the DODI 5000.02 implementation. Since then, professionals have understood the link between increased costs and regulation. Figure 8 represents a 1990 depiction of where regulation correlates to cost. Since then, costs and regulations have increased even more. It is unclear how the increase affects the current PPBE model. However, Congress does recognize inefficiencies. Still, both programs remain under the PPBE model, beholden to cost regulation.

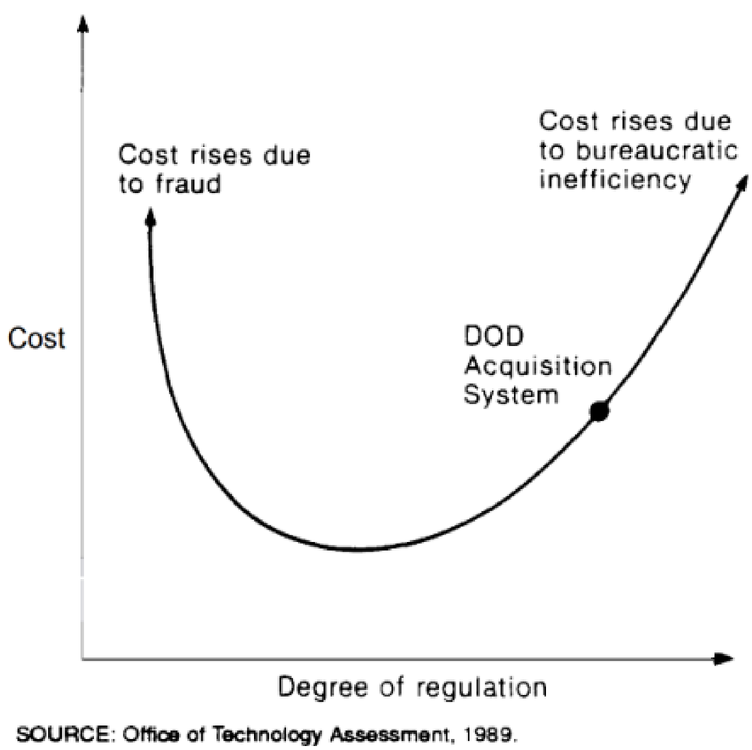

Figure 8. Cost Versus Regulatory Intensity. Source: OTA (1990a, p. 35).

The recently signed 2022 National Defense Authorization Act (NDAA) contains a provision to create a commission on PPBE. This commission, the Section 1004 Panel, could greatly affect the future variants of the ACV family of vehicles (FoV). However, like the previous Section 809 Panel, the DOD might extend these reforms. Until then, PMs must remain flexible and use all available tools to make resource trade-offs. Dr. Spencer Brien, Naval Postgraduate School, presented a 2021 template to characterize four common cost trades or alternatives, known as the 4 Rs, typically used by PMs: *resourcing* priority programs, *restructuring*, *reengineering*, and underfunding and accepting the *risk*. These alternatives help explain the extremely complex PPBE process regarding program resourcing. I searched the programs for instances of these trades to try and compare and understand how each PM decided to manage cost-associated risks (see Table 7).

Table 7. EFV/ACV Analysis Criteria: Planning, Programming, Budgeting, and Execution

DOD Decision Support System	COMPARISON	
Planning, Programming, Budgeting, Execution	**EFV**	**ACV**
Price per Copy (APUC)	*TBD*	*TBD*
Cost Trade-off Decisions	*TBD*	*TBD*

C. PROGRAM MANAGEMENT TOOLS

1. Knowledge-Based Acquisition Model

Knowledge-based acquisition (KBA) strives to inform decision-makers throughout a program's life cycle, incorporating sequential triggers to advance the program through the phases. For example, managers withhold milestone gates until they collect sufficient appropriate data or knowledge to justify entry or exit decisions in the life cycle. In 2004, the GAO helped PMs with this process and released a knowledge-based best practices study where they pointed to three critical junctures, or knowledge points "at which firms must have the knowledge to make large investment decisions" (GAO, 2004, p. 3). Simplified, these knowledge points are:

- **Knowledge Point 1 (KP1)**: Resources and needs match.
- **Knowledge Point 2 (KP2)**: Product design is stable.
- **Knowledge Point 3 (KP3)**: Production processes are mature.

The GAO aligns the KPs to the major capability milestone and decision points, precisely: MS B and preliminary design review (PDR), mid-MS B and the critical design review (CDR), and finally, MS C and low-rate initial production (LRIP, see Figure 9). However, I found that, unfortunately, "DOD programs continue to not fully implement knowledge-based acquisition practices" (GAO, 2018, p. 35).

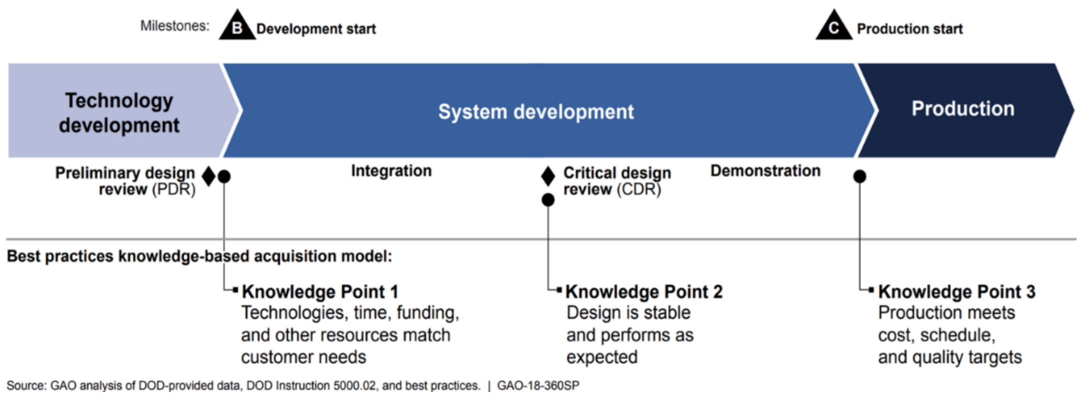

Figure 9. Defense Acquisition Cycle and GAO-Identified Knowledge Points. Source: GAO (2018, p. 6).

To understand KBA further, the DOD DSS can be likened to a computer system consisting of inputs and outputs. Using this comparison, the *Handbook of Human-Computer Interaction* describes a knowledge-based system, stating,

> Traditionally, such systems have been realized as goal-driven, *rule-based systems* [emphasis added], where the dialogue with the end-user is generated during the process of collecting enough information to allow a conclusion to be drawn from *relevant rules in the knowledge base* [emphasis added]. With this approach, the system has the initiative, and the user is asked to provide additional information whenever needed. (Helander et al., 1997, p. 1162)

Using this analogy, I view the DOD DSS as a *rule-based paradigm.* Figure 9 reveals how knowledge translates into milestones within this framework, assisting the paradigm. However, it does require that one adheres to and applies the KP metrics. In this sense, the rational "Big A" model remains subordinate and dependent upon knowledge. Still, humans are incapable of complete understanding and cannot rely solely on systems for decision-making. Individuals are critical in how they manage knowledge requirements. Using the computer system analogy, the handbook cautions that

> Users may all too easily accept the systems' recommendation without considering the reliability of expert advice. Such a dependence would lead to errors in decisions because it is difficult for both the system and the user

> to keep track of the limits and applicability of the system knowledge. (Helander et al., 1997, p. 1162)

Although the system may entail vast program knowledge, individuals can use KP metrics to scope their understanding.

Regarding the organization and contractors, levels of trust vary, unfortunately. Trust within an organization dramatically affects the value management places on the knowledge or information. In 2005, Project Air Force enlisted the RAND Corporation to determine the *Implications of Modern Decision Science for Military Decision-Support Systems* (Davis et al., 2005). The study states that decision-makers should strive to have the "correct level of trust in [their] decision aids" (Davis et al., 2005, p. 84). The GAO endorses KBA as a trustworthy aid; however, the people remain the unknown. RAND helps by delivering a framework to connect trust and knowledge, "(1) appropriate trust–information is good, and the user trusts it, (2) false trust–information is poor, and the user trusts it, (3) false distrust–information is good, and the user distrusts it, and (4) appropriate distrust–information is poor, and the user distrusts it" (Davis et al., 2005, p. 84). When considering trust within each program, Robbins and Judge state that "we come to trust people by observing their behavior over a period of time. To help, leaders need to demonstrate integrity, benevolence, and ability in situations where trust is important—say, where they could behave opportunistically or let employees down" (2018, p. 202).

In addition to KP adherence, I gauge trust based on trends in government reports (APBs, SARs) and open-source characterizations. Robbins and Judge found that trust (1) encourages taking risks, (2) facilitates information sharing (KBA relationship), (3) creates more effective groups, and (4) enhances productivity (2018, p. 201). Finally, I analyze the program's decision paradigms to determine if they properly scope the attainment of knowledge. Table 8 summarizes my knowledge-based criteria.

Table 8. EFV/ACV Analysis Criteria: Knowledge-Based Acquisition

Program Management Tools	**COMPARISON**	
Knowledge-Based Acquisition	**EFV**	**ACV**
Adherence to Knowledge Points	*TBD*	*TBD*
Evidence of Program Trust	*TBD*	*TBD*
Decision Paradigm: Scope of Knowledge	*TBD*	*TBD*

2. Systems Engineering

Systems Engineering (SE) certainly did not arise after the EFV program. One system engineer, Eberhart Rechtin, provided valuable insight when considering engineering a system. He stated that "the success or failure of many civil and defense systems depends mainly on their architecture" (Rechtin, 1992, p. 66). Furthermore, he stated that "the design of complex systems must blend the *art* of architecture with the *science* of engineering" (Rechtin, 1992, p. 66). PMs must realize that creativity and art are inherent to program development. Indeed, the warfighter understands the art of warfighting. Inversely, one could argue art remains absent throughout acquisitions. Rechtin added to his belief by incorporating heuristics, defined as "empirical *rules of thumb* derived from experience and judgment, useful for attacking problems too complex to be solved by analytical techniques alone" (Rechtin, 1992, p. 66). Indeed, the EFV vehicle can be classified as a complex system. However, the Marine Corps might have missed specific opportunities Rechtin exposed with his artful SE viewpoints. In Figure 10, we see the design and end-product linked at the bottom of the decomposed SE V-Diagram. Here, System *design* remains fundamentally related to art and heuristics.

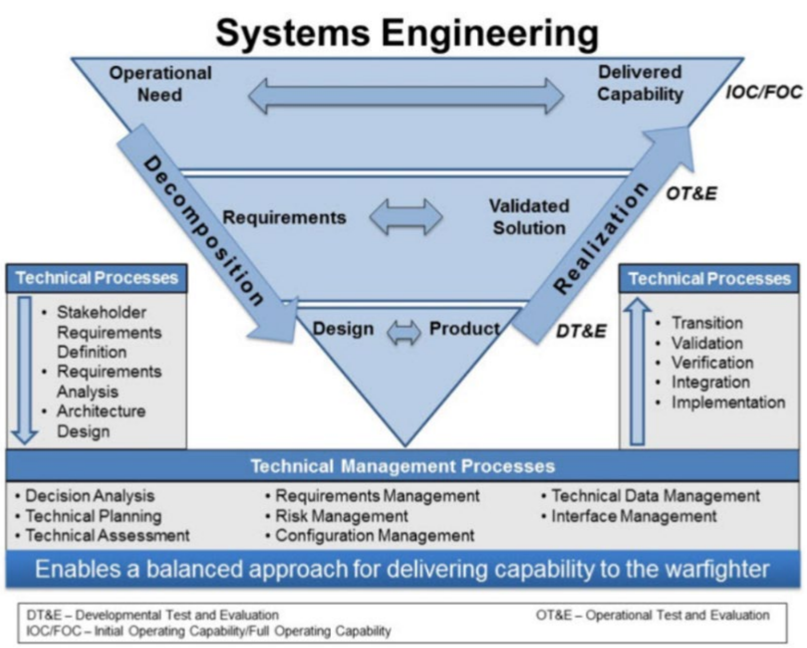

Figure 10. Systems Engineering V-Diagram. Source: DAU (2021, p. 3-2).

Further, Rechtin provided a list of commonly used “rules of thumb” for building a system. He categorized 21 of them into their acquisition phase at the time, including conceptual, build and test, and operations (Rechtin, 1992, p. 67). I use Rechtin’s *mental shortcuts* to analyze and explain the program’s successes and failures. Additionally, I used various government reports referencing SE to ascertain if adequate design change mechanisms were advantageous or disadvantageous to the programs. Rechtin’s heuristics are shown below, followed by the overall SE analysis criteria in Table 9.

Conceptual Phase (MSA Phase; Rechtin, 1992, p. 67):

1. “Extreme requirements should remain under challenge throughout system design, implementation, and operation.”
2. “No complex system can be optimum to all parties concerned, nor functions optimized.”

Build and Test Phases (TMMR and EMD Phases; Rechtin, 1992, p. 67):

1. “Within the same class of products and processes, the failure rate of a product is linearly proportional to its cost.”
2. “Regardless of what has gone before, the acceptance criteria determine what is actually built.”

Operations Phase (P&D and O&S Phases; Rechtin, 1992, p. 67):

1. “The first quick-look failure analyses are often wrong.”
2. “Success is defined by the beholder, not the architect.”

Table 9. EFV/ACV Analysis Criteria: Systems Engineering

Program Management Tools	**COMPARISON**	
Systems Engineering	**EFV**	**ACV**
Application of Rechtin’s Heuristics	*TBD*	*TBD*
Design Change Processes	*TBD*	*TBD*

3. Risk Management

There are almost infinite levels of risk management (RM) decisions, from when to wake up in the morning to strategic strikes in war. Likewise, when acquiring amphibious vehicles, the levels are just as substantial. The high-level risk decisions reside with the SECDEF, SECNAV, CJCS, JCIDS, and JROC levels. Mid-level risk managers include service chiefs, MDAs, and PEOs. The PMO manages risk daily, but milestone decisions flow up to the MDA for ACAT I programs like the EFV and ACV. During their respective life cycles, PMs should "decide whether [the] risk should be accepted (and monitored), avoided, transferred, or controlled. [They] should alert the next management level when the ability to mitigate a high risk exceeds their authority or resources" (DAU, 2021, p. 3-4.1.5.1). Therefore, PMs must communicate and engage stakeholders to accomplish their duties. They will never have the complete picture. The *Systems Engineering Fundamentals* guidebook describes how communication and RM are interconnected,

> Program managers are burdened with the expectations of superiors and others that have control over the program office's environment. Pressure to accommodate these expectations is high. If the system engineer cannot communicate the reality of *risk* [emphasis added] in terms that are understandable, acceptable, or sufficiently verifiable to management, then *these pressures may override vertical communication of actual risk* [emphasis added].
>
> Formal systems engineering with risk management incorporated can provide verifiable information. However, the systems engineer also has the responsibility to adequately explain probability and consequences such that the program manager can accept the reality of the risk and override higher-level expectations.
>
> Uncertainty is a special case and very dangerous in an atmosphere of high-level expectations. Presentation of uncertainty issues should strongly emphasize consequences, show probability trends, and develop "most likely" alternatives for probability. (Department of Defense Systems Management College, 2000, p. 143)

The *DOD Risk, Issue, and Opportunity Management Guide* (RIO) defines risk as a "potential future event or condition that may negatively affect achieving program objectives for cost, schedule, and performance. Risks are defined by (1) the probability (greater than zero, less than 1) of an undesired event or condition and (2) the consequences, impact, or severity of the undesired event, were it to occur" (Office of the Deputy Assistant Secretary of Defense for Systems Engineering [ODASD(SE)], 2017, p. 76). Issues, on the other hand, are defined as "event or condition with the negative effect that *has occurred* (such as a realized risk) or is *certain to occur* (probability = 1)" (ODASD[SE], 2017, p. 78). Unrealized risk at the requirements and subsystem levels remains an insidious indicator and points towards knowledge within a program. Historically, these latent risks gain energy, increasing the potential for program cancelation. The ongoing ACV program seems to have learned from EFV issues. However, program risk can never be fully mitigated. Figure 11 shows the standard RIO cycle, with a center jutting out communication and feedback.

Figure 11. Risk and Issue Management Process Overview. Source: ODASD(SE, 2017, p. 17).

Additionally, the RIO guidebook illustrates various methodologies to assess a program's risk. Again, highly interlinked with the SE process, RM must be a synchronized effort throughout any program. Some of the items that must be communicated include metrics associated with schedules, budgets, design changes, KPPs, key system attributes (KSAs), technical performance measurements (TPMs), and earned value management system (EVMS) data.

I analyze each program to identify risk communication associated with critical technologies. After identifying these technology risks in each program, I compare the impact. Additionally, I correlate the four everyday risk mitigation activities (accept, avoid, transfer, and control) and compare the effect (DAU, 2021). Table 10 lists the RM analysis criteria.

Table 10. EFV/ACV Analysis Criteria: Risk Management

Program Management Tools	COMPARISON	
Risk Management	**EFV**	**ACV**
Critical Technology Risk	*TBD*	*TBD*
Risk Mitigations	*TBD*	*TBD*

4. Test and Evaluation

RM should drive system test and evaluation (T&E), but the extent of T&E varies with each program. Amphibious vehicle test plans should include systems tests for overall safety, land and water mobility, vibrations, firepower, survivability, and communications. During each test, the program risks revealing issues with test article vehicles. Figure 12 shows a simplified five-step process from the *T&E Management Guide*.

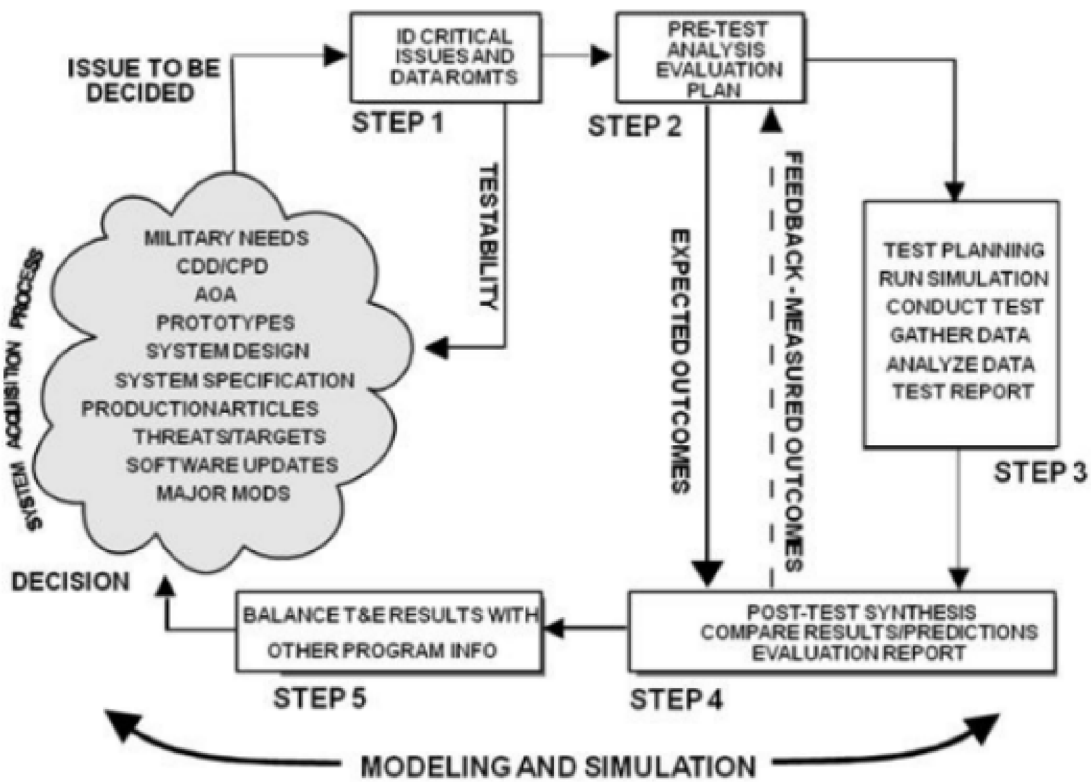

Figure 12. Five-Step T&E Process. Source: DAU (2012, p. 207).

The T&E process requires user-initiated inputs and outputs like the SE and RM processes. Consequently, multiple layers of decision-making processes stack up within a hierarchy of information, especially with iterative cycles. Each loop must return to the beginning to synthesize results and incorporate new analyses. If the information does not transfer up the hierarchy appropriately, MDAs are left basing their decisions on inadequate knowledge. Through proper planning, PMs strive to deliver positive test results. However, this is not always the case. In my analysis, I determine if T&E issues feed other program issues, such as poor SE, poor communication, and inadequate RM, and ultimately compare T&E expectations with reported results (see Table 11).

Table 11. EFV/ACV Analysis Criteria: Test and Evaluation

Program Management Tools	**COMPARISON**	
Test and Evaluation	**EFV**	**ACV**
Expected Outcome vs. Test Results	*TBD*	*TBD*

5. Earned Value Management System

The earned value management system (EVMS) remains an essential DOD PM tool for assessing "cost, schedule, and technical progress on programs to support joint situational awareness and informed decision-making" (Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics [OUSD(AT&L)], 2018, p. 2). Typically, earned value management (EVM) is relegated to reactive risk mitigation regarding contract compliance or performance. Similarly, T&E risk is directly associated with the PMO response following the revelation of technical issues. However, the significance of both remains much more significant than one realizes. EVM is an essential tool for assessing the "cost, schedule, and technical performance of programs for *proactive course correction*" (OUSD[AT&L], 2018, p. 5). The tool is built upon a RM foundation and should supplement or, at a minimum, inform existing decision aids. The EVM guide states that "to be effective, EVM practices and competencies must *integrate* into the PM's acquisition decision-making process" (OUSD[AT&L], 2018, p. 2).

Further, the PM's "use of EVM depends on a well-developed work-breakdown structure (WBS) to ensure that a program is completely defined" (Office of Management and Budget [OMB], 2017, p. 8). Therefore, to remain *proactive* and ensure successful program performance, PMs must understand how a program's value is earned to a high-level of detail in the WBS. Per DODI 5000.85, PMOs must utilize EVM best practices with a contract value greater than $100 million; this instruction applies to the EFV and ACV. Table 12 details the specific EVMS utilization requirements.

Table 12. EVM Application Requirements. Adapted from DAU (2022a).

Contract Value	Applicability	Notes	Source
≥ $100M	EVMS required; contractor is required to have an EVMS that has been determined to comply with the guidelines in EIA-748.	The contractor will provide access to all pertinent records and data requested by the contracting officer or duly authorized representative to permit initial and ongoing government compliance reviews to ensure that the EVMS complies and continues to comply with the guidelines EIA-748.	Part 7 of OMB Circular A-11; FAR 52.234-4, FAR subpart, 34.2; DFARS 234.201; DODI 5000.85, para. 3C.3. c.(3)

Initial research into the EFV and ACV programs reveals costs far higher than $100 million. Therefore, both contractors must utilize an approved EVM system that reports costs, schedules, and performance via a monthly Integrated Program Management Data and Analysis Report (IPMDAR). Table 13 details this requirement. However, the condition only exists if EVMS is "on contract" (DAU, 2022b).

Table 13. EVM Reporting Requirements. Adapted from DAU (2022b).

Contract Value	Applicability	Notes	Source
≥ $100M	Required monthly when EVMS requirement is on contract.	IPMDAR is required. All files are required.	IPMDAR data management item.

As mentioned earlier, earned value typically relates to contract performance, or dollar amounts paid to the contractor. The system tracks performance with numerous metrics and calculations, including the budgeted cost of work scheduled (BCWS) and performed (BCWP), the actual cost of work performed (ACWP), budget at completion (BAC), estimate at completion (EAC), cost performance index (CPI), schedule performance index (SPI), cost variance (CV), and schedule variance (SV; DAU, 2018). These metrics rely heavily on the WBS, the integrated master schedule, and the critical path. Ideally, contract management offices coordinate the contract awards with a surveillance plan in mind. As such, the Defense Contract Management Agency (DCMA) and the Defense Contract Audit Agency (DCAA) remain critical program assets. However, each agency remains understaffed and under-skilled (Garrett & Beatty, 2011, p. 12). If a contract does not perform per its award, these agencies must issue corrective action requests (CARs). However, *reactive* CARs do not align with the stated goal that EVM should remain a *proactive* tool.

In analysis, I determine whether or not the programs used EVMS as a *proactive* management tool (see Table 14). The Earned Value Management System–Central Repository (EVMS-CR) online resource provides all past and current EVMS data for this analysis criterion.

Table 14. EFV/ACV Analysis Criteria: Earned Value Management System

Program Management Tools	**COMPARISON**	
Earned Value Management System	**EFV**	**ACV**
EVMS Utilization	*TBD*	*TBD*

D. DECISION SCIENCE PRINCIPLES

In the 2005 RAND study, researchers analyzed human decision-making through "descriptive, normative, and prescriptive aspects (how humans actually make decisions, how they perhaps should make decisions, and how to go about doing so effectively, respectively)" (Davis et al., 2005, p. 2). Concerning the ACV and EFV, it is essential to understand deviations from the "Big A" acquisition model and pinpoint where and why these departures exist. The following mental models, or paradigms, help detect different decision-making thought processes that lead to success or failure.

1. Rational Choice Model

Rational decisions are made based on the available data to make a reasonable choice, followed by optimization. A rational decision-making model "assumes the decisionmaker has *complete information* [emphasis added], is able to identify all relevant options in an unbiased manner and chooses the option with the highest utility" (Robbins & Judge, 2018, p. 88). It tends to describe how individuals *should* behave to maximize outcomes. This model is analytical and encapsulates normative or prescriptive behavior. RCM typically involves deep analysis consisting of numbers, facts, and figures. "Big A" acquisition could be considered a RCM due to the web of processes, charts, tools, and analytics.

Furthermore, each element of the DAS, PPBE, and JCIDS seem to strive for rationality in their own rules, and governing documents strive for a perfect solution. Within the "little A" DAS, rational triggers are apparent at various junctures throughout the life cycle, like milestones. Similarly, PPBE deals heavily with dollar metrics, driving their decisions. The JCIDS decision trees represent an almost automated rational model, lacking interpretive and persuasive qualities.

RAND summarized the near-perfect logical process in Figure 13. Of note, when recognized in the circular depiction on the right, the model parallels the RIO process but leaves out the importance of communication and feedback. Despite our desire for pure rationality, individual interests and subjectivity cannot be eliminated from decisions. Additional partiality is evident in words like "review," "assess," and "fine-tune," which are defined differently by each individual.

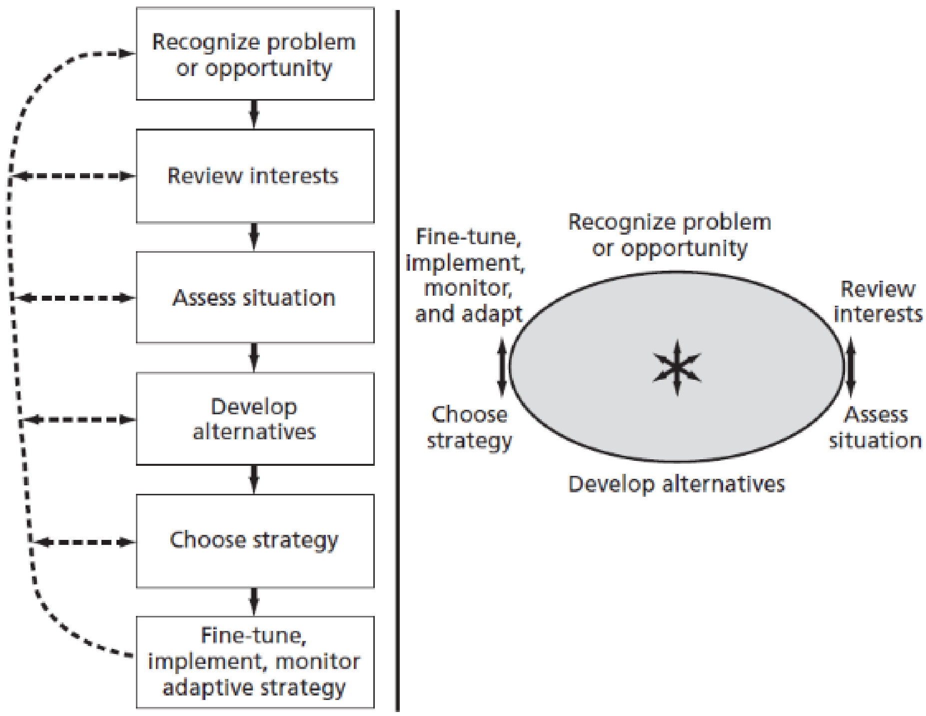

Figure 13. Idealized Decision-Making. Source: Davis et al. (2005, p. 8).

Each of these words can drive decision-makers in a different direction. RAND found that "a debate now exists as to the form that decision support should take, with doubts arising about the appropriateness of the 'rational analysis paradigm' because of its unnatural fit with human cognition" (Davis et al., 2005, p. xiii). In other words, professionals remain skeptical that complete rational analysis is appropriate or even possible. Thus, arguments for the strict process-driven "Big A" model seem to lose impact. For instance, different interests and assessments inevitably cause disparities in decision-making. Political scientist Herbert Simon recognized this human problem in the 1970s. He found that "human behavior, even rational human behavior, is not to accounted for by a handful of invariants … its basic mechanism may be relatively simple … but that simplicity operates in interaction with extremely complex boundary conditions imposed by the environment" (Davis et al., 2005, p. 8). Given these discoveries, he proposed the notion of bounded rationality.

I analyze the EFV and ACV programs' evidence concerning rational choice and compare rationality against realism. For example, I consider evidence of illogical paths or conflicting statements that stress the DSS model, pointing toward irrational behavior and hindering progress. Table 15 lists this criterion.

Table 15. EFV/ACV Analysis Criteria: Rational Choice Model

	COMPARISON	
Decision Science	**EFV**	**ACV**
Realism versus Rationality	*TBD*	*TBD*

2. Bounded-Rationality Model

The DSS acquisition model involves humans at every level. Thus, objectivity becomes flooded with perception. To account for these variables, unlike RCM, the bounded-rationality model (BRM) considers a simplified decision-making environment where individuals "extract the essential features from problems without capturing all their complexity" (Robbins & Judge, 2018, p. 88). This model acknowledges a person's "limited cognitive capabilities, time, and other resources" during the decision-making process (Davis et al., 2008, p. 9). For example, I find that SE processes incorporate these realizations into their decisions by acknowledging limitations in the science. Figure 14 shows one early example of a SE process for developing measures-of-effectiveness (MOE). Although it reveals a structured flow, the second block down on the right acknowledges boundaries. The Military Operations Research Society realized that requirements must be defined and cannot be all-encompassing because systems are confined to their environments. Likewise, BRM describes how humans then react to our environments and "muddle through" to "good enough" solutions (Davis et el., 2005, p. 9; Robbins & Judge, 2018, p. 88).

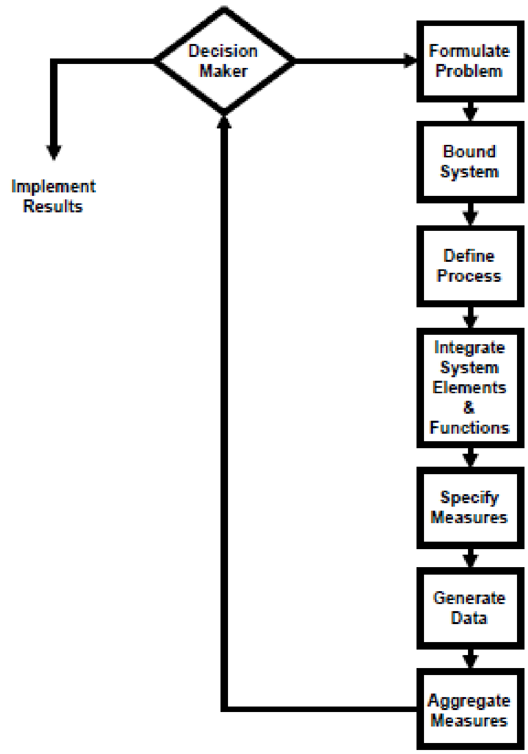

Figure 14. BRM Example: MOE System Definition Process. Source: Green (2001, p. 2).

I believe that as programs progress, PMOs struggle to find rational answers. Consequently, they either 1) continue to strive for a rational solution or 2) *muddle through* to a *good enough* solution. Given the natural boundaries within the acquisition system, I identify each program's explicit constraints and restraints and analyze the management team's response. Additionally, I recall and compare the boundaries faced by industry (see Table 16).

Table 16. EFV/ACV Analysis Criteria: Bounded-Rationality Model

	COMPARISON	
Decision Science	**EFV**	**ACV**
Constraints and Restraints	*TBD*	*TBD*
Industry Boundaries	*TBD*	*TBD*

3. Attempts at Synergy

Some BRM proponents might admit that RCMs are the appropriate model, albeit not entirely understood by decision-makers. The *prescriptive* RCM and *descriptive* BRM paradigms do not suggest that decision-makers must choose one over the other. Moreover, they can be related to an objective and threshold. The models reveal divergences between how one *should* make decisions and how decisions are *actually made*. RAND contextualizes the interaction between the two, stating that "the proper balance between stories and analysis depends on the characteristics of the decision being faced, the decision environment, and the decision-maker" (Davis et al., 2005, p. 88).

One DOD tool that helps the decision-maker *synergize* these models and characteristics is the cost-benefit analysis (CBA). If done well, CBAs consider both tangible and intangible effects. However, stakeholders do generally not account for intangibles in defense acquisition, such as the cost of poor employee productivity or the added social benefit of a system, because the time required to account for intangibles can be extensive and subjective. Also, the CBA model does not account for workplace pressures, such as production demands or schedule risk. Therefore, the CBA seems to be a more 'processed' RCM construct, providing data, yet failing to reach a decisive conclusion.

It is important to note that the PMO cannot describe the entire internal costs and benefits of a program. However, the OMB Circular A-94 clearly states that "both intangible and tangible benefits and costs should be recognized" (OMB, 2015, p. 6). The document recommends that "social net benefits, and not the benefits and costs to the federal government, should be the basis for evaluating government programs or policies that affect private citizens or other levels of government" (OMB, 2015, p. 6). Again, PMs typically do not have the time or luxury for this level of CBA. Consequently, the services often conduct a less-extensive AoA, considered a more practical, timely, and cost-effective study. Notably, the AoA acknowledges subjectivity in the process, stating that,

> Interpretation is a *subjective* [emphasis added] endeavor; it is not uncommon for stakeholders involved in a study to view the same data and results in very different ways. In these situations, discussion and honest scrutiny are necessary to remove *perceptual biases* [emphasis added], but, ultimately, there will often be legitimate dissenting interpretations that should be discussed in the study report." (Headquarters Air Force Office of Aerospace Studies, 2017, p. 100)

Given the AoA, the services then weigh their options based on cost, schedule, and performance metrics. Naturally, weighting involves partiality in military utility, threats, or the operational environment. (DON, 2013, p. 40). Therefore, individual disagreements cannot be solved solely by analytical data alone. Again, most decisions should entertain some level of dissenting interpretation. The United Nations Industrial Development Organization's (UNIDO; 1986) *Guide to Practical Project Appraisal* summarizes this notion:

> The literature on project appraisal commonly gives the impression that the goal is to produce a number or set of numbers that tell whether the project is good or bad. It is not the numbers themselves that are important but rather *the appreciation of the project's relative strengths and weaknesses gained while appraising it* [emphasis added]. The numbers are simply an instrument of discipline … It is, therefore, essential to season the quantitative aspects of appraisal *with a large measure of common sense* [emphasis added]." (UNIDO, 1986, p. 6)

The DSS model ultimately attempts to arrive at a rational solution. However, the program's strengths and weaknesses vary among stakeholders. Consequently, PMs are tasked to combine or *synergize* rational data with internal and external limitations. I was unable to delve into the AoAs for both programs. Instead, in Table 17, I consider the converging descriptive model against the norm, looking for pressures, low-data quality, and ambiguity. Observations are based upon government and open-source reporting.

Table 17. EFV/ACV Analysis Criteria: Synergy

	COMPARISON	
Decision Science	**EFV**	**ACV**
Synergistic Elements	*TBD*	*TBD*

4. Heuristics and Biases Paradigm

To improve the decision-makers model, processes, and tools, the user must appreciate decision-maker biases, including "situations in which they might be vulnerable to them" (Davis et al., 2005, p. 86). For this reason, PMs should consider their shortcuts and predispositions and those of their workforce. Through recognition and analysis, management can better posture themselves against the potentially catastrophic effects of a heuristics and biases paradigm (HBP).

Both heuristics and biases deviate from *normative* RCMs and are associated with *interpretive* BRM behavior. Merriam–Webster defines *heuristics* as "involving or serving as an aid to learning, discovery, or problem-solving by experimental and especially trial-and-error methods" (Merriam–Webster. [n.d.]). In other words, a heuristic is a cognitive shortcut. But one might wonder, how do heuristics apply to government acquisition? We know Rechtin argues their importance concerning SE. Too, Davis et al. (2005) found that "heuristics often yield *cost-effective decisions* [emphasis added] compared with so-called rational processes that are expensive in terms of both time and mental energy" (p. 15). Therefore, heuristics save decision-makers time, albeit with trade-offs.

Similarly, Merriam–Webster defines *biases* as "tendencies to believe that some people, ideas, etc., are better than others," such as "an inclination of temperament or outlook" (Merriam–Webster. [n.d.]). Typically, decision-makers fall victim to biases when looking "to minimize effort and avoid trade-offs" (Robbins & Judge, 2018, p. 89). Biases inevitably filter into DOD acquisition when decision-makers "rely too heavily on personal experience, impulses, gut feelings, and convenient rules-of-thumb" (Robbins & Judge, 2018, p. 89). One resource detailed over 175 common cognitive biases (Ritholtz, 2016); of those illustrated, ten of the most common biases can be grouped into four problem sets (Benson, 2016; see Table 18). The problems describe how the PMO can be affected by an unknown or deep reliance on HBP.

Table 18. Ten Common Problem Sets and Biases. Adapted from Ritholtz (2016), Benson (2016), Robbins and Judge (2018), and Cherry (2021).

Problem 1: Too Much Information	
1	**Availability Heuristic/Bias (AH):** We often notice things that are already primed in memory or repeated.
2	**Confirmation Bias (CB):** "The tendency to seek out information that reaffirms past choices and to discount information that contradicts past judgments" (Robbins & Judge, 2018, p. 90). In other words, it is the "seeking or interpreting of evidence in ways that are partial to existing beliefs, expectations, or hypothesis in hand" (Nickerson, 1998, p. 1)
3	**Anchoring Bias (AB):** The tendency to be overly influenced by the first piece of information that we hear.
Problem 2: Not Enough Meaning	
4	**Hindsight Bias (HB):** We project our current mindset and assumptions onto the past and future; sometimes, this bias is referred to as the "I knew it all along" phenomenon.

5	**Halo Effect (HE):** We imagine things and people we are familiar with or fond of as better than those we are not fond of or familiar with.
Problem 3: Need to Act Fast	
6	**Actor–Observer Bias (AB):** The tendency to attribute our actions to external influences and other people's actions to internal ones.
7	**False Consensus Effect (FCE):** The false consensus effect is a tendency people have when they overestimate how much other people agree with their own beliefs, behaviors, attitudes, and values. This can lead people to think incorrectly that everyone else agrees with them. Conversely, it can sometimes lead them to overvalue their own opinions.
8	**Self–Serving Bias (SSB):** People tend to give themselves credit for successes but blame failures on external causes.
9	**Optimism Bias (OB):** A tendency to overestimate the likelihood that good things will happen while underestimating the probability that adverse events will impact our lives.
Problem 4: What Should Be Remembered	
10	**Misinformation Effect (ME):** The tendency for memories to be heavily influenced by things that happened after the actual event.

I analyze each program through the HBP lens, searching for problems and identifying common biases which could contribute to poor decisions within each program. Then, through observation, I compare deviations to the model and attempt to correlate program issues under the "little A" DAS process. Table 19 lists the associated criteria derived from a HBP.

Table 19. EFV/ACV Analysis Criteria: Heuristics and Biases Paradigm

	COMPARISON	
Decision Science	**EFV**	**ACV**
DSS Abnormalities	*TBD*	*TBD*
Problem Set Barriers and Effects	*TBD*	*TBD*

E. SUMMARY CRITERIA

Chapter III reviewed the literature surrounding specific mandatory requirements, the DOD DSS "Big A" acquisition model, 5 PM tools, and incorporated decision science principles to determine the analysis criteria (see Table 20). The reader will find that some of the determinants overlap in the criteria. I acknowledge the interconnectedness of similar elements when deciphering the differences. Following the literature review, the Chapter IV analysis explains the impact that each measure had on the success of each program.

Table 20. ACV/EFV Analysis Criteria Summary

	COMPARISON	
Mandatory Requirements	**EFV**	**ACV**
Acquisition Program Baseline Data Change	*TBD*	*TBD*
Selected Acquisition Report Change	*TBD*	*TBD*
Nunn-McCurdy Breaches	*TBD*	*TBD*
Level of Market Research and Effect on Program	*TBD*	*TBD*
DOD Decision Support System	**COMPARISON**	
Joint Capability Integration and Development System	**EFV**	**ACV**
Effect of Changes in Key Performance Parameters	*TBD*	*TBD*
Effect of Changes in Strategic Guidance	*TBD*	*TBD*
DOD Decision Support System	**COMPARISON**	
Defense Acquisition System: Little "A"	**EFV**	**ACV**
Acquisition Approach	*TBD*	*TBD*
Schedule Change	*TBD*	*TBD*
Change to the Number of Units	*TBD*	*TBD*
DOD Decision Support System	**COMPARISON**	
Planning, Programming, Budgeting, Execution	**EFV**	**ACV**
Price per Copy	*TBD*	*TBD*
Cost Trade-off Decisions	*TBD*	*TBD*
Program Management Tools	**COMPARISON**	
Knowledge-Based Acquisition	**EFV**	**ACV**
Adherence to Knowledge Points	*TBD*	*TBD*
Evidence of Program Trust	*TBD*	*TBD*
Decision Paradigm: Scope of Knowledge	*TBD*	*TBD*
Program Management Tools	**COMPARISON**	
Systems Engineering	**EFV**	**ACV**
Application of Rechtin's Heuristics	*TBD*	*TBD*
Design Change Process	*TBD*	*TBD*
Program Management Tools	**COMPARISON**	
Risk Management	**EFV**	**ACV**
Critical Technology Risk	*TBD*	*TBD*
Risk Mitigation Activities	*TBD*	*TBD*
Program Management Tools	**COMPARISON**	
Test and Evaluation	**EFV**	**ACV**
Expected Outcome vs. Test Results	*TBD*	*TBD*
Program Management Tools	**COMPARISON**	
Earned Value Management System	**EFV**	**ACV**
EVMS Utilization	*TBD*	*TBD*
	COMPARISON	
Decision Science	**EFV**	**ACV**
Realism versus Rationality	*TBD*	*TBD*
Constraints and Restraints	*TBD*	*TBD*
Industry Boundaries	*TBD*	*TBD*
Synergistic Elements	*TBD*	*TBD*
DSS Abnormalities	*TBD*	*TBD*

	COMPARISON	
Mandatory Requirements	**EFV**	**ACV**
Problem Set Barriers and Effects	*TBD*	*TBD*
Better (green)		
Equal (yellow)		
Worse (red)		

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IV. ANALYSIS

This chapter applies the timeline data and literature to both programs and expands them to form comparisons. Although EFV and ACV program aspects are separated in most analyses, some remain combined based on the topic. Finally, Chapter V will answer the research question and provide recommendations for future research.

A. MANDATORY REQUIREMENTS

Chapter II analyzes the directed data from statutes and regulations, including APB, SAR, Nunn–McCurdy breaches, and market research.

1. Acquisition Program Baseline Data

The PM uses the APB to manage program life cycle costs, schedule, and performance. They provide goals and can inform a program's trade-off potential, either proactive or reactive. I retrieved most of the following EFV and ACV program data from the now-defunct DAMIR portal (ebiz.acq.osd.mil/DAMIR).

The milestone decision-maker approves the APB at MS B, or previously MS II, in the early phases of AAAV/EFV development. This milestone initiates entry into the EMD phase, formerly the SDD phase. Since the original establishment of the initial EFV requirements, the PMO baselined the program seven times from March 1995 to August 2007 (see Figure 15; DAMIR, 2007). Two baselines attribute to conceptual APBs, and five to developmental APBs within the SDD phase. The developmental APBs highlight significant changes that did occur within the life cycle. The program never exited the SDD/EMD phase and was canceled in 2011. Five years before its cancelation in 2007, the Navy finally admitted it must "relax EFV performance and reliability requirements for the program to continue" (Feickert, 2011, p. 4), acknowledging performance trade-offs. This response spurred the final developmental APB Change 4 in August 2007.

APB Dates for EFV (PNO: 515)
from APB Aug 2007

Acquisition Program Baseline Dates							
Approval Date	**Name**	**Phase**	**Event**	**Authority**	**Base Year**	**Original**	**Change**
08/13/2007	APB Chg 4	Development		DAE	2007	Yes	Yes
03/24/2005	APB Chg 3	Development		DAE	1993	No	Yes
03/21/2003	APB Chg 2	Development		DAE	1993	No	Yes
11/02/2002	APB Chg 1	Development			1993	No	Yes
12/07/2000	APB	Development	MS II	DAE	1993	Yes	No
03/22/2000	APB Chg 1	Concept			1993	No	Yes
03/17/1995	Concept APB	Concept			1993	No	No

Figure 15. EFV APB Dates: March 1995 to August 2007. Source: DAMIR (2007).

The ACV program started under an incremental acquisition construct and was labeled a Family of Vehicles (FoV). Three versions included the ACV 1.1, a wheeled regeneration of the MPC program, the ACV 1.2, the proposed tracked fully amphibious variant, and the ACV 2.0 HWS variant (see Figure 16).

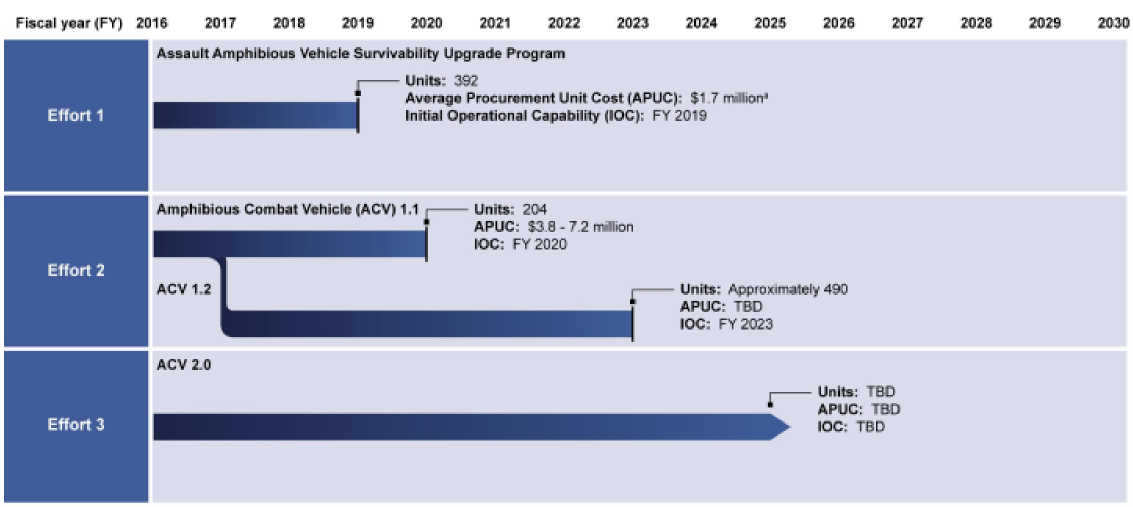


Figure 16. ACV Incremental Acquisition Approach. Source: GAO (2015b, p. 6).

Figure 17 details the ACV 1.1 APB dates and events. Initially, the swimming capability of the ACV 1.1 did not include ship-to-shore maneuver. However, the requirement changed, and the service combined increments of 1.1 and 1.2 in 2019, citing "satisfactory water mobility performance in high surf conditions and, in doing so, met the full water mobility transition requirement for ACV 1.2 capability" (Feickert, 2020, Summary). Seemingly, the Marines continue pressing for HWS, stating that "ACV 2.0

serves as a conceptual placeholder for a future decision point (~2025, or sooner)" (Marine Corps Combat Development Command [MCCDC], 2018).

APB Dates for ACV FoV (PNO: 472)
from APB Nov 2020

Acquisition Program Baseline Dates							
Approval Date	Name	Phase	Event	Authority	Base Year	Original	Change
11/24/2020	APB Change 1	Production	FRP	Assistant Secretary of the Navy (Research, Development & Acquisition) (ASN(RDA))	2014	No	Yes
09/28/2018	Production APB	Production	MS C	Assistant Secretary of the Navy (Research, Development & Acquisition) (ASN(RDA))	2014	No	No
05/26/2016	Development APB	Development	MS B	Component Acquisition Executive (CAE)	2014	Yes	No

Figure 17. ACV APB Dates: May 2016 to November 2020. Source: DAMIR (2020).

2. Selected Acquisition Report Data

SARs are due by December 31 for all ACAT I programs. They are due quarterly if the Program Acquisition Unit Cost (PAUC) or Average Procurement Unit cost (APUC) estimates exceed APB estimates by 15% or greater, schedule growth estimates greater than six months, or the program meets a milestone. Except for milestone arrivals, SARs reported outside of the last calendar year (CY) quarter are irregular and only provide data, not an indication of performance.

From December 1997 to December 2010, DAMIR revealed that the EFV PM position moved between six Marine O-6s (Feigley, 1997, p. 5, & Moore, 2010, p. 5). EFV PMs submitted a total of 15 SARs. Of these fifteen reports, three were off-cycle SARs submitted for various restructuring actions associated with the OA, EMD phase, and prototyping schedule additions. Notably, the second-to-last SAR presented in December 2010 shows 12 SAR schedule breaches (DAMIR, 2010).

From June 2016 to December 2019, DAMIR reveals that the ACV PM position moved between three individuals (Garner, 2016, p. 5, & Mullins, 2019, p. 5). To date, the ACV program has submitted five SARs. The only SAR threshold breaches occur on the latest submission and surround cost. The ADM signed on January 9, 2019, by PEO, Land Systems, combined ACV 1.1 and 1.2 increments. Consequently, procurement quantities increased due to both 1.1 and 1.2 combining under 1.1, which breached the 1.1 APB threshold. This breach highlighted a previously non-approved departure. The SAR breach, although not descriptive of program performance, emphasizes significant restructuring efforts on behalf of the program office.

3. Nunn–McCurdy Breaches

In 1981, Senator John Tower stated that Nunn–McCurdy reports are "closing the gate after the horse has galloped off into the boondocks" (Schwartz & O'Connor, 2016, p. 1). This statement illustrates that Nunn–McCurdy programs are far from saving.

The EFV program reported one significant breach in December 2005, with an APUC increase of 28.45% and a PAUC of 33.69% (DAMIR, 2021). More detrimental, the program reported two significant breaches beginning 1 year later. The first occurred in December 2006, with an APUC increase of 86.69% and a PAUC increase of 112.90% (DAMIR, 2021). Then, in December 2010, just before cancelation, the program reported an APUC rise of 1,110.53% and a PAUC increase of 673.97% (DAMIR, 2021), mainly due to the substantial decrease in units which caused an increase in price per copy. Despite a potential adequate explanation, Nunn–McCurdy breaches of this magnitude gain the attention of the SECDEF and Congress.

The choice to decrease EFV units late in the program potentially exacerbated the Nunn–McCurdy issue. For example, in 1993 base year dollars, the APUC was $5.312 million. If the USMC chose to keep the original 1,013-unit procurement goal (not including RDT&E units) through the 2007 APB, the APUC estimate would equal $7.499 million. Therefore, the 7-year APUC difference would've revealed an increase of $2.187 million/unit. Instead, in 2007 the USMC chose to decrease unit procurement quantity from 1,013 units to 574 units. When comparing the APUC estimates from 2000 to 2007, the estimate jumped from $5.312 to $13.118 million due to the decrease in units revealing an increase of $7.806 million/unit. Therefore, the APUC estimates would have been $5.619 million/unit less if the USMC did not choose to decrease production quantities. With the base year 1993, this decision caused an APUC increase of 356%, followed by a Nunn-McCurdy breach.

In 2006, the GAO reported that the EFV program's total cost grew by $3.9 billion, or 45%, in just 6 years (GAO, 2006, p. 3). In December 2010, the APUC unit cost rose from $16.8 million/unit to $202.8 million/unit (Moore, 2010, p. 31). This increase caused a $1,110.53% cost overage and the final critical Nunn–McCurdy breach (DAMIR, 2021). One month later, the SECDEF canceled the program. Concerning Nunn–McCurdy as a whole, from 2007 to 2015, there were 24 critical breaches and 13 significant breaches. In 2010, the EFV was just one of four (25%) critical-type breaches.

Concerning the ACV, the Marine Corps was given the flexibility to tailor the program using the incremental approach, which helped in its ability to control cost. The DOD "authorized the USMC to seek a new solution, emphasizing the need for cost-effectiveness and requiring the establishment of cost goals" (GAO, 2015b, p. 5). To date, the ACV program has not breached the Nunn–McCurdy thresholds. Following the 2019 combination (see Figure 48 in the appendix), the Marine Corps increased ACV quantities from 204 to 632 and then 636. Following this decision, the program reported four APB cost breaches (RDT&E, procurement, MILCON, and O&M). However, the PMO acknowledged the departure from the November 2020 approved APB, stating,

> The merger effectively added considerable quantities of vehicles and budgetary resources to the program in terms of RDT&E, Procurement, MILCON, and O&M, making the program breach the APB established solely for ACV 1.1. Both the merger and the additional lot of LRIP are departures from the approved APB. All acquisition documentation (including the APB) will be updated at FRP. (Mullins, 2019, p. 10).

Unless the program accounts for the increment combination, these APB breaches *could* grow into Nunn–McCurdy level breaches, but it remains doubtful. However, with the tailorable leniency given to the Marine Corps, they should find relief from Congress if asked to testify. The ACV future is uncertain, but with the FRP decision in December 2020, the ACV program officially started its P&D phase. Due to combining increments, the potential impact of ACV 2.0 funding remains unknown as the 2025 tentative decision point approaches. With the POM cycle for 2025 underway, the Corps must either plan funding ACV 2.0 or look to cancel the last increment sooner than later.

The ACV program has not reported a Nunn–McCurdy breach. The SAR breach could trigger a program rebaseline, but it is unlikely to meet the Nunn–McCurdy threshold. Interestingly, the increase in unit quantities due to increment combination resulted in only a minor PAUC and APUC increases, both less than $1 million. Overall, the 1.1–1.2 combination did not significantly impact the cost. Nevertheless, the tracked ACV 1.2 will not be designed, developed, acquired, or fielded. Here, trade-off analysis reveals that cost and schedule reduced future ACV performance.

4. Market Research

FAR 2.101 (2022) defines market research as a "means of collecting and analyzing information about capabilities within the market to satisfy agency needs." There are several ways to conduct market research; the most common methods are submitting RFIs to industry and holding industry days, trade shows, or engagements. This section explores the various techniques the Marine Corps looked to increase its amphibious knowledge.

OTH capability research began before the EFV concept development. Anti-ship missile technologies started in the 1980s, driving ship-to-shore requirements to greater ranges. For example, during the "1982 Falklands War between Great Britain and Argentina, the British lost two ships to French-built Exocet missiles" (Groom, 2018). Similarly, in 2007, a Hezbollah C-802 cruise missile struck both Israeli and Egyptian ships at 10 and 36-miles, respectively (Feickert, 2011, p. 1). Smartly and reactively, the Marine Corps adjusted its ship-to-shore requirement from 12 to 25 NM during the AAV years.

Prior, the government attempted twice to solve the water speed and range problems in the late 1970s and 1980s with the canceled LVT(X) and LVA programs. The LVA program awarded feasibility/concept contracts to FMC Corporation (now BAE), Bell Aerospace Textron, and Pacific Car Foundry (Adams, 1999, p. 143). These companies conducted the earliest HWS amphibious vehicle research. In 1984, concerning the low-water speed LVT(X) option, the secretary of the Navy for research, engineering, and systems voiced his concern about the low water speed requirement. As a result, the CMC provided a list of options to the SECNAV, who canceled the LVT(X) program in favor of the HWS AAAV, or EFV.

The original AAAV/EFV acquisition strategy was not available on DAMIR. However, according to DOD Directive 5000.2 from 1987, the AAAV/EFV program adhered to the MS 0-V construct. The Marine Corps included a Mission Needs Statement (MS 0) in the 1988 POM submission (Adams, 1999). The concept exploration/definition (CE/D) phase followed in trail. The Marine Corps leveraged prior industry knowledge for the CE/D contract competition. However, only two companies competed, GDLS and United Defense Industries (UDI), formerly FMC and now BAE. Due to unique requirements placed upon potential competitors, such as contractor collocation with the PMO to enable the newly integrated product team (IPT) structure, full and open competition was significantly reduced (Adams, 1999, p. 61). Srivastava (2019) states that,

> After the initial competition in 1990, which ended when the government selected one participant at a very early stage ("early" even by its own typical standards), this program never had another full and open competition. General Dynamics continued as the sole participant in the concept development/validation (CD/V) phase, and until the program's cancelation in 2011, *no further contracts were procured competitively* [emphasis added] (p. 69).

Due to the budgetary and requirements fluctuations, market research and competition seems to have been stifled (Adams, 1999, p. 61; Srivastava, 2019, p. 69). The specific requirement to collocate the contractor's operations to Virginia potentially inhibited commitment from alternative industry partners. Here, minimal information exists concerning the business case between the government and industry. However, based on a prevalent 1996 Marine Corps concept paper, *Operational Maneuver from the Sea*, it is fair to assume that the HWS concept captured industry interest (Krulak, 1996). The document details the ongoing amphibious maneuver endeavor, which still exists today. In the paper, General Krulak alluded to the need for continued market research. Regarding mobility, he stated we must "move units from ships lying OTH to objectives lying far from the shore; we will require the capability to cross great distances, reduce the limitations imposed by terrain and weather, and most importantly, seamlessly transition from maneuvering at sea to maneuvering ashore and vice-versa" (Krulak, 1996, p. 23). These concepts remained valid during the EFV years yet proved extremely challenging.

Following EFV cancelation, the Marine Corps looked to further add to their body of knowledge. As a result, the Corps conducted a variety of industry engagements during the EFV transition years from 2011 through 2015. They held industry days and spread EFV lessons learned to increase the community's knowledge while ensuring adherence to acquisition regulations, statutes, and best practices.

Internal to the government and before the EFV concept award, the Corps teamed up with the DARPA AVM program. In December 2011, DARPA announced the FANG ground vehicle program "to parallel the ACV program of record and produce a heavy, amphibious infantry fighting vehicle" (DARPA, 2011, p. 53). DARPA created FANG "to use the challenge/competition open innovation strategy" (Srivastava, 2019, p. 47). Originally, DARPA scheduled three challenges, FANG-1, -2, and -3. Drivetrain development was the first FANG-1 challenge. -2 tackled the chassis and survivability, while -3 involved the complete vehicle design. As FANG progressed, multiple issues beleaguered the program, such as challenges with classification and intellectual property (IP) rights. Ultimately, FANG-2 and -3 were canceled by DARPA, stressing that "the consideration of sensitive materials and analysis [is] not suited for the public domain" (Srivastava, 2019, p. 53). Concerning a HWS vehicle, "no matter what it tried, the government could not crack the nut" (Srivastava, 2019, p. 46).

Though this effort did not work as expected, the Marines did not stop trying. Shortly after, in April 2012, the Marine Corps released its Amphibious Capabilities Working Group (ACWG) report. It compared MPC and ACV options and reinforced the necessity to build combat power ashore. In addition, this report acknowledged that emerging threat conditions required extended ship-to-shore ranges and "identified a required self-deploying range of 25 NM from shore, at a speed of eight knots" (ACWG, 2012, p. S-12). Early in the transition years, this statement reveals that the OTH capability did remain valid.

Then in January 2013, the Marine Corps commissioned a HWS trade study. They sought to establish "technical feasibility and affordability of a HWS amphibious vehicle, quantify performance, determine capability trade-offs that can be made to reduce cost and technical risk, and compare capabilities with those of a low water speed variant" (Burrow, 2014b, p. 1). The HWS study looked at distinct options surrounding varying sea states, speeds, armor, and troop capacity. In July 2013, Director for Marine Corps Systems Command and the ACV Team, John Burrow, called on industry, stating,

> We need your input. … Dollars are tight, and we only have one chance to get this thing right. Your inputs are absolutely critical, and I can guarantee you it's going to be of significant value to us and to the leadership that's going to make the decision later on. (Randolph, 2013)

One result of this study, Figure 18, reveals that only six of the 24 prospects were deemed feasible, representing a 25% chance of success.

Trade Study Results

Capabilities	14 Troops; "A" Direct Fire Protection	14 Troops; "B" Direct Fire Protection	17 Troops; "A" Direct Fire Protection	17 Troops; "B" Direct Fire Protection
"C" Under-Blast Protection; Weapon "X"	**Feasible**	**Feasible**	**Feasible**	**High Risk Feasibility**
"C" Under-Blast Protection; Weapon "Y"	**Feasible**	**Feasible**	**Feasible**	**High Risk Feasibility**
"C" Under-Blast Protection; Weapon "Z"	**High Risk Feasibility**	**Not Feasible**	**Not Feasible**	**Not Feasible**
"D" Under-Blast Protection; Weapon "X"	**High Risk Feasibility**	**Not Feasible**	**Not Feasible**	**Not Feasible**
"D" Under-Blast Protection; Weapon "Y"	**High Risk Feasibility**	**Not Feasible**	**Not Feasible**	**Not Feasible**
"D" Under-Blast Protection; Weapon "Z"	**Not Feasible**	**Not Feasible**	**Not Feasible**	**Not Feasible**

Figure 18. 2013 ACV Feasibility Assessment. Source: Burrow et al. (2014b, p. 10).

Again, the Marine Corps began a potentially rewarding endeavor to realize HWS trade-offs. However, water mode operations for a semi-planing craft require an immensely powerful engine, which increases weight, causing a reduction of armor. Burrow et al. (2014a) explained that HWS requires a vehicle to crest a "hump" (see Figure 19) between 12 and 18 knots before it "can accelerate to a higher speed in the 20–28 knot range" (p. 5-6). The trade study concluded that

- A survivable, capable, high water speed ACV is technically feasible.
    - No new technology is required.
- Additional R&D could enable increased planing weight.

- [Could produce] more capability.
- [Could] use heavier but less expensive components. (Burrow, 2014a, p. 23)

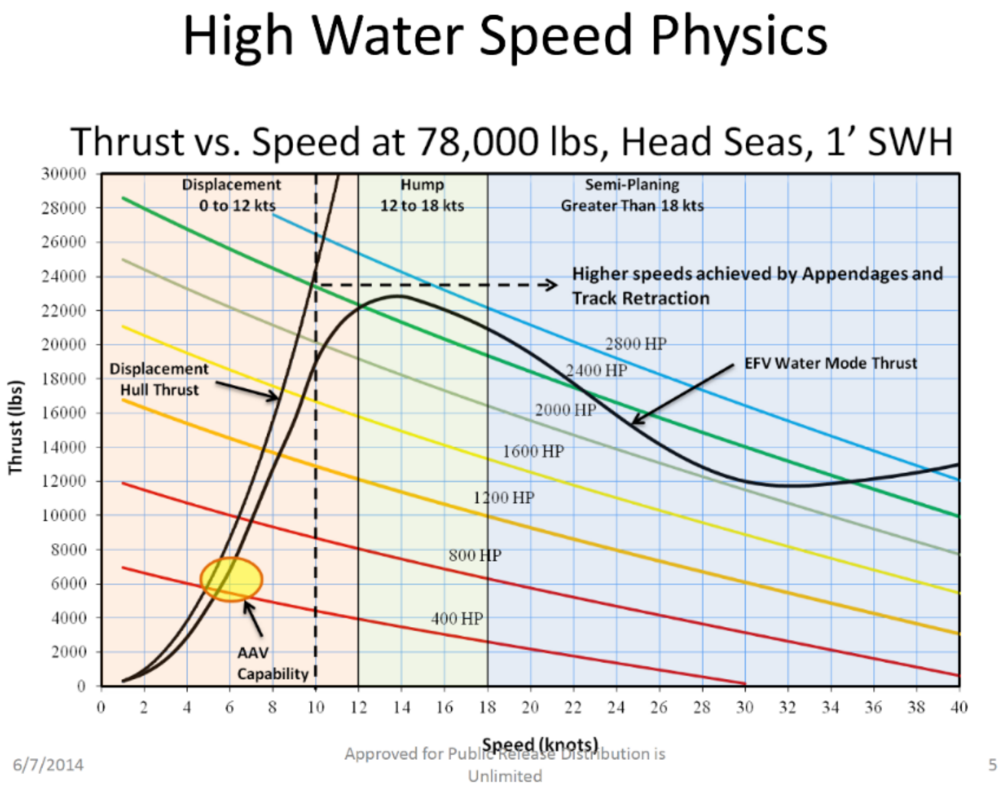


Figure 19. ACV HWS Physics. Source: Burrow et al. (2014a, p. 5).

One difference was noted between the 2013 HWS study brief and the report. The report stated that a “HWS ACV is weight critical … For vehicles such as a HWS ACV where providing all desired capabilities together is currently not feasible*, modularity* [emphasis added] enables optimizing the vehicle for a particular mission” (Burrow, 2014b, p. 14). Here, modularity points toward an incremental approach, which was ultimately decided. This report gave the Marine Corps hope that if the fiscal environment allowed, HWS could become a reality in the future. Eventually, modularity opened the door to consider different options and vehicle variants.

Based on these studies, Lieutenant General Glueck, deputy commandant of combat development and integration, stated that “an amphibious combat vehicle with HWS capability is technically feasible, but only after trading the survivability and lethality that Marines require to operate on land” (Sicard, 2014). The Marine Corps’

HWS study was briefed to Marine Corps leadership in January 2014 (Burrow, 2014b, p. 2). Two months later, in March 2014, General Amos released *Expeditionary Force 21*, stating his vision for designing and developing the force. He envisioned the Corps could "chart a course over the next 10 years to field a Marine Corps that will be: ***the right force in the right place at the right time***" (Amos, 2014, p. 3). This document expanded the Corps' previous 25 NM ship-to-shore requirement increasing the range by 260%. Gen Amos, an aviator, requested the Corps "develop initial assault/raid capability for surface and vertical assault from greater than 65 NM" (Amos, 2014, p. 43).

Continuing to press forward with HWS, the Corps engaged the Office of Naval Research (ONR). On August 27, 2015, an ONR Focus Area Forum was held in Arlington, VA, named the "Expeditionary and Irregular Warfare: The Amphibious HWS Challenge" (ONR, 2015). The goal of the industry day was to understand warfighter needs, discuss ongoing science and technology challenges regarding HWS, and exchange new and innovative ideas (ONR, 2015). One brief titled *Advanced Hull Forms/Propulsor Hydrodynamics Technology Area* stated that,

> Minimizing drag is of prime concern since added drag means more thrust is required to achieve desired speed which means more installed horsepower is required, which means vehicle weight must increase, which means more drag, and so on and so on. (Fu & Becnel, 2015, p. 12)

Following the EFV, market research led the Marine Corps to an incremental acquisition approach consisting of three synchronized efforts: (1) AAV survivability upgrade program, (2) ACV 1.1 and ACV 1.2, and (3) further ACV 2.0 HWS technology exploration. Bluntly, the GAO reported ACV 1.2 was to "achieve parity with the legacy AAV" (GAO, 2015b, p. 2). Later, in November 2015, BAE and SAIC were awarded contracts to develop ACV 1.1 prototypes. Figure 20 summarizes and compares the capabilities of the AAV, AAV SLEP upgrade, and the first ACV 1.1 increment.

Capability	Assault Amphibious Vehicle (AAV)	Upgraded AAV	Amphibious Combat Vehicle (ACV) 1.1
Improvised Explosive Device Protection (Underbelly)	Baseline Protection	Increased Protection	Increased Protection
Lethality (Armament)	.50 caliber machine gun and 40 mm grenade launcher Directly Manned Unstabilized[a]	.50 caliber machine gun and 40 mm grenade launcher Directly Manned Unstabilized[a]	.50 caliber machine gun or 40 mm grenade launcher Remotely Manned Stabilized[a]
Troop Capacity	21	17	10
Weight Growth Margin	0 lbs	No requirement	Gross Vehicle Weight + 15%
Water Speed	6 knots	6 knots	5 knots
Operating Sea State[b]	3	3	2
Self-Deployed	Yes	Yes	No

Figure 20. Comparison of Selected Assault Amphibious Vehicle and Amphibious Combat Vehicle Capabilities. Source: GAO (2015b, p. 8).

In 2018, the USMC PM of Advanced Amphibious Assault (AAA), PEO Land Systems, Col Mullins, stated that "the ACV provides a mobile capability that mechanizes the force to maintain tempo with the remainder of the [Marine Air-Ground Task Force]; specifically, the M1A1 tank" (Trevithick, 2018). Since then, threats and strategy changed. Recently, the CMC divested all tanks from the Marine Corps inventory (Berger, 2020, p. 3). Therefore, the required preconditions guiding the development of the faster-wheeled ACV no longer hold as much weight when advocating for a like tank speed. Concerning acquisition speed, Col Mullins stated that "to be a step ahead of the adversaries in the future, the Marine Corps needed to find a modern vehicle at an *affordable price range* [emphasis added] that provided significant capability enhancement and performance over the AAV" (Trevithick, 2018). However, when comparing the AAV to the ACV 1.1/1.2, Figure 20 reveals minimal capability improvement, if any.

Amphibious vehicle market research remains ongoing in line with the statutory requirements for ACAT programs and GAO best practices. The HWS ACV 2.0 decision point remains a "conceptual placeholder" set around 2025. To date, the Marine Corps has not released any ACV 2.0–specific RFIs. Overall, the GAO agrees with the approach, stating that "the adoption of an incremental approach has helped the program progress towards achieving the balance between customer needs and resources (e.g., technologies, cost, and schedule) that is sought in accordance with best practices" (GAO, 2015b, p. 3). The ACV increments attempt to achieve realistic goals, aligning Marine Corps and industry efforts. However, the increment combination in 2019 (see Figure 48 in the appendix) effectively canceled the plan, driving the eventual unit growth of ACV 1.1. Initially, the ACV 1.1 requirement required connectors to move from ship-to-shore, while ACV 1.2 would be a self-deploying, tracked vehicle. The increment combination reveals acquisition flexibility. However, it also highlights the rigidity of cost and schedule over performance. Overall, a HWS ACV 2.0 requires a resurgence of amphibious vehicle R&D, which I could not locate during my research.

B. DOD DECISION SUPPORT SYSTEM

This section analyzes data based on the "Big A" acquisition triad through JCIDS, DAS, and PPBE. Analysis criteria are split into two JCIDS sections (key performance parameters [KPPs], strategic guidance), three DAS sections (schedule change, unit change, acquisition approach), and three PPBE sections (cost change, resourcing decisions).

1. JCIDS: Key Performance Parameter History Data

Initially, the Marine Corps designed the EFV based on requirements to launch from 25 NM offshore, embark a crew of three with seventeen combat-equipped Marines, achieve an intended speed of twenty knots, and attain a range of 345 miles at 45 km/hour (Feickert, 2011, p. 1). Table 21 highlights the EFV KPP changes throughout seven rebaselines, from the beginning to the end of the program. Bolded items reveal changes.

Table 21. EFV KPP History. Adapted from DAMIR (2007).

Concept APB (Concept) 03/17/1995 Objective/Threshold		APB Change 4 (Development) 08/13/2007 Objective/Threshold	
High Water Speed (HWS) (kts) (24-inch Significant Wave Height [SWH])			
N/A	N/A	**25**	**20**
Forward Speed on a Hard Surface Road (kph)			
72	69	72	69
Armor Protection Against (mm/m)			
30/1000	14.5/300	30/1000	14.5/300
Armor Protection Artillery Fragment (mm/m)			
N/A	N/A	**155/15**	**155/15**
Carry Capacity (AAAV[P]) (Marines)			
18	17	18	17
Firepower (AAAV[P]) (m) (MER)			
2000	1500	2000	1500
Reliability (hours) MTBOMF			
95	70	**56**	**43.5**
Interoperability			

Objective - 100% of Top Level IERs Threshold - 100% of Critical Top Level IERs			
N/A	N/A	**100%**	**100%**
Operational Availability (Ao)			
N/A	N/A	**0.85**	**0.81**
High Water Speed (kts) (SS-3, 36-inch SWH)			
25	20	**DELETED**	**DELETED**

When considering the changes over time, it can be seen that four of 10 requirements (40%) remain unchanged: forward speed on a solid surface road, armor protection, carrying capacity, and firepower. From the initial APB concept, three performance requirements were not initially identified (30%): armor protection artillery fragment, interoperability, and operational availability (A_O). One was downgraded (10%): high water speed (36 in SWH) to high water speed (24 in SWH). Overall, six of 10 (60%) were either added or changed. Not including new or modified requirements, the most meaningful change exists in the category of reliability or mean time between operational failure (MTBOF). From conception, the MTBOF objective shifted from 95 hours to 56 hours, a 58.9% adjustment; the threshold went from 70 hours to 43.5 hours, a 62.1% adjustment. The JROC approved these significant MTBOF shifts on March 24, 2005, 10 years after the program's start. On May 8, 2007, the JROC deleted the *36-inch* HWS SWH requirement, reducing the requirement to *24-inches* SWH, indicating a 33% water-mobility capability reduction.

Various government reports echo severe reliability problems throughout the program's history. For example, during the 2006 OA, the EFV failed to meet reliability requirements and failed the assessment. "During the test, the "vehicles could operate for *only 4.5 hours* [emphasis added] between breakdowns and required about 3.4 hours of corrective maintenance per operating hour" (U.S. House, 2008, p. 8). Even with the Navy's subsequent performance relaxation in 2007, the program needed to increase MTBOF by *40 hours* following the assessment.

The original new amphibious vehicle (NAV) RFI was released to industry in February 2011, 1 month after EFV cancelation. These initial requirements were more detailed than its predecessor:

> The proposed vehicle must be able to self-deploy from amphibious shipping and deliver a reinforced Marine infantry squad (17 Marines) from a launch distance at or beyond 12 miles with a speed of not less than 8

> knots in seas with 1-foot significant wave height and must be able to operate in seas up to 3-foot significant wave height.
>
> The vehicle must be able to maneuver with the mechanized task force for sustained operations ashore in all types of terrain. The vehicle's road and cross-country speed and its range should be *greater than or equal to the M-1A1 Tank* [emphasis added].
>
> The vehicle's protection characteristics should be able to protect against direct and indirect fire and mines and improvised explosive device (IED) threats.
>
> The vehicle should be able to accommodate command and control (C2) systems that permit it to operate both at sea and on land. The vehicle, at a minimum, should have a stabilized machine gun to engage enemy infantry and light vehicles. (Feickert, 2020, p. 3)

Almost 2 years after the EFV cancelation in November 2012, budgetary pressures forced the Marine Corps to choose between the MPC and ACV. ACV officials continued to "flesh out" their requirements during MPC program cutbacks, including HWS (Hudson, 2012, p. 13). Following the MPC AoA held in 2012, Marine Corps officials increased the ship-to-shore distance to "a required self-deploying range of 25 NM … at a speed of eight knots" (USMC, 2012). The Marine Corps then agreed to "resurrect" the MPC as the ACV in March 2014, combining the programs (Feickert, 2020, p. 5). Through various government and industry engagements, requirement generation began again. The CDD (v2.1) contained 198 ACV requirements during one industry brief, and approximately forty were deemed tradeable following a July 2013 workshop (Burrow, 2014a, p. 20). Three years after the initial industry RFI, the Marine Corps released a second in April 2014. A few of the updates included a SWH of 2 feet, a .50 caliber remote weapon system (RWS) with growth potential for 30 and 40 mm, a capacity of three crew plus 10 troops, and government-furnished equipment (GFE) C2 integration. A draft RFP was released in November 2014, then updated in 2015. The updates included requirements for an eight-wheeled vehicle that can travel at least 3 NM from ship-to-shore in 2 feet SWH at 5 to 6 knots. The need to keep pace with the M-1A1 also remained (Feickert, 2020, p. 3).

Compared to the EFV KPPs, the ACV KPPs provide more detail for acquisition professionals and contractors. Table 22 accurately lists the ACV KPPs, including changes from the 2016 development APB to the latest 2020 production APB. Over 4 years, the APB was updated with certain KPP objective/threshold words, such as *shall* and *should*. Other minor changes specified the exact type of sea connector capability, added specific crew and infantry numbers, and removed the net ready and training requirements.

Table 22. ACV KPP History. Adapted from DAMIR (2020).

Development APB (Development) 05/26/2016 Type/Objective/Threshold			APB Change 1 (Production) 11/24/2020 Type/Objective/Threshold		
Sustainment Materiel Availability					
KPP	The Amphibious Combat Vehicle (ACV) shall have a Materiel Availability of 90%, defined as “operational end items/ total population.”	The ACV shall have a Materiel Availability of 75%, defined as “operational end items/total population.”	KPP	**The ACV should have a Materiel Availability of 90%, defined as “operational end items/ total population.”**	The ACV shall have a Materiel Availability of 75%, defined as “operational end items/total population.”
Sustainment Operational Availability					
KPP	ACV shall have an Operational Availability of 90%	ACV shall have an Operational Availability of 81%.	KPP	**ACV should have an Operational Availability of 90%.**	ACV shall have an Operational Availability of 81%.
Energy					
KPP	An ACV shall achieve at least 1.6 miles per gallon (mpg) across the land portion of the mission profile. ACV shall consume less than 0.80 gallons per hour (gph) while stationary and provide 5.6 kilowatts (kW) to power battle-command systems, weapon systems, and other key onboard systems.	An ACV shall achieve at least 1.28 mpg across the land portion of the mission profile. ACV shall consume less than 1.9 gph while stationary and provide 5.6 kW to power battle-command systems, weapon systems, and other key onboard systems.	KPP	**An ACV should achieve at least 1.6 mpg across the land portion of the mission profile. ACV should consume less than 0.80 gph while stationary and provide 5.6 kW to power battle-command systems, weapon systems, and other key onboard systems.**	An ACV shall achieve at least 1.28 mpg across the land portion of the mission profile. ACV shall consume less than 1.9 gph while stationary and provide 5.6 kW to power battle-command systems, weapon systems, and other key onboard systems.
Sea Connectors					
KPP	The ACV at gross vehicle weight (GVW), without preparation, shall be transportable via Sea Connectors to the beach, through the surf zone. Two ACVs shall be transportable on the Ship to Shore Connector (SSC) at GVW.	(T = O) The ACV at GVW, without preparation, shall be transportable via Sea Connectors to the beach, through the surf zone. Two ACVs shall be transportable on the SSC at GVW.	KPP	**The ACV at GVW, without preparation, shall be transportable via Sea Connectors to the beach, through the surf zone. Two ACVs shall be transportable on the Landing Craft Air Cushioned (LCAC) 100 at GVW.**	**(T = O) The ACV at GVW, without preparation, shall be transportable via Sea Connectors to the beach, through the surf zone. Two ACVs shall be transportable on the LCAC 100 at GVW.**
System Survivability: Egress Kill Zone/Protected Fuel					
KPP	Given ballistic penetration damage to the fuel system external to the engine compartment, the ACV shall be capable of	Given ballistic penetration damage to the fuel system external to the engine compartment, the ACV shall be capable	KPP	**Given ballistic penetration damage to the fuel system external to the engine compartment, the ACV should be capable of**	Given ballistic penetration damage to the fuel system external to the engine compartment, the

Development APB (Development) 05/26/2016 Type/Objective/Threshold			APB Change 1 (Production) 11/24/2020 Type/Objective/Threshold		
	maneuvering for 25 miles on level primary roads without manual manipulation of any fuel system components or repair.	of maneuvering for 5 miles on level primary roads without manual manipulation of any fuel system components or repair.		**maneuvering for 25 miles on level primary roads without manual manipulation of any fuel system components or repair.**	ACV shall be capable of maneuvering for 5 miles on level primary roads without manual manipulation of any fuel system components or repair.
Water Mobility					
KPP	ACV up to GVW shall be capable of ship-to-shore maneuver from distances of 12 NM in water conditions up to 3 feet (ft). Significant Wave Height (SWH) to land an infantry company ashore.	ACV up to GVW shall be capable of shore-to-shore maneuver from distances of 3 NM in water conditions up to 2 ft. SWH to land an infantry company ashore.	KPP	ACV up to GVW shall be capable of ship-to-shore maneuver from distances of 12 NM in water conditions up to 3 ft. SWH to land an infantry company ashore.	**(T = O) ACV up to GVW shall be capable of ship-to-shore maneuver from distances of 12 NM in water conditions up to 3 ft. SWH to land an infantry company ashore.**
Cyber Survivability					
KPP	N/A	N/A	KPP	**The ACV will prevent, mitigate, and recover from cyberattacks. The ACV shall prevent unauthorized external physical access to ports that connect to automotive Controller Area Network (CAN) bus(ses) and J1939 network(s). The ACV shall allow only authorized users to update firmware and software on the system. The ACV shall not possess wireless capability beyond the C4I-related Government Furnished Equipment (GFE) systems. <u>The ACV should counter attempted malicious data injection, other corruption, and denial of service activities.</u> The ACV-C will possess additional cyber-related attributes.**	**The ACV will prevent, mitigate, and recover from cyberattacks. The ACV shall prevent unauthorized physical access to ports connecting to automotive CAN bus(ses) and J1939 network(s). The ACV shall allow only authorized users to update firmware and software on the system. The ACV shall not possess wireless capability beyond the C4I-related GFE systems. The ACV-C will possess additional cyber-related attributes.**
Payload					
KPP	ACV shall carry a crew and infantry with full combat loads (which includes 1st	ACV shall carry a crew and infantry with full combat loads (including 1st DoS),	KPP	**<u>ACV-P</u> shall carry <u>a crew (3) and 13 embarked Marines</u> with full combat loads**	**<u>ACV-P</u> shall carry <u>a crew (3) and 13 embarked Marines</u> with full combat**

Development APB (Development) 05/26/2016 Type/Objective/Threshold			APB Change 1 (Production) 11/24/2020 Type/Objective/Threshold		
	Day of Supply [DoS]), additional 2nd and 3rd DoS, and Combat Essential Equipment (CEE).	additional 2nd DoS, and CEE.		**(including 1st DoS), additional 2nd and 3rd DoS, and CEE <u>totaling 8,500 lbs</u>.**	**loads (including 1st DoS), additional 2nd DoS, and CEE <u>totaling 7,600 lbs</u>.**
Net Ready (NR)					
KPP	The ACV shall enable a Net-Centric military capability by integrating Command, Control, Communications, Computers, and Intelligence (C4I) devices that are secure, interoperable, and operationally effective. The ACV shall support the execution of joint information/system exchanges using C4I devices listed in the Platform Integration Information Table (PIIT).	(T = O) The ACV shall enable a Net-Centric military capability by integrating C4I devices that are secure, interoperable, and operationally effective. The ACV shall support the execution of joint information/system exchanges using C4I devices listed in the PIIT.	KPP	**DELETED**	**DELETED**
Training					
KPP	The ACV and ACV training systems shall be designed such that the time to train a single ACV operator or ACV maintainer is 20% less than the Assault Amphibious Vehicle (AAV) equivalent course.	The ACV and ACV training systems shall be designed such that the time to train a single ACV operator or ACV maintainer is no longer than the AAV equivalent course.	KPP	**DELETED**	**DELETED**

The bolded text highlights the changes evident over the 4 years, while the underlined text represents significant wording updates. In addition, other minor adjustments were made, such as reducing long-form words in cells to acronyms and text spacing between symbols.

When comparing the vehicle requirements in Table 23, it remains relevant that the first two are tracked vehicles, and the ACV 1.1 is wheeled (see Table 23). ACV 1.2 was to incorporate tracks per the original incremental acquisition structure. However, in 2019, the plan for a tracked ACV 1.2 fell through when the assistant secretary of the Navy for research, development, and acquisition (ASN[RD&A]), James Geurts, combined them to save money (Lee, 2019). Col Mullins, the Marine Corps ACV product manager, stated, "In essence, 1.1 gave us the 1.2 performance requirements, so there was really no need to continue using the vernacular of 1.1, 1.2" (Lee, 2019). Other than the proposed tracked capability, I could not find any other ACV improvements when moving from 1.1 to 1.2

requirements. Therefore, I conclude that the ACV increment combination reveals an overall capability decrease, exclusively regarding land mobility. Table 23 compares both the performance characteristics of both vehicles, including the AAV.

Table 23. USMC Amphibious Vehicle Performance Characteristics. Adapted from Garner et al. (2015, p. 4), GlobalSecurity.com (2022), Groom (2018), and Military.com (2022).

Capability	AAV7A1	EFV	ACV 1.1
Max Water Speed	7 knots	25 knots	> 6 knots
Watercraft Type	Displacement	Semi-Planing	Displacement
Launch Distance from Shore	> 12 NM	12-25 NM	12 NM
Range (Land Only)	200 miles @ 25 mph	250 miles @ 25 mph	325 miles @ 55 mph
GVW (with Embarked Troops)	58,105 lbs	78,200 lbs	67,500 lbs
Required Horsepower	525 HP	2,750 HP	690 HP
Crew and Troop Capacity	3 and 21	3 and 17	3 and 13
Length (Land/On Ship)	27’	30’ 10”	29’ 2”
Width (On Ship)	12’	12’	10’ 4”
Height (On Ship)	11’	10’	9’ 5”
Weapon System	Turret, Un-stabilized, Dual Mk 19 AGL/M2 .50 cal	Turret, Stabilized, 30mm, Coaxial 7.62	30mm (under development), M2 .50 cal, M2/Mk 19 (under development)
IOC	1972	N/A	2020

2. JCIDS: Changes in National Strategy and Policy

Since the AAV IOC in 1972 through 2011, the United States has amassed 39 years of national strategy and policy changes. During this time, eight presidents held office from Nixon to Obama, 15 defense secretaries from Laird to Gates (including acting), 22 Navy secretaries from Warner to Mabus (including acting), and 11 commandants of the Marine Corps from Cushman Jr. to Amos. Leaders produced three National Military Strategies (1992, 1995, 1997), four Quadrennial Defense Reviews (1997, 2001, 2006, and 2010), and two National Defense Strategies (2005 and 2008; Office of the Secretary of Defense [OSD], 2022). Additionally, from 1972 to 2011, the United States and DOD supported or engaged in combat operations in Bosnia and Croatia, Cambodia, Lebanon, Somalia, Grenada, Haiti, Panama, Kosovo, Libya, Iran, Iraq, Afghanistan, Yemen, and Pakistan.

During the early EFV program concept development phase, Marines were involved with Lebanon, Grenada, Panama, and the Gulf War. Amphibious capabilities were at the forefront of DOD minds to ensure an OTH capability to amass combat power was available. However, during the multiple iterations of the EFV milestones and phases, the United States became heavily involved in Iraq and Afghanistan. During this time, Congress recognized that the design of the EFV did not incorporate a V-shaped hull, which drastically helped prevent severe injury or death from improvised explosive device (IED) threats. This threat posed a significant challenge to EFV engineers and officials because the EFV was designed with applique armor like the AAV. The PMO struggled with changing the hull of the EFV, which would require considerable changes to the design. The swimming capability of the EFV was designed with various moving mechanisms and a flat bottom hull for a reason, speed. This issue only added to the already growing list of extensive engineering changes found during testing. Adding to the mounting change and uncertainty of the EFV, SECDEF Gates publicly expressed concern about the amphibious joint forcible entry mission. Before the 2010 Quadrennial Defense Review, he "called for the Pentagon to review the EFV … and questioned if the United States will again launch major amphibious actions requiring such a forcible-entry vehicle" (Rutherford, 2009).

Since the cancelation of the EFV in January 2011 to date, the United States has experienced 11 years of change. During this time, three presidents held office from Obama to Biden, 15 defense secretaries from Gates to Austin (including acting), 10 Navy secretaries from Mabus to Del Toro (including acting), and four commandants of the Marine Corps from Amos to Berger. In addition, leaders produced three National Military Strategies (2011, 2015, 2018), one Quadrennial Defense Review (2014), and one National Defense Strategy (2018; OSD, 2022).

In 2011, the DOD supported or engaged in combat operations in Afghanistan, Yemen, Iraq, Pakistan, Somalia, Libya, and Central Africa. One could argue that these conflicts did not necessitate the amphibious vehicle capability. However, in late 2011, President Obama looked to refocus the United States from the Middle East to Asia in his first term (Nye, 2011). The Pivot to the Pacific initiatives strived to "devote more effort to influencing the development of the Asia-Pacific's norms and rules, particularly as

China emerges as an ever-more influential regional power" (Manyin et al., 2012, Summary). Through these policies once again, the Marine Corps began to adjust the amphibious vehicle requirement back to its roots in the Pacific theater.

Overall, the amphibious ship-to-shore requirement aligns with national security interests abroad. From World War II, we've seen the ship-to-shore requirement span from < 3NM, to 12 NM, to 25 NM, to 65 NM, and back to the current 12 NM. As the weapons engagement zone (WEZ) of the potential enemy threat grew beyond what is both technically and cost-feasible, the Marine Corps began to shift its focus toward "risk-worthy" platforms to be operated within an enemy WEZ (Berger, 2019, p. 4). Thus, the ACV will be employed under a newly developed *Stand-In Force* strategy (Berger, 2019, p. 10, 2020, p. 5). As a result, the ACV seems to adhere to the JCIDS process interactions, given the current focus.

3. DAS: Acquisition Approach

The EFV did not incorporate an incremental acquisition approach during its 23-year life cycle from 1988 to 2011. The PMO used a standard major capability pathway of the time. However, one could broaden the timeline and include everything after the LVT upgrade because the failed LVA and AAAV/EFV programs attempted to achieve HWS capability. For example, the LVA program established the original OTH and HWS "tentative operational requirement" (Adams, 1999, p. 21) as early as 1973. Since then, both the AAV and the upgraded AAV SLEP have failed to surpass eight knots in the water. Therefore, the LVA could be considered an early HWS AAAV/EFV increment, despite failure. In 1979, the CMC and SECNAV canceled the LVA program, including the OTH requirement, due to ballooning costs (Adams, 1999, p. 22). At the time, the CMC, General Wilson Jr., was quoted during congressional testimony, stating,

> I felt the Marine Corps simply could not afford the vehicle *complexity* [emphasis added] that the HWS required. It would have been difficult to maintain in the field because of its complexity. (Sullivan, 1992, p. 12)

Nine years went by until the AAAV PMO started in 1988. In the interim, the Marine Corps attempted a low-water speed solution, the LVT(X), which was also canceled. Moreover, during its 3-year lifespan from 1982 to 1985, the LVT(X) experienced egregious schedule slips of 11 years, with costs reaching $9 billion for 1,300 vehicles. Interestingly, the LVA and EFV were born from the same contractor, GDLS. Still, these increments are separate programs under the DSS model with different congressional authorizations.

The three-phased incremental approach for the ACV took hold in 2014, starting with the AAV survivability upgrade program (SUP). The AAV Upgrade looked to prolong the AAV capability while simultaneously initiating the development of ACV 1.1 and 1.2 during phase two. The planned third phase, HWS ACV 2.0, remains a longer-term goal without much activism. Nevertheless, the GAO mentioned that the "ACV acquisition's pursuit of HWS capabilities via technology exploration is aligned with best practices" (GAO, 2015b, p. 14). However, I find that the Marine Corps was constrained to use an incremental ACV approach due to the complexity and cost surrounding HWS, the need to replace the aging AAV, and their history of numerous failed HWS attempts. The benefit of an incremental approach enables contractor technological maturity and continuity while keeping the hope alive for innovative engineering. However, 2025 and the HWS decision point is only 3 years away.

4. DAS: Schedule History Data

> The quality of decision is like the well-timed swoop of a falcon which enables it to strike and destroy its victim (Hagy, 2013).

— Sun Tzu, *The Art of War*

As Sun Tzu alludes to, the speed of military decisions pays dividends. To keep up with the speed of relevance*,* PMs must ensure the schedule receives due attention. Before the AAAV/EFV, the Marine Corps struggled to keep programs on schedule. Nevertheless, looking into the future with the AAAV/EFV, the Marine Corps had to contend with its prior history of schedule growth. Of note, the canceled LVT(X) program schedule grew by 11 years in just 4 years (Adams, 1999).

The EFV's schedule also shifted right considerably during the program's existence. From December 2000 to August 2007, the program entered five different SDD, or EMD, phases. In 2006, 5 years before cancelation, the program schedule grew by "35% or 4 years" (GAO, 2006, p. 3). This trend continued. Director, Operational Test and

Evaluation (DOT&E) test events pushed their plan twice during the SDD phase. In November 2002 and March 2003, DOT&E grew the schedule by 12 months (GAO, 2006, p. 13-14). In 2007, with what has been described as “the largest program setback,” the fifth SDD phase pushed the schedule 8 years behind schedule. Original estimates called for a 2003 SDD completion, but the rebaseline in 2007 moved this milestone to 2011 (Feickert, 2011, p. 3-4). Schedule growth stemmed from poor test results and engineering changes. In 2008, the program passed the second CDR decision point. However, with only 3 years to improve vehicle reliability, the PM left the meeting with over “400 engineering design improvements” to incorporate. Earlier and more compelling, the first CDR was conducted in January 2001, just 1 month after the program started the SDD phase. Summarizing the issue, the GAO concluded that the PMO “did not allow adequate time for testing, evaluating the results, fixing the problems, and retesting to ensure that problems are fixed before moving forward” (U.S. House, 2008, p. 3).

Almost immediately following the cancelation of the EFV in 2011, the CMC, Gen Amos, committed the Marine Corps to field a new AAV replacement within 4 years (Feickert, 2011, p. 9). Due to budgetary pressures, the Corps entered a transition period between 2011 and 2014. Initially, the MPC was to augment the EFV. Then, the MPC became the main effort as the AAV replacement. Before settling on the ACV name, the replacement was termed the New Amphibious Vehicle (NAV) briefly during the transition. Soon after Gen Amos left office in September 2015, the program restructured itself. In November 2015, under the new CMC, General Neller, the ACV began under a new MS B decision memorandum. Since 2017, I found approximately 15 months of schedule growth, including a 1-year decrease at FRP, for a sum increase of 5 months (see Figure 21).

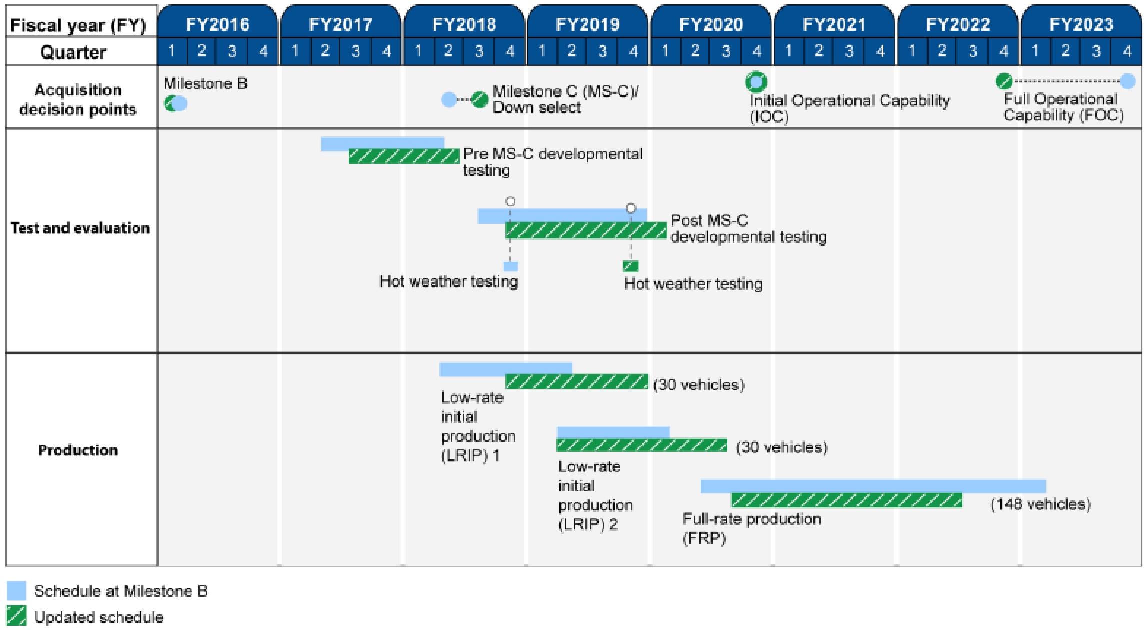


Figure 21. ACV MS B Baseline Schedule Compared to January 2017. Source: GAO (2017, p. 14).

As of December 2020, BAE announced the FRP award decision, and the program remains ongoing (Judson, 2020). Overall, ACV acquisition and initial fielding took 9 years from the MSA through the transition years to FRP–5 years longer than Gen Amos's original 4-year vision, even with EFV lessons learned.

5. DAS: Unit History Data

From the concept baseline in March 1995, the Marine Corps planned to acquire 1,025 EFVs (12 for RDT&E, 1,013 procurement). The quantity remained the same throughout the rebaselining and APB changes until 2007 when the amount dropped to 593 (19 for RDT&E, 574 procurement). Primarily, cost concerns drove this substantial 42% decrease in units. One of the last efforts to save the EFV program money and prevent cancelation resulted in a proposal for an additional unit decrease. GDLS recommended building only 200 units (16 for training, a mere 184 operational) in their final recommendation. According to them, this reduction would have saved the Marine Corps $6 billion (Feickert, 2011, Summary). Overall, the PMO attempted to retain EFV performance by sacrificing the number of units. The approximate halving of units occurred twice during the EFV program life cycle and represented a Marine Corps focus on amphibious performance over cost and schedule.

The ACV program reveals an opposing unit history. The first development APB in May of 2016 showed an estimated procurement quantity of 204 units. At the time, this initial quantity applied only to the ACV 1.1 increment. The production APB of 2018 also shows this number. However, since the 2019 decision to combine ACV 1.1 and 1.2, the objective quantity increased to 632 units (Mullins, 2020, p. 10). Therefore, the increase in unit quantity represents a Marine Corps focus on cost and schedule over the proposed 1.2 performance. For perspective, the United States produced a staggering 18,816 tracked landing vehicles (LVTs) during World War II (Adams, 1992).

6. PPBE: Cost History

Currently, funding levels are a significant driver in Marine Corps decision regarding acquisition programs. The CMC, Gen Berger (2019), expressly stated in his planning guidance that "every activity within HQMC must support the POM build and inform the PPBE process. Our current structures and processes fail to meet this standard" (p. 6). This statement highlights organizational challenges concerning Marine Corps resourcing efforts. Here, the CMC does not neglect the PPBE process but instead refocuses the Corps' actions on adequately allocating resources and practical programming. Historical cost overruns might have led the CMC to this statement, precisely like those exhibited by the EFV and other programs.

It is no surprise that the EFV cost the taxpayer billions of dollars, totaling $3 billion in developmental spending alone (Feickert, 2020, Summary). This sunk cost did not occur all at once, but over time. Initially, GDLS estimated that the EFV would be complete by October 2003, with an SDD phase cost of $712 million. In 2006, costs ballooned to $1.2 billion, an over 50% increase (U.S. House, 2008, p. i). Concerning unit costs, the original December 2000 developmental APB reported an estimated objective PAUC (including RDT&E, MILCON, and O&S) of $6.488 million (1993 base year). The final August 2007 developmental APB changed the base year from 1993 to 2007 based on an ADM on June 5, 2007. To compare, the DOD used a 1.2771 conversion factor. When converting the base year 2007 developmental APB PAUC of $22.240 million to the base year 1993, the total comes to $17.414 million. Therefore, in 1993 dollars, the PAUC estimates *increased by 268% in 7 years*, almost triple the original estimate.

Similarly, the 1993 base year APUC (rollaway cost) estimate increased from $5.312 to $13.118 million, *or 247% in 7 years*. Concerning the lesser APUC, the final EFV SAR reported the egregious $202.8 million/unit figure. Compared to the $16.7 million/unit APB of August 2007, one can calculate the 1,110.53% Nunn-McCurdy breach. The Total Ownership Cost (TOC) objective, which includes infrastructure and disposals costs, grew from $11.2 billion in 2000 to $22.4 billion in 2007 (converted to 1995 dollars), a *199% increase*. Again, planned units decreased from 1,013 in 1995 to 574 in 2007, not including test articles. Therefore, the *439-unit reduction* drove both the PAUC and APUC cost increases (DAMIR, 2007).

Unlike the EFV, the ACV program did not produce a conceptual APB, I assume due to the established SuperAV design offered by BAE–Iveco. It contained just one development and two production APBs. In the 2014 base year, the original May 2016 developmental APB reported an estimated objective PAUC of $7.612 million. As of November 2020, the current APB reports an objective PAUC of $7.136 million, revealing a decrease of $476,000 per unit. However, the current estimate in the September 2021 SAR lists a PAUC of $7.906 million, an estimated *increase of $294,000 per unit* (Defense Acquisition Visibility Environment [DAVE], 2022a). Concerning the lesser APUC, the final ACV SAR reported a $6.608 million/unit cost. Compared to the $5.797 million/unit APB cost of November 2020, one calculates an APUC *increase of 13%* (DAVE, 2022a). This number is less than the 15% significant Nunn–McCurdy threshold.

In analyzing both programs, the EFV chose to *decrease units* due to ballooning costs to save on performance. The ACV program, on the hand, decided to *increase units* by combining 1.1 and 1.2 increments, resulting in an overall decrease in long-term performance.

7. PPBE: Cost Trade-off Decisions

The 4 Rs give PMs convenient options for distributing resources to meet cost, schedule, and performance goals. The possibilities include *resourcing* priority programs, *restructuring*, *reengineering*, and underfunding and accepting the *risk*. At the time, the EFV remained the Marine Corps' priority ground vehicle program during development. In 2006, the EFV totaled 25.5% of the total Marine Corps acquisition costs. Figure 22 shows how the Marine Corps prioritized EFV *resourcing* across its other programs in 2006. Overall, the EFV was highly resourced compared to the service's entire portfolio.

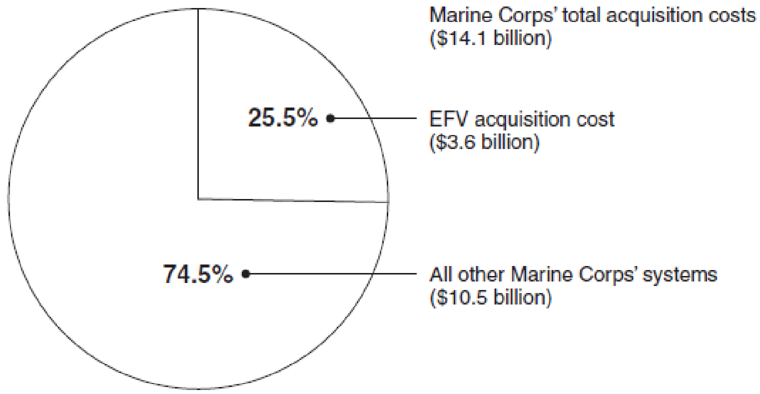


Figure 22. Comparison of EFV Acquisition Costs to All Marine Corps' Systems for FY2006-2011, Then Year Dollars. Source: GAO (2006, p. 6).

Since MS I in March 1995, management *restructured* the program multiple times. The most significant restructuring was the decision to repeat the SDD phase in August 2007. A 2010 GAO brief highlighted some of the leaders' efforts, stating that the PMO

> hired engineers, enlisted experts from the Army Material Systems Analysis Activity (AMSAA) and set up a restructured development effort to test redesigned components on existing prototypes while building seven new prototypes for a second OA and future reliability growth efforts. (GAO, 2010b, p. 9)

Additionally, reducing procurement quantities can be categorized as a significant *restructuring* decision. The EFV program attempted minimal effort to *reengineer* the program, either by adding efficiency or reducing capability. It tried to retain all proposed capabilities over time and continued implementing new requirements. However, some *reengineering* efforts resulted in a "reduction in high-speed transit sea state capability from 3-feet to 2-feet SWH; proposed removal of integrated Nuclear, Biological, and Chemical [NBC] protection; and reduction in required vehicle land range following amphibious landing" (GAO, 2010b, p. 13). Still, reliability issues persisted despite these attempts, especially when considering the associated space and weight specifications.

Overall, the EFV program accepted more cost *risk* than mitigated. Throughout the DOT&E events, reliability issues plagued the program. In 2006, "the most recent

DOT&E annual report found that the EFV system's reliability is the area of highest risk in the program" (GAO, 2006, p. 20). Additionally, DOT&E stated that the "EFV-equipped units will carry less equipment than current AAV-equipped units because of less internal volume. Interior noise and vibration levels limit the time Marines can ride in the EFV" (DOT&E, 2005, p. 127). Similarly, the PMO accepted these *risks* by trading costs and schedule for performance. It seems most of the *risk* stemmed from a poor initial design.

The ACV 1.1 program continues to be *resourced* appropriately. The GAO compared the ACV CAPE analysis with the president's budget submission in 2017. The independent cost estimate (ICE) came in lower in both development and procurement when compared to the president's budget (see Figure 23). However, the president's budget included early ACV 1.2 and 2.0 funding. With the *restructuring* of 1.2 to 1.1, the Corps could overfund the program resulting in future *reprogramming* fluctuations.

Then-year dollars, in millions	**Cost estimate**	**President's Budget 2017**	**Difference**
Development	810.5	951.8	141.3
Procurement	1,168.4	1,173.3	4.9

Figure 23. ACV 1.1 ICE to President's FY2017 Budget. Source: GAO (2017, p. 10).

The primary program *reengineering* effort surrounds the combination of the ACV 1.1 and 1.2 increments. This decision increased efficiency while simultaneously reducing capability, leaving the Marine Corps without a tracked amphibian. However, this decision balanced cost *risk* with performance. ASN(RD&A) James Geurts stated in April 2019 that combining increments is "much more cost-effective, and now we can focus some of that R&D on what is past 1.2, not just redoing the R&D for just the same of redoing it" (Lee, 2019). By *reengineering* the program this way, the Marine Corps can reprogram and focus on Marine Corps force design initiatives.

C. PROGRAM MANAGEMENT TOOLS

This section explores and analyzes data through some of the critical tools and processes available to a PM. Analysis criteria are split into five sections: KBA, SE, RM, T&E, and EVMS.

1. KBA: Adherence to Knowledge Points and Trust

In January 2004, the GAO released a best practice guide detailing using a *Knowledge-Based Approach to Improve Weapon Acquisition* (GAO, 2004). Additionally, Appendix A of the 2012 *Assessments of Selected Weapons Programs* provides detailed metrics (GAO, 2012). These documents remain a benchmark for how PMOs should "deliver sophisticated products in less time and at lower costs" (GAO, 2004, Summary). Knowledge Point (KP) 1 ensures that resources and current technology match requirements (see Figure 24; GAO, 2012, p. 20). KP 2 ensures the design is stable and performs as expected (see Figure 25; GAO, 2012, p. 20).

Knowledge Point 1: Technologies, time, funding, and other resources match customer needs. Decision to invest in product development
Demonstrate technologies to a high readiness level—Technology Readiness Level 7—to ensure technologies will work in an operational environment
Ensure that requirements for product increment are informed by preliminary design review using systems engineering process (such as prototyping of preliminary design)
Establish cost and schedule estimates for product on the basis of knowledge from preliminary design using systems engineering tools (such as prototyping of preliminary design)
Constrain development phase (5 to 6 years or less) for incremental development
Ensure development phase fully funded (programmed in anticipation of milestone)
Align program manager tenure to complete development phase
Contract strategy that separates system integration and system demonstration activities
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review for development start

Figure 24. KP 1 Key Practices. Source: GAO, 2012, p. 178.

Knowledge Point 2: Design is stable and performs as expected. Decision to start building and testing production-representative prototypes
Complete system critical design review
Complete 90 percent of engineering design drawing packages
Complete subsystem and system design reviews
Demonstrate with system-level integrated prototype that design meets requirements
Complete the failure modes and effects analysis
Identify key system characteristics
Identify critical manufacturing processes
Establish reliability targets and growth plan on the basis of demonstrated reliability rates of components and subsystems
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to enter system demonstration

Figure 25. KP 2 Key Practices. Source: GAO, 2012, p. 178–179.

KP 3 ensures that production processes are mature and can meet cost, schedule, and quality targets (see Figure 26; GAO, 2012, p. 21).

Knowledge Point 3: Production meets cost, schedule, and quality targets. Decision to produce first units for customer
Demonstrate manufacturing processes
Build and test production-representative prototypes to demonstrate product in intended environment
Test production-representative prototypes to achieve reliability goal
Collect statistical process control data
Demonstrate that critical processes are capable and in statistical control
Conduct independent cost estimate
Conduct independent program assessment
Conduct major milestone decision review to begin production

Figure 26. KP 3 Key Practices. Source: GAO, 2012, p. 179.

The EFV failed to follow the GAO KP best practices. Most prominent, according to KP 2, the GAO recommends that 90% of the engineering drawings be releasable before the critical design review (CDR). The official EFV program started during the SDD phase in December 2000. Just 1 month later, in January 2001, with only 84% of drawings completed, the program held its first CDR (GAO, 2006, p. 7). A 2008 House of Representatives report referenced the GAO analysis, stating that the EFV accelerated schedule "did not allow adequate time for testing, evaluating the results, fixing the problems, and retesting to make sure that problems are fixed before moving forward"

(GAO, 2006, p. 13). In fairness, the KBA methodology started around the same time, approximately 2 months before program initiation. “Starting in October 2000, DOD incorporated a KBA in its policy that guides major acquisitions and expanded this approach in its May 2003 policy” (GAO, 2006, p. 2). In another report detailing KBA, the GAO stated that “a best practice is to achieve design stability at the product’s CDR, usually held *midway through* [emphasis added] development” (GAO, 2004, p. 5). Fast-forwarding to December 2008, continued lapses in maturity were seen. After multiple rebaselines over 8 years, the program finally passed its second CDR with “94% of the system’s design models releasable” (Feickert, 2011, p. 4). This goal equates to only a 0.8% increase per year. Of note, Figures 27 and 28, respectively, reveal achievement/attainment of knowledge from December 2000 through December 2011. Through the 11 years, the GAO found that the design and technology maturity was never achieved.

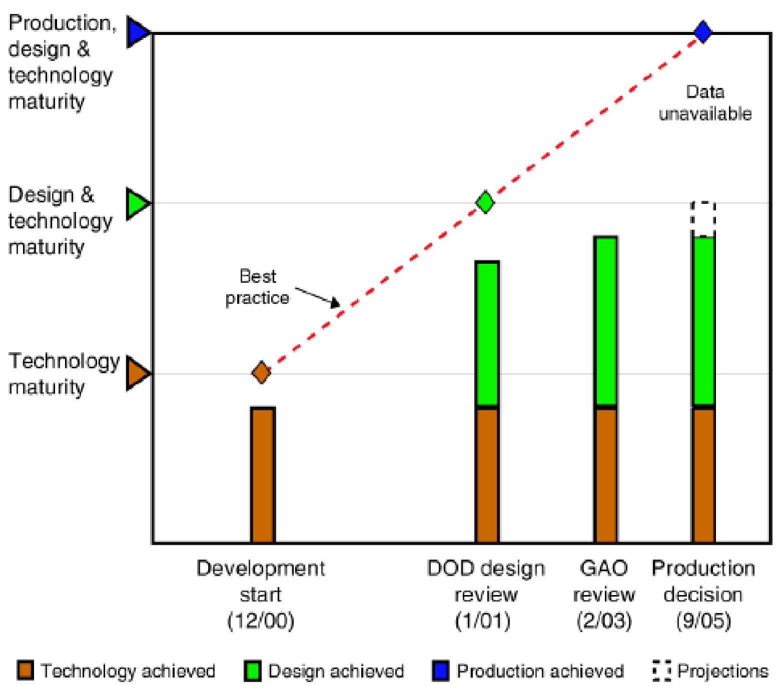


Figure 27. EFV Achievement of Knowledge. Source: GAO (2003, p. 15).

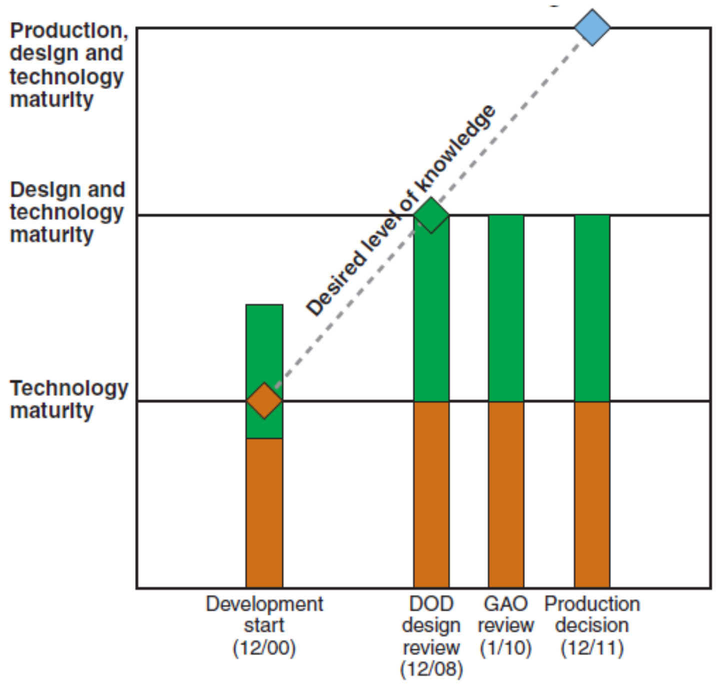


Figure 28. EFV Attainment of Knowledge. Source: GAO (2010a, p. 25).

The GAO reported that "four of the five [EFV] critical technologies had demonstrated an acceptable level of maturity at the start of product development" (GAO, 2003, p. 16). However, it is essential to note that KPs must comply with the program's acquisition strategy. The GAO mentioned that

> while it is necessary to demonstrate one KP before a subsequent one can be demonstrated, this alone is insufficient. Attaining one KP does not guarantee the attainment of the next one. Rather, the acquisition strategy for any program must provide for the attainment of each KP. Even in programs, such as the EFV, which were in a favorable position at the start of SDD. (GAO, 2006, p. 27)

It can be seen that although the GAO found the EFV started favorably, the program's accelerated schedule and unresponsive acquisition strategy permitted the EFV to proceed with an unstable design. Initially, the EFV program experienced the first form of trust RAND describes, "(1) appropriate trust–information is good, and the user trusts it" (Davis et al., 2005, p. 84). However, the PMO response to accelerating the schedule moved stakeholders to the second form, "(2) false trust–information is poor, and the user trusts it" (Davis et al., 2005, p. 84). KPs gained are fragile and fleeting without an underlying acquisition strategy that enables them. Despite the negative connotations and realized risk, the PMO accurately reported cost overruns and performance issues throughout execution. In this regard, the EFV program upheld its organizational trust by not violating its statutory responsibility. However, this trust eroded through their continued attempts at restructuring the SDD phases, five in total.

Concerning the ACV, while in the MSA phase in November 2011, the program conducted a thorough AoA while still under the MPC umbrella. During this time, the PMO was filled with unknowns, and the Marine Corps concluded that "in the near term, current technology and budget resources will not be adequate to attain the desired HWS of the ACV while still providing other desired capabilities" (GAO, 2014, p. 4). Concurrent with best practices, the Marine Corps adopted an early foundation of knowledge to match resources with what was technologically feasible. In contrast with the EFV, the "ACV 1.1 program completed at least 90% of expected drawings at the system-level CDR in July 2016. As of October 2017, the program office reported that it completed 100% of the expected design drawings, indicating that the design was stable" (GAO, 2018, p. 79).

Figures 29 and 30 detail the KPs over 2 years, revealing KP 1 and KP 2 attainment. However, according to the GAO, the Marine Corps did not meet KP 3 before the MS C FRP decision in November 2020. The GAO reported that

> the contractor identified two critical manufacturing processes since production start: (1) identifying the alignments of vehicle components, such as the transfer case and engine motor mounts, during hull fabrication and vehicle assembly, and (2) using thermal examination weld quality inspections of the vehicle hull after fabrication to determine weld quality. (GAO, 2021, p. 162)

Here, this lack of knowledge may delay deliveries or cause premature vehicle failures. By failing to demonstrate manufacturing processes, the ACV program chose to accept risk and proceed with full-rate production. Going forward, the PMO will benefit from not falling victim to third trust level identified by RAND's regarding the GAO's analysis, specifically "(3) false distrust–[where] information is good, and the user distrusts it" (Davis et al., 2005, p. 84). Knowledge should not be disregarded.

Overall, the ACV program upholds reliable risk-based decisions. However, like the FRP decision, I find minor trust erosion regarding the explanation for combining increments 1.1 and 1.2 in the first place. The CRS reported that "Navy and Marine Corps leadership announced that during the fall of 2018, ACV 1.1 prototypes demonstrated satisfactory water mobility performance in high surf conditions" (Feickert, 2020, Summary). This statement formed the basis for the increment combination. However, the 2019 combination ADM stated that "the recommendation was based on the demonstrated performance of the ACV 1.1 program meeting the requirements for the ACV 1.2." ACV 1.2 requirements included more than just water mobility. The 1.2 tracked requirement surrounded land mobility, which was not a 1.1 KPP. Therefore, the abandonment of ACV 1.2 reduces organizational trust by disregarding the intended purpose of the incremental approach to increase capability. With the planned 1.2 increment going away, the service may find it challenging to attempt incremental strategies in the future. Regardless of the aforementioned examples, knowledge, and trust remain high.

	Status at	Current Status
Resources and requirements match	**Development Start**	
• Demonstrate all critical technologies are very close to final form, fit and function within a relevant environment	●	●
• Demonstrate all critical technologies in form, fit and function within a realistic environment	○	●
• Complete a system-level preliminary design review	○	●
Product design is stable	**Design Review**	
• Release at least 90 percent of design drawings	●	●
• Test a system-level integrated prototype	○	○
Manufacturing processes are mature	**Production Start**	
• Demonstrate Manufacturing Readiness Level of at least 9 or critical processes are in statistical control	NA	NA
• Demonstrate critical processes on a pilot production line	NA	NA
• Test a production-representative prototype in its intended environment	NA	NA

● Knowledge attained, ○Knowledge not attained, … Information not available, NA Not applicable

Figure 29. ACV Attainment of Knowledge as of January 2018. Source: GAO (2018, p. 78).

	Status at	Current Status
Resources and requirements match	Development Start	
Demonstrate all critical technologies are very close to final form, fit and function within a relevant environment	●	●
Demonstrate all critical technologies in form, fit and function within a realistic environment	○	●
Complete a system-level preliminary design review	○	●
Product design is stable	Design Review	
Release at least 90 percent of design drawings	●	●
Test a system-level integrated prototype	○	●
Manufacturing processes are mature	Production Start	
Demonstrate Manufacturing Readiness Level of at least 9, or critical processes are in statistical control	○	○
Demonstrate critical processes on a pilot production line	●	●
Test a production-representative prototype in its intended environment	●	●

● Knowledge attained, ○ Knowledge not attained, ... Information not available, NA Not applicable

Figure 30. ACV Attainment Knowledge as of January 2020. Source: GAO (2020b, p. 113).

2. KBA: Decision Paradigms and the Scope of Knowledge

KP gates fall into the rule-based arena. Figures 29–30 attempt to rationalize and clarify milestone triggers. However, the KBA remains interpretive. KP definitions include word metrics like “estimate,” “analysis,” and “plan,” which allow for degrees of interpretation. Further, KP completion criteria are just that–an individual or entity “conducting” or “establishing” a measurement system, irrespective of content. Although KPs prove beneficial, management cannot disregard the human-in-the-loop. The human element within the KBA presents an inexplicable part of decision-making, melding decision-making with individual analysis. Because KBA involves many individuals, the autonomous decision-maker cannot disregard the necessity for trade-offs, especially when faced with complex designs. In 2002 General Conway, CMC, strongly advocated for the EFV’s range at the highest levels, stating that

> We’ve got to close [those] 25 miles. It’s an *absolutely essential requirement* [emphasis added] that we have that kind of capability. And from my perspective, sooner is much better because we shorten that period of risk that we’re in right now with the Navy ships not wanting to get close to those anti-access systems. (Johnson, 2007)

The CMC did not entertain the possibility of performance trade-offs. Consequently, in 2009, 19 years after the first GDLS award, a Seapower committee finally acknowledged the increasing anti-access/area denial (A2/AD) threat that limits self-deploying amphibians in supporting an amphibious forcible entry strategy. Similarly, the same committee continued to deliberate requirements arguing for adding detachable underbelly armor (Rutherford, 2009). Nevertheless, until its cancelation, EFV stakeholders attempted to overcome their technical, budgetary, and strategic obstacles related to requirements. Performance trade-offs were almost non-existent in that the program continued to increase its scope of knowledge, favoring rational solutions to every need. This paradigm contradicts the description of actual decision-making, which fails to capture complete rationality. Compared to the ACV, the EFV program relied more on the rule based DSS's rational aspects. Rebaselining actions, changing requirements, and increasing costs were considered manageable risks, not dangerous or uncontrollable issues. Consequently, the PMO's *scope expanded* to remedy these issues, stemming from an inability to bound the program and its knowledge.

The ACV differs from the EFV in that program officials adopted an incremental approach to attaining knowledge. From early 2011 to 2014, the Marine Corps spent 3 years formulating its requirements through numerous studies and industry days. Once the incremental efforts were decided, officials accepted trade-offs within a bounded paradigm. By favoring certainty, technical maturity, and realism, the PMO "muddled through" the acquisition environment to acquire the 1.1 vehicles (Davis et el., 2005, p. 9). This approach *limited the scope of knowledge* when compared to the EFV.

3. SE: Rechtin's Heuristics Application

Rechtin (1992) explained his heuristic methodology for system architecting. He described heuristics as "the use of empirical insights, tricks of the trade, and lessons learned from past successes and failures–that is, heuristics" (p. 67). When considering the EFV and ACV timelines, I categorized just six of his heuristics based on my interpretation and the applicability to the program.

a. Conceptual Phase (MSA)

(1) "Extreme requirements should remain under challenge throughout system design, implementation, and operation" (Rechtin, 1992, p. 67).

Early on, from 1995 to 2000, the EFV program could have benefited from this heuristic. The program received four special awards during this time. For example, the David Packard Excellence in Acquisition award signified "contributions which demonstrated exemplary innovation and the best acquisition practices" (USMC, 2000). Still, the potential existed for the PMO to misinterpret risk based on external praises and forgo early risk mitigation. The importance of getting the requirements right cannot be overstated. 60% of requirements were changed during the program, primarily due to reliability issues. However, *changing* a requirement is not synonymous with *challenging* its existence. In 2011, the EFV acknowledged the problem of adding requirements yet failed to correct it. For the ACV, the program began development in the EFV's shadow and benefited by understanding the cost of requirements creep. Throughout the initial NAV and MPC deliberations, ACV stakeholders remained skeptical of extreme requirements, such as HWS, and opted for an incremental approach to reducing complexity.

(2) "No complex system can be optimum to all parties concerned, nor functions optimized" (Rechtin, 1992, p. 67).

This heuristic applies more to EFV program complexity than the ACV. As the EFV program progressed from 1988 through 2011, costs grew as reliability and armor concerns caused more technical additions and refinements. Through five SDD phases, the program struggled to demonstrate a reliable capability. Various government reports highlight that the "schedule proved too ambitious" and "did not allow enough time to demonstrate the maturity of the EFV design" (GAO, 2006, p. 3). These statements infer that the EFV schedule was prioritized over cost and performance, which reduced the ability to mature the design. Officials would have benefited from adhering to KPs and applying judicious earned value metrics. Communication between stakeholders must be clear and concise to ensure all understand trade-offs. The implications of prioritizing the EFV's schedule early on were not communicated to the appropriate decision-makers.

The ACV PMO recognized an opportunity to capitalize on the prior lessons learned through its incremental approach. Following their market research efforts, ACV proponents chose an optimum path of least resistance. Although 1.1 presented minor capability improvements over the AAV, the proposed increments limited initial complexity and delayed the HWS decision. By waiting for HWS until ACV 2.0, stakeholders enable the growth of knowledge and technical maturity.

b. Build and Test Phases (TMMR, EMD)

(1) Within the same class of products and processes, the failure rate of a product is linearly proportional to its cost" (Rechtin, 1992, p. 67).

Following the OA in 2006, the EFV only completed two of the fourteen mission profiles. Consequently, the MTBOF requirement decreased from the initial 95 hours to 43.5 hours, while cost triggered two critical Nunn–McCurdy breaches. Notably, DOT&E recognized these issues and recommended the EFV program appoint a 'Blue-Ribbon Panel,' similar to the MV-22 tiltrotor aircraft, to analyze reliability, affordability, maintenance (RAM); design stability; and schedule realism. (DOT&E, 2006, p. 124). Undoubtedly, this panel would have proved beneficial to understanding the correlation between cost and failure. Yet again, the EFV's schedule trumped cost and performance. The ACV has not seen significant cost increases or losses due to the existing SuperAV foundation. However, this heuristic will apply if modifications are made for ACV 2.0.

(2) "Regardless of what has gone before, the acceptance criteria determine what is actually built" (Rechtin, 1992, p. 67).

The EFV program pushed forward with the initial requirements, adding others along the way. As a result, each prototype lot experienced its own type-failures affecting different components. Consequently, in February 2007, following an OA in 2006, "The Navy announced that it would have to relax EFV performance and reliability requirements for the program to continue" (Feickert, 2011, p. 4). This heuristic highlights the need to get the requirements right from the outset to prevent drastic design changes and prototype modifications, which increase the cost.

The ACV acceptance criteria began in 2011, and the Marine Corps outlined five options moving forward from the EFV. The possibilities included upgrading legacy

AAVs in different configurations, continuing with the EFV, or developing new vehicles. Initially, the service canceled the MPC program due to its redundant and incorrect requirements (acceptance criteria). Once resurrected as the ACV with the appropriate criteria, the incremental approach enabled the PMO to delay the HWS requirement. Still, ACV 2.0 requirements are not advertised and cannot be scrutinized. Like the tracked- and ship-to-shore criteria of ACV 1.2, the HWS ACV 2.0 requirement lacks early definition. Currently, the Marine Corps will benefit from industry engagement if it intends to continue with HWS. ACV 2.0 risks failure if the criteria remain vague.

c. *Operations Phase (P&D, O&S)*

(1) "The first quick-look failure analyses are often wrong" (Rechtin, 1992, p. 67).

The first EFV program audit was conducted in December 2002, spurring multiple program rebaselines over the life cycle. One auditor stated that "management does not have a handle on reality, particularly with the unrealistic schedules" (U.S. House, 2008, p. 3). Proposed schedules were "described by some individuals as a paper dream that everyone accepts but have only a casual resemblance of reality" (U.S. House, 2008, p. 3). The rationale behind three of the rebaselines surrounded late prototype deliveries, added time testing, and budget constraints (GAO, 2006, p. 9). The EFV was in a constant *first quick-look* stage, constantly addressing issues and adjusting the prototype designs. Therefore, this heuristic may have funneled the PMO into an early false sense of security in that an overreliance on prototyping potentially exacerbated critical design issues.

(2) "The beholder, not the architect, defines success" (Rechtin, 1992, p. 67).

Since the first LVT amphibious vehicles in the 1930s, the Marine Corps remains historically and lawfully connected to the amphibious capability. Throughout EFV development, the Marine Corps remained dedicated to producing the vehicle despite growing issues. Even Secretary Gates rationalized the vehicle when he canceled it, stating that "if pursued to completion without regard to time or cost, [the EFV] would be an enormously capable vehicle" (Feickert, 2011, p. 7). As the heuristic suggests, determination does produce results; however, high-level decision-makers remain bounded within "Big A" constraints. As a result, the Marine Corps eventually terminated the EFV program.

The CMC "called the ACV program the service's top ground priority" (Freedberg Jr., 2014a). As the amphibious vehicle guardians, the Marine Corps again looks to reattack its statutory amphibious commitment. Even though the ACV does not provide a tracked or HWS capability, the Marine Corps defined success with the 1.1 increment.

4. SE: Design Change Process

The EFV began on the heels of two previous failed amphibious vehicle replacements. First, the LVA program and the OTH requirement were canceled in 1979, citing "vulnerability, affordability, and maintainability" (Adams, 1999, p. 22). Then, the following replacement program, LVT(X), was canceled in 1985, citing minimal firepower and armor improvements compared to the AAV SLEP option (Adams, 1999, p. 24). The Marine Corps and GDLS systems engineers faced significant design hurdles during EFV development with this unfortunate acquisition history.

Initially, the PMO noticed that SE processes required an update. As a result, they revitalized their SE configuration management processes during the development with the introduction of a virtual design database (Bolon, 1995, p. 8). The new process shown in Figure 31 included seven steps to ensure each engineering design change was appropriately routed and approved.

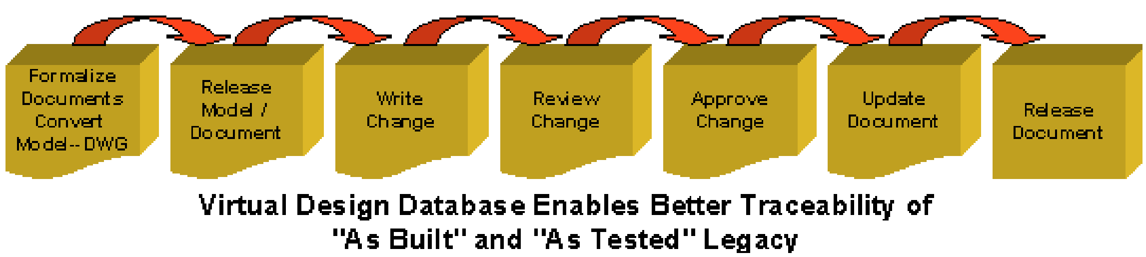


Figure 31. EFV Configuration Management Process. Source: Bolon (1995, p. 8).

Yet, following the Air Force Software Technology Support Center (STSC) audit in December 2002, the standardized EFV SE change process became combined with an unusual "test-fix-test" approach (U.S. House, 2008, p. 3-4, 11). This approach grew from the aggressive schedule set early in the SDD phase. However, it caused more problems than it solved. For example, redesigns took multiple prototype iterations, specifically with the blow flap and hell electronics unit (HEU). “Under the ‘test-fix-test’ process, the contractor would fix problems as they were discovered, rather than minimize problems through a comprehensive design process” (U.S. House, 2008, p. 3). Program officials viewed the “test-fix-test” approach as risk mitigation, while auditors found it “exacerbated the risks” (U.S. House, 2008, p. 4).

As late as 2010, the PM stated the program increased its reliability efforts using “overarching SE processes to mature the design” (GAO, 2010a, p. 62). However, at the same time, risks continued to grow with added capability, which aggravated challenges already apparent in the SE process. Before the “test-fix-test” implementation and requirement additions, a 2006 audit saw SE as a significant problem. Early on, auditors stated that “the SE process is inadequate and a major shortcoming of the EFV program. It is a *root cause* of … disarray, uncoordinated design decisions, reliability issues, and the general lack of planning and status monitoring” (U.S. House, 2008, p. 5). Even earlier, 2002 DOD auditors said, “There seems to be no one steering the ship technically on either the [government] or [contractor] sides” (U.S. House, 2008, p. 5). Roger M. Smith, deputy assistant secretary of the Navy, expeditionary warfare, stated during congressional testimony in 2007,

> Through four different independent assessments, we have determined that the lack of SE that was not performed is one of the main factors that caused the reliability to be so poor. (United States House of Representatives Armed Services Committee [HASC], 2007)

Following the Nunn–McCurdy breaches and the subsequent notification to Congress, in early 2006, the Marine Corps requested to extend the development effort of the EFV. The Pentagon agreed, and the program continued. Then, the 2006 OA revealed that “the vehicle’s poor reliability has shown the vehicle is too immature to graduate on schedule to the next phase” (Castelli, 2006). The system complexity of the EFV became overwhelming. While SE issues were identified by many, they were not corrected by the program office in time. Due to poor results, the PEO and Congress floated cancelation options as early as 2007. In an EFV update to Congress, the Deputy Under Secretary for

Defense for Acquisition and Technology David Ahern, when asked if cancelation was an option, replied that "it is a possibility, yes, sir … that is certainly a possibility" (HASC, 2007). However, following the testimony, one analyst stated that "the Marines had little choice but to continue with the existing EFV program, given the 'decrepit' state of the current AAV. … There is no time to start over" (Shalal-Esa, 2007). Therefore, the Marines found themselves in a bind, deciding whether to correct their systems issues or cancel the program. The talk of cancelation swirled overhead the program for 4 years until 2011.

In 2013, the Marine Corps took a different approach with the ACV, looking to leverage DARPA's AVM portfolio and industry challenges to assist in their new amphibious vehicle design efforts. In a 2010 briefing, DARPA's AVM vision looked to "shorten development times for complex defense systems" (Eremenko & Wiedenman, 2010, p. 33). Early on, DARPA understood the SE challenges surrounding a new complex amphibious vehicle and desired to crowdfund a solution. BAE Systems teamed up with DARPA during this time and became an early proponent of their vision, which undoubtedly benefited early SE efforts. Figure 32 shows a 2010 DARPA industry brief on the standard SE-V. Their vision incorporated an iterative SE-V diagram, which included size, weight, and power (SWaP) considerations to confront complexity (see left side). Despite these efforts, the Corps mandated in 2013 "that any design be based on existing platforms," especially given the budgetary pressures of their environment (Military.com, 2013). Thus, BAE teamed up with Iveco to modify its established SuperAV design (Trevithick, 2018).

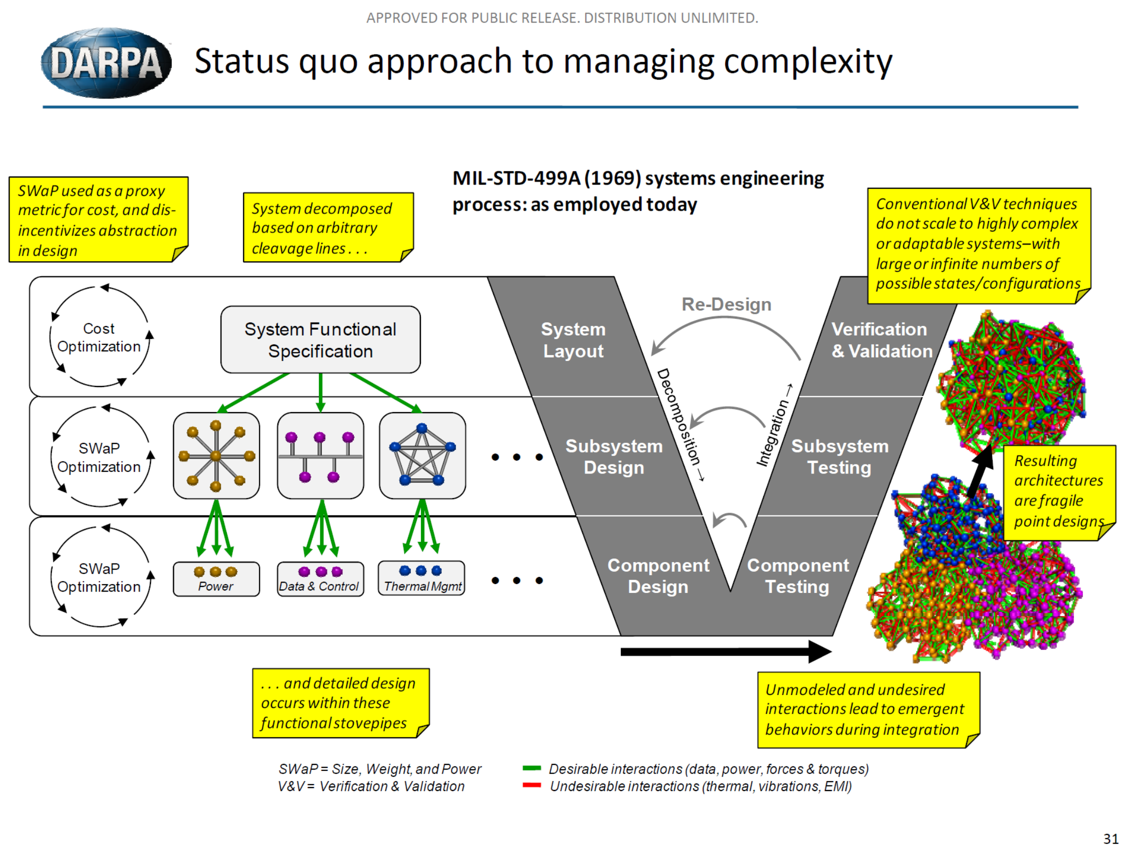


Figure 32. DARPA SE Complexity-V. Source: Eremenko and Wiedenman (2010, p. 31).

However, some ACV design elements were missed by engineers at the beginning, which caused challenges with reliability metrics. A 2019 DOT&E report stated that "based on reliability growth testing, ACV demonstrated reliability was 27% of its planned growth estimate" (DOT&E, 2019, p. 113). Recent ACV engineering changes affect the suspension, steering, RWS, cold weather considerations, and force protection. Additionally, the recent August 2020 AAV mishap highlighted amphibious vehicle safety requirements. Like Congress's concerns over EFV IED protection, the ACV PMO now faces more scrutiny over the ACV design, survivability, and egress (Feickert, 2021, p. 2).

Overall, there is no indication of poor SE effort within the ACV 1.1 compared to the EFV. The Marine Corps has simplified its strategy, shifting away from ACV 1.2 changes, folding them into 1.1. Prior, the CRS reported that the "Marines planned to develop ACV Increment 1.2, a *tracked* [emphasis added], fully amphibious version" (Feickert, 2020, Summary). The Corps' ACV Product Manager responded that "part of the 1.1 effort was to test the vehicle to the 1.2 requirements … which really centered around a more robust swim capability in the ocean" (Eckstein, 2019). Therefore, the requirement to base the ACV design on an existing platform requires the Marine Corps to change that existing platform and add the *tracked* 1.2 capability. Here, the cost and schedule implications were deemed unacceptable. Since the increment consolidation, the ACV 1.1 completed 12 of 13 mission sets during initial operational T&E (IOT&E), but tire failures continue plaguing the vehicle (Athey, 2021). Still, the program continues exercising BAE–Iveco contract options and following FRP in December 2020, and ACV 1.1 is on track. The tire failures are not related to a faulty SE process but the terrain. Although I have not found any reports of a potential ACV 2.0 change implementation, it is clear the Marine Corps will again have to determine if the existing 1.1 platform can be effectively modified to meet the following increment requirement.

5. RM: Critical Technology Risk

Throughout the EFV acquisition effort, stakeholders increased system complexity and promoted new requirements throughout the fluid 22 years after the program started. Following the first and second SDD phases, the primary program challenges concentrated on the overall SE scope, architecture, and absence of engineering leadership (U.S. House, 2008, p. 5-6). Therefore, Congress recognized the SE issues in the program, but the service struggled to implement changes.

After the third rebaselining in 2003, the EFV program met distinct challenges with the HEU, hydraulics system, and bow flap. Each of these subsystems required multiple redesigns throughout the SDD phases. Then, Congress and the DOD focused on Afghanistan and Iraq, and technologies and requirements shifted. For example, the 2004 DOT&E annual report stated that "the Marine Corps recently formalized the IED requirement for the EFV but did not make it a KPP for the program" (GAO, 2010a, p. 62). Although the previous technologies remained concerning, armor became the focus. However, size and weight were already plaguing the EFV. Therefore, complexity continued to grow, dragging down reliability targets.

The 2006 OA again shifted stakeholder criticality focus. The assessment reported significant issues with the *gun turret*. Specifically, "the turret basket floor bent and a turret support stanchion broke … suggesting the turret structure might not be sufficiently robust to survive the force generated during cross-country movement" (U.S. House, 2008, p. 8). Concerning *HWS*, "Approximately 1,900 pounds of armor had to be removed" to achieve the requirement (U.S. House, 2008, p. 9). Officials also pondered removing the nuclear, biological, and chemical (NBC) system and reducing land range as options to save weight as late as 2010 (GAO, 2010b, p. 12). Finally, *excessive noise and limited visibility* concerned OA evaluators. These three technologies issues compounded other issues already plaguing the program. Other critical problems surrounded the thermal sights for night operations, the thermal signature from the exhaust, and the ammunition feed system that jams and damages rounds (U.S. House, 2008, p. 10). SECDEF Gates stated that he canceled the program due to "significant technology problems, development delays, and cost increases" (Feickert, 2011, p. 7).

In 2015, during the ACV TMMR phase, ONR hosted a HWS forum. One briefing highlighted the technology challenges faced by the ACV program (see Figure 33). Gen Amos, CMC, understood the technological challenges the EFV faced. However, concerning ACV HWS, he stated that "my sense is the S&T [science and technology], the R&D [research and development] is not quite there yet" (Freedberg Jr., 2014b). As a result, the Marine Corps opted for the incremental approach to reducing risk through mature technologies.

During ACV 1.1 development, few critical technologies have surfaced as insufficient. In 2018, DOT&E mentioned that the government-furnished RWS does retain advantages over the AAV up-gunned weapon system. However, in their 2019 annual report, DOT&E found that the RWS optics "were prone to icing and fogging and could lead to performance or reliability problems" (DOT&E, 2019, p. 113). The *FY2020 DOT&E Annual Repor*t stated that the RWS "was the source of the largest number of operational failures" (DOT&E, 2021, p. 121). Additionally, the CRS echoed DOT&E concerns, stating,

> The government-furnished RWS–an internally controlled, exterior-mounted MK 19 automatic grenade launcher or M2 .50 caliber heavy machine gun, was the source of the largest number of operational mission failures (OMFs). The government furnished RWS reliability issue was reported by the GAO in 2019. (Feickert, 2021, p. 2)

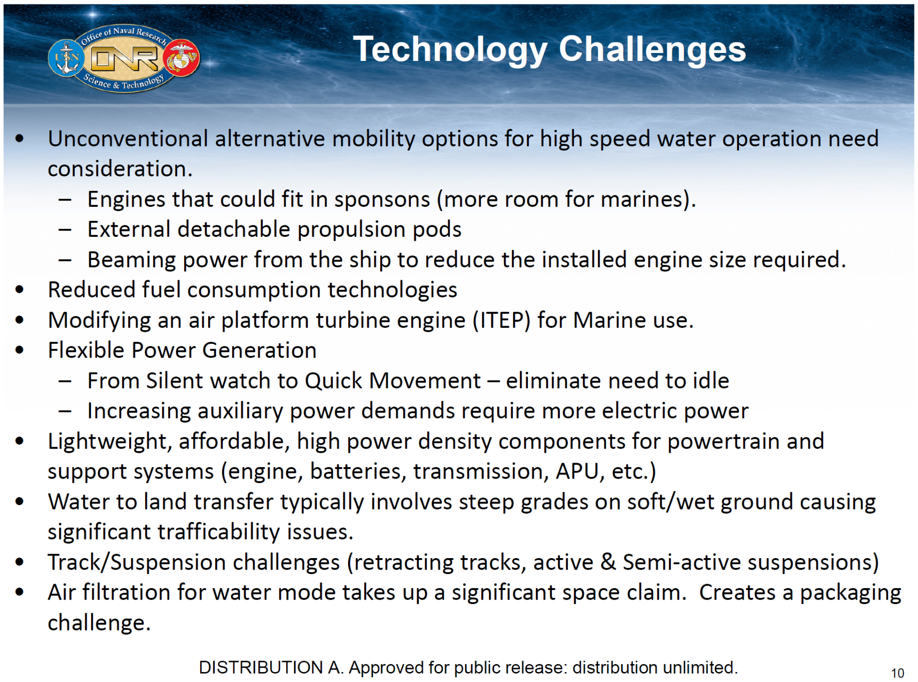


Figure 33. ACV 2.0 Challenges. Source: Tasdemir and Sumner (2015, p. 10).

The most concerning aspect of ACV procurement surrounds future variants. The personnel variant remains the focus of the ACV program office (DOT&E, 2021, p. 121). However, three other variants require attention, including the ACV-C, ACV-30, and ACV-R. These will undoubtedly experience technology risk due to the integration of modern technology on an existing platform due to the unique characteristics of each subsystem.

Each ACV variant is currently planned as a wheeled vehicle, decreasing terrain mobility yet increasing range. DOT&E’s 2020 annual report mentioned that tire failure “led to 2-hour mission delays while crews replaced or swapped tires” (DOT&E, 2021, p. 122). Additionally, “Other subsystems with a high failure rate included suspension components, hatch and ramp sensors, and switches” (DOT&E, 2021, p. 123). Overall, the RWS and tires present *critical technology risks,* and future variants offer an *unknown number of subsystem risks*.

6. RM: Risk Mitigation Activities: Accept, Avoid, Transfer, Control

Chapter II found that a proper risk analysis aids the PM and provides four typical responses: accept (and monitor), avoid, transfer, or control the risk (DAG, 2021). Here, I have found examples of each mitigation and have separated them by program and activity.

a. EFV: Accept

The EFV program *accepted* tremendous risk throughout its development. More resources might have reduced risk; however, the SECNAV decided otherwise. The most suggestive evidence for *accepting* risk stems from the program's aggressive initial schedule. From the beginning of the first SDD phase in December 2000, the program schedule allowed just 1 month before the CDR in January 2001. Due to this accelerated review process, GAO KPs were not met, and the schedule slipped soon after with 2 12-month extensions. IED and mine threats presented another area where the program *accepted* risk. The program worked to incorporate survivability upgrades, but the Marine Corps' response did not include a V-shaped hull redesign. Instead, to provide the necessary protection, their response centered around an "underbelly armor applique after the EFV comes ashore" (Feickert, 2011, p. 5-6). The Corps suggested that "the EFV would have to be totally redesigned at great cost to incorporate a V-shaped hull" (Feickert, 2011, p. 5). The decision to forgo a hull re-design revealed one example when the USMC chose to trade performance.

b. EFV: Avoid

EFV decision-makers *avoided* just minimal risk during execution. For example, in June 1996, the decision to co-locate the EFV program office with the prime contractor showed a potential effort to prevent risks associated with contractor communication. Cost as an Independent Variable (CAIV) presented another perceived risk *avoidance* technique early on. In 1996, DOD 5000.2R established CAIV in acquisition regulation and ushered in the beginnings of the trade-off process, now common among government programs (Rush, 1997, p. 161). The CAIV analysis allowed decision-makers to conduct constraint trade-offs as the program matured, which discounted cost as the sole driver of the program. The EFV won an award for implementing this new strategy. Accordingly, this process benefited the program by *avoiding* early performance and schedule growth while lessening their hardline cost goals. However, one article critiquing CAIV stated that "to some extent, previous attempts at cost-performance trades fell victim to inflexible requirements from the user or over-specified requirements by the acquirer" (Rush, 1997, p. 164). Therefore, while CAIV enables flexibility, the EFV program fell victim to strict requirements and poor design.

c. EFV: Transfer

Due to combining stringent requirements and the CAIV strategy, the EFV program began *transferring* risk into T&E activities. Consequently, T&E activities requested multiple schedule extensions to perform their mission. The GAO highlights one extreme example where "two key performance parameters—reliability and interoperability—[were] not scheduled to be demonstrated until the IOT&E phase in FY2010, about 4 years after LRIP has begun" (GAO, 2006, p. 21). The program office did acknowledge these reliability issues as early as the 2002 audit. However, throughout development, risks continued to be *transferred* to critical T&E events from other program areas.

d. EFV: Control

EFV officials looked to *control* risk in the program but shifted the schedule and cost goals in the process. While attempting to manage the accelerated schedule, the PMO implemented a "test-fix-test" approach in late 2002 to *control* risk. This approach is a departure from normal T&E processes, and it contributed to the delayed testing of the initial prototypes. Consequently, "Testing continued for 3 years into SDD, well after the program office established the SDD critical design decision to begin building the SDD prototypes" (GAO, 2006, p. 12). Here, controls address the *symptoms* of poor SE and the accelerated schedule. In mid-2010, the GAO prepared a report for the SECDEF in reviewing the EFV business case. The EFV PMO identified four significant risks and highlighted mitigation measures. However, their response included phrases such as "working with," "achieve," and "provide" without detailing the specific actions to mitigate the risk (see Figure 34). Overall, the program took 3 years after the last rebaselining and 22 years after the original AAAV baseline before determining the vague control measures in 2010 (GAO, 2010b, p. 20).

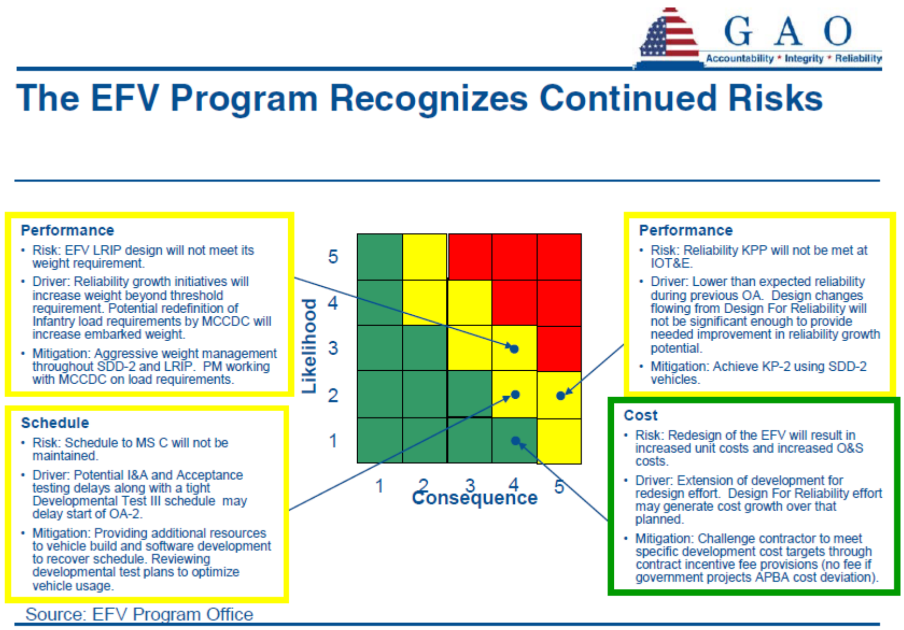


Figure 34. EFV Risk Assessment. Source: GAO (2010b, p. 20).

e. ACV: Accept

Firstly, the ACV does *accept* more cost and performance risks than its previous in-service amphibious vehicle, the AAV, but significantly less than the EFV. One ACV critic stated that "the taxpayer will be footing the bill for a connector [ACV] that holds fewer Marines than in 1972 (13 versus 20), swims at the same speed, and is more expensive" (Groom, 2018). The performance characteristics do seem to resemble the status quo, the AAV. Compared to the EFV, the ACV offers significantly less performance at lower cost.

The ACV program also chose to *accept* manufacturing risk. Specifically, a 2020 GAO report recommended that "the Marine Corps (1) not enter the second year of LRP for ACV 1.1 until after the contractor has achieved an overall MRL of 8, and (2) not enter FRP until achieving an overall MRL of 9" (Feickert, 2020, p. 9). The Marine Corps stated that it was "reasonable to proceed at lower MRL levels if steps are taken to mitigate risks" (Feickert, 2020, p. 9). However, the report did not detail mitigations or controls. In December 2020, the Marine Corps *accepted* the risk and decided to proceed with MS C and FRP.

The Marine Corps also *accepts* risk by reneging on its original incremental acquisition strategy, even if realizing cost savings. Initially, the "ACV 1.1 was meant to get vehicles to Marines quickly so men and women in the field could provide feedback and help refine the requirements for ACV 1.2" (Eckstein, 2014). Nevertheless, the Corps' decision to combine increments removed the option for users to provide feedback on 1.2 improvements. Lastly, the ACV *accepts* the specific terrain-associated risk with its wheeled design.

f. ACV: Avoid

The ACV program *avoided* new vehicle development risk by modifying an already established amphibious vehicle, the SuperAV by Iveco. The BAE–Iveco team does retain Marine Corps-specific subsystem risk during modification; however, overall design risks remained minor. Interestingly, early on during the program start, the Marine Corps incentivized industry to merge ACV requirements/increments. As industry competitors, GDLS, BAE–Iveco, and Lockheed Martin researched competing for the initial award, the Marine Corps continued their ACV 1.2 incentives. In 2015, CMC General Dunford stated, "My assessment … is industry is leaning into our requirements for 1.2 even as they try to deliver 1.1, and I think they'll get pretty close" (Eckstein, 2015). This tactic resembles a risk *avoidance* technique pertaining to future increment costs.

g. ACV: Transfer

MCCDC stated that ACV 2.0 and the HWS requirement continue to be a "conceptual placeholder for a future decision point (~2025, or sooner)" (MCCDC, 2018). Therefore, the Marine Corps continues to *transfer* the HWS requirement to a future acquisition life cycle. However, needs, resources, and threats will change by that time, and it remains possible this risk *transfer* will disappear.

h. ACV: Control

The Marine Corps continues to execute its in-depth T&E Master Plan (TEMP), integrating developmental, operational, and live-fire tests. Current recommendations to *control* risk include "implementing corrective actions on future LRIP vehicles to reduce failure rate and maintenance demand … provide equipment that allows more efficient tire changes [and] … consider the modification of troop seat pad to accommodate infantry body armor" (DOT&E, 2021, p. 123). Overall, *control* efforts surround minor design and equipment modifications and do not associate with significant engineering issues.

7. T&E: Expected Outcomes vs. Test Results

The EFV program reached MS II, currently MS B, and entered a 3-year SDD phase from December 2000 to October 2003. The original plan called for the MS II decision in the third quarter of 2001; however, "increased funding from Congress … contributed to the Program Office's ability to accelerate the MS II decision" (DOT&E, 2001, p. IV-2). Consequently, the program required that the planned live-fire T&E (LFT&E), early operational assessment (EOA), and other test events shift left. This move gave both developmental and operational test (DT/OT) authorities minimal time to analyze EFV testing requirements. Smartly, the program identified the risks associated with accelerating the schedule in the DOT&E *FY2002 Annual Report*. Still, the nonstandard "test-fix-test" approach persisted. This unusual test process gave the contractor freedom to "fix problems after they were discovered rather than anticipating them through a comprehensive design process" (U.S. House, 2008, p. 3). Concurrently, the Marine Corps paid GDLS "over $60 million in bonuses, including $25.6 million in bonuses for a 'very good' job in being on schedule and under cost" (U.S. House, 2008, p. ii). Strikingly, DOT&E reported that the PM relied upon and referenced "several contractor-conducted tests and analyses" and did not provide results to DOT&E (DOT&E, 2001, p. IV-4). Consequently, critics note that the ambitious upfront schedule "did not allow enough time to demonstrate the maturity of the EFV design" (GAO, 2006, p. 13).

The 2006 OA represents another turning point for the threatened EFV program. The assessment "revealed the EFV's inability to consistently get on–plane in water without employing a driving technique that caused uncontrolled vehicle turns and unsafe operating characteristics" (DOT&E, 2009, p. 126). DOT&E explained that

> EFVs often could not get *on–plane* [emphasis added] when combat-loaded unless drivers employed a hands-free technique, in which they did not steer while getting on–plane, which typically led to large, unpredictable turns in the water. This would be an unsafe condition for combat with multiple vehicles. The inability to demonstrate this critical performance characteristic without significant and impractical physical modifications to the vehicles and potentially unsafe and tactically unsound operating procedures highlighted a major performance concern. (DOT&E, 2007, p. 120)

One of the requirements of the EFV was to self-deploy OTH for joint forcible entry missions. However, due to various testing failures and program issues, DOT&E reported *in late 2009* that "there has been no end-to-end testing of the vehicle's weapon system in the water" (DOT&E, 2009, p. 126). The most noteworthy T&E outcome surrounds the vehicle's abysmal reliability test data. As early as 2004, DOT&E highlighted the MTBOMF risk, stating that "the risk is high that the vehicle's 70-hour MTBOF requirement (a KPP) will not be met during IOT&E" (DOT&E, 2004). Following a significant program restructuring in 2007, the Marine Corps reduced the MTBOMF objective/threshold from 95/70 hours to 56/43.5 hours. During the second CDR conducted in 2008, the Marine Corps "predict [ed] a reliability of 56 hours MTBOMF based on models and prediction processes" (GAO, 2010a, p. 62). However, the PMO expected *newly scheduled prototypes* "to demonstrate on average at least 16 hours of operation between operational mission failures, which will keep the EFV on the reliability path needed to reach its minimum requirement of 43.5 hours" (GAO, 2010a, p. 62). GDLS planned to deliver these prototypes in August 2010, with an OA scheduled for April 2011. Notably, this was around the same time as SECDEF Gates began questioning the future of amphibious operations.

Overall, the test data revealed awful results. The GAO reported that the EFV program "anticipated 17 hours of MTBOMF reliability, but by Marine Corps Test and Evaluation Agency's (MCOTEA) measure achieved *4.5 hours* [emphasis added]" (GAO, 2010b, p. 9). The U.S. House, Committee on Oversight and Government Reform stated that "on average, the vehicles could operate only 4.5 hours between breakdowns and required approximately 3.4 hours of corrective maintenance per operating hour” (U.S. House, 2008, p. 8). At program cancelation, a 4.5-hour MTBOMF represents only 6.4% of the original 70-hour threshold or 10.3% of the restructured 43.5-hour threshold. Figures 35 and 36 detail the initial reliability growth alongside the updated 2006 plan and represent significant differences from measured T&E results.

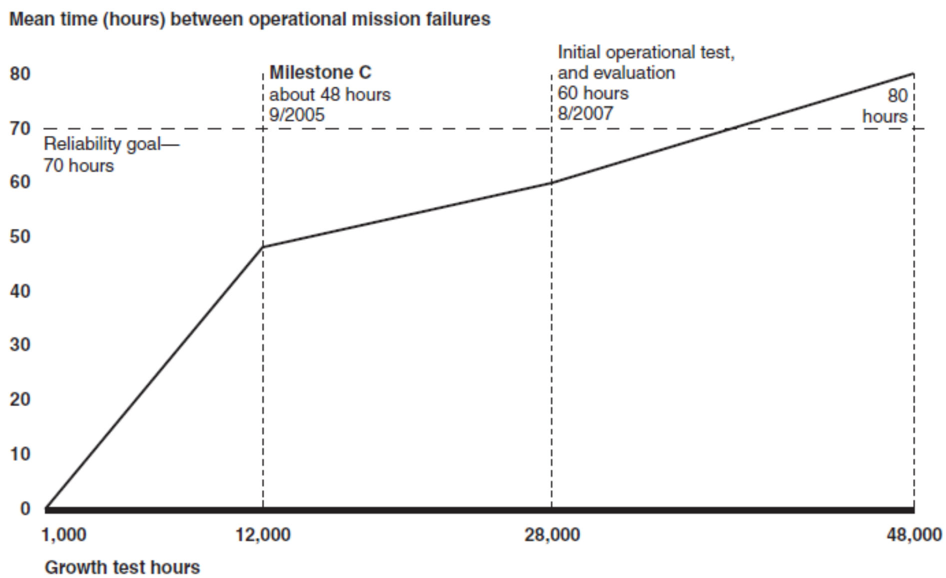


Figure 35. Original EFV Reliability Growth Plan. Source: GAO (2006, p. 19).

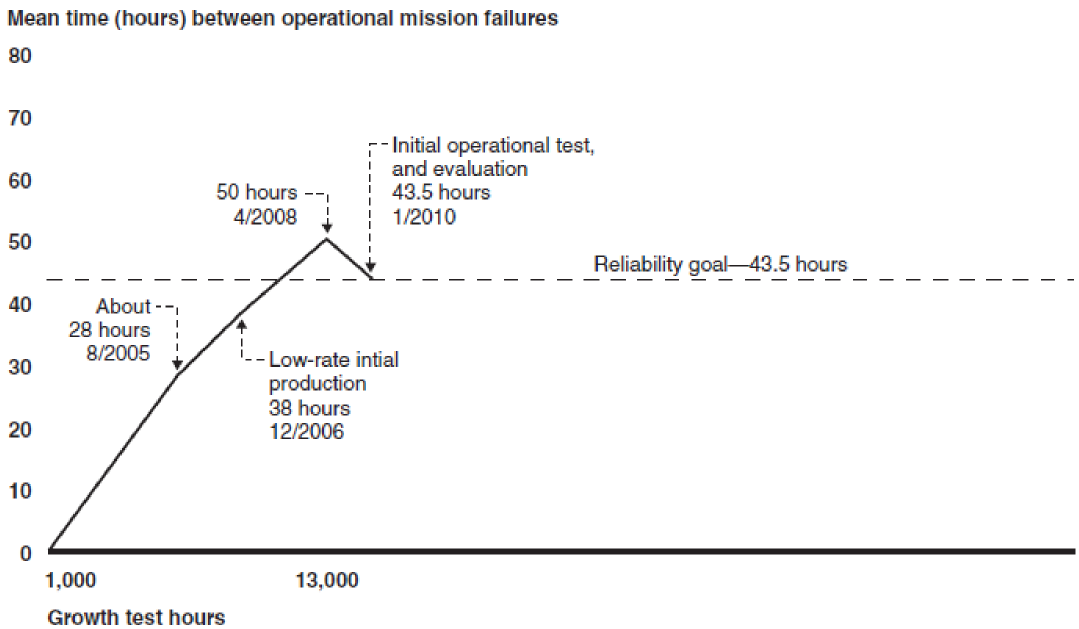


Figure 36. 2006 EFV Reliability Growth Plan. Source: GAO (2006, p. 20).

In retrospect, the GAO recommended in 2006 that the program should have allowed for early prototype testing before the original CDR to incorporate changes into the SDD prototypes. However, this 2006 recommendation does not alleviate 4-plus years of poor reliability. The crux of the T&E failures was more profound, spanning multiple disciplines.

Concerning the ACV, full-up system-level and live-fire tests began at Aberdeen Test Center in December 2018, completing in August 2020. In addition, the PMO conducted a logistics demonstration in December 2019, and MCOTEA ran IOT&E from June 1, 2020, to September 5, 2020 (DOT&E, 2020, p. 122). Overall, ACV T&E remains on track, despite 3- to-4-month schedule slips due to "supply chain challenges" and an "overly optimistic learning curve" (GAO, 2020b, p. 114).

In FY2018, DOT&E reported, "Based on data from the OA, reliability is below the program reliability growth curve (58 hours MTBOMF). BAE vehicles demonstrated 24.9 hours MTBOMF. There were no systemic problems identified that indicate a major redesign is required" (DOT&E, 2018, p. 119). In FY2020, DOT&E reported that "while the ACV demonstrated good operational availability and maintainability during IOT&E, it did not meet its 69-hour MTBOMF threshold … The ACV demonstrated an MTBOMF of 39.0, which is less than the 69-hour MTBOMF reliability requirement" (DOT&E, 2020, p. 121). Therefore, the most up-to-date reports showed that the ACV reliability growth reached only 56.5% of its 69-hour threshold and pursued FRP. Given reliability concerns inherent with amphibious vehicles, the program requires a significant increase in this area post-FRP. The program does "plan to continue reliability improvement efforts beyond full-rate production" (DOT&E, 2020, p. 123). If unable to reach the 69-hour threshold, the program will experience reduced effectiveness and A_O, a KPP. The ACV did not require significant redesign following the 2018 OA. However, DOT&E has identified various issues to fix, such as suspension damage, the arrangement of the troop commander station, cold weather kits, and government-furnished remote weapon systems (RWSs). Of note, DOT&E reported that "The RWS … was the source of the largest number of [operational maintenance failures] OMFs" (DOT&E, 2018, p. 120).

In 2021, the GAO reported that "during testing to support the FRP decision, testers determined that the ACV was operationally effective, suitable, and survivable" (GAO, 2021, p. 162). However, similar to the EFV, reliability became an issue. Of note, one difference in terms of requirements between the programs is the reliability metric. The EFV lists MTBOMF hours as a KPP, while the ACV program does not. Still, the GAO found that the ACV program "did not meet all reliability, availability, and maintainability threshold requirements" (GAO, 2021, p. 162).

Currently, ACV program tests remain ongoing. Pending the results, user feedback could result in minor redesigns. Of note, the program did combine IOT&E with LFT&E, and a report was submitted to Congress in November 2020 (DOT&E, 2022, p. 294). However, I did not find the results and could not correlate issues with this approach. However, known issues, such as the number and placement of blast-mitigating seats, interior space, and egress, remain concerns (Feickert, 2021, p. 2). Overall, DOT&E did report, nonetheless, that the "Marines involved with [IOT&E] noted that the ACV performed better than the legacy vehicle [AAV] across all mission profiles" (DOT&E, 2021, p. 122).

8. EVMS: EVMS Utilization

The EFV program used an EVMS, although poorly executed. However, I believe it can pay dividends to PMOs if they understand the data and its purpose. The GAO agrees, stating that

> perhaps the biggest challenge in using EVM is the *tendency to rebaseline* programs. This happens when the current baseline is not adequate to complete all the work, causing a program to fall behind schedule or run over planned costs. A new baseline serves an important management purpose when program goals can no longer be achieved because it gives perspective on the program's current status. However, auditors should be aware that comparing the latest cost estimate with the most recent approved baseline provides an incomplete perspective on a program's performance because a rebaseline *shortens the period of performance reported and resets the measurement of cost growth to zero* [emphasis added]. (GAO, 2020a, p. 15)

As mentioned in Chapter IV, the EFV PMO baselined the program seven times from March 1995 to August 2007 (DAMIR, 2007). Four are considered rebaselines. The process of rebaselining runs against current GAO best practices. The GAO (2020) *Cost Estimating Guide* states that

> a program that a program that frequently changes its baseline can appear to be trying to "get well" by management's hiding its real performance, leading to *distorted EVM data reporting* [emphasis added]. When this happens, decision-makers tend to lose confidence in the program. (p. 285)

Although not a great metric, EFV EVMS rebaselining data does reveal poor program performance. Two EVM indicators show the program's efficiency during execution: cost performance index (CPI) and schedule performance index (SPI). Figure 37 shows the index formulas.

Cost Efficiency	CPI	= BCWP / ACWP	Favorable is > 1.0, Unfavorable is < 1.0
Schedule Efficiency	SPI	= BCWP / BCWS	Favorable is > 1.0, Unfavorable is < 1.0

ACWP Actual Cost of Work Performed	Cost actually incurred in accomplishing work performed = **ACTUAL COST**
BCWP Budgeted Cost for Work Performed	Value of completed work in terms of the work's assigned budget = **EARNED VALUE**
BCWS Budgeted Cost for Work Scheduled	Time-phased Budget Plan for work scheduled = **PLANNED VALUE**

Figure 37. CPI and SPI Formulas. Source: DAU (2018).

EVM-CR provides two CPI/SPI graphs for EFV program contract numbers, M677854-01-C-0001 and M67854-08-C-0003, respectively (see Figures 38 and 39). The first started after the first GDLS CPAF award in 2001 and ended before the major program restructuring in 2007. The second began in 2007 through program cancelation in 2011. When looking at the first graph, CPI remains at a negative < 1.0 value throughout the entire period, indicating poor resource allocation. Conversely, SPI stays a favorable > 1.0, except on four occasions, albeit decreasing overall. From October 2003 to October 2005, both the CPI and SPI remain flat, indicating program stagnation. This period correlates to multiple EFV testing and design issues with the bow flap, hydraulics, and HEU. Of note, the first significant dip following stagnation in December 2005 connects to the first significant Nunn–McCurdy breach.

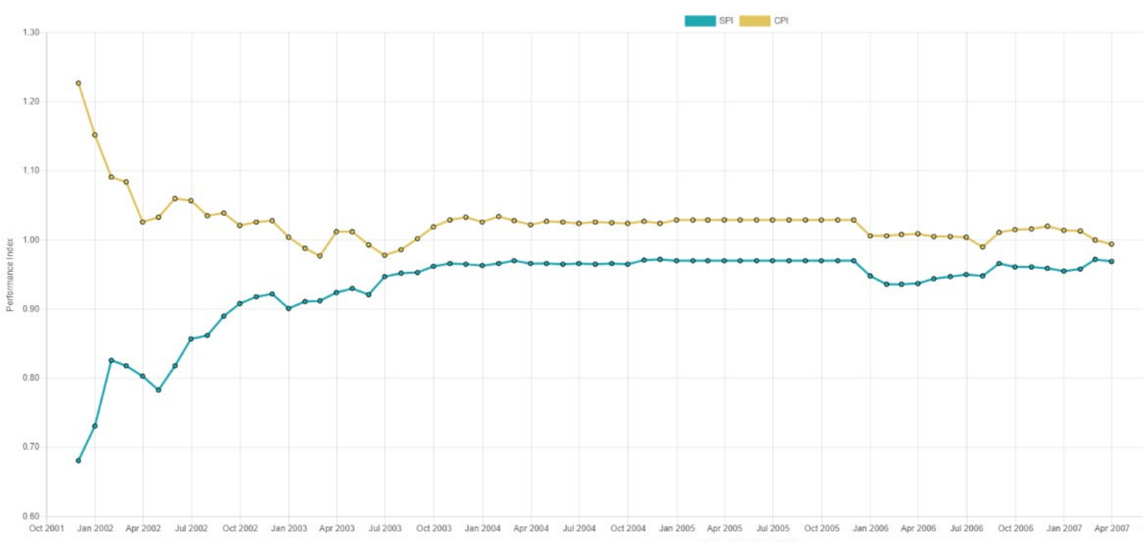


Figure 38. EFV Performance Index, 2001–2007. Source: EVM-CR (2022).

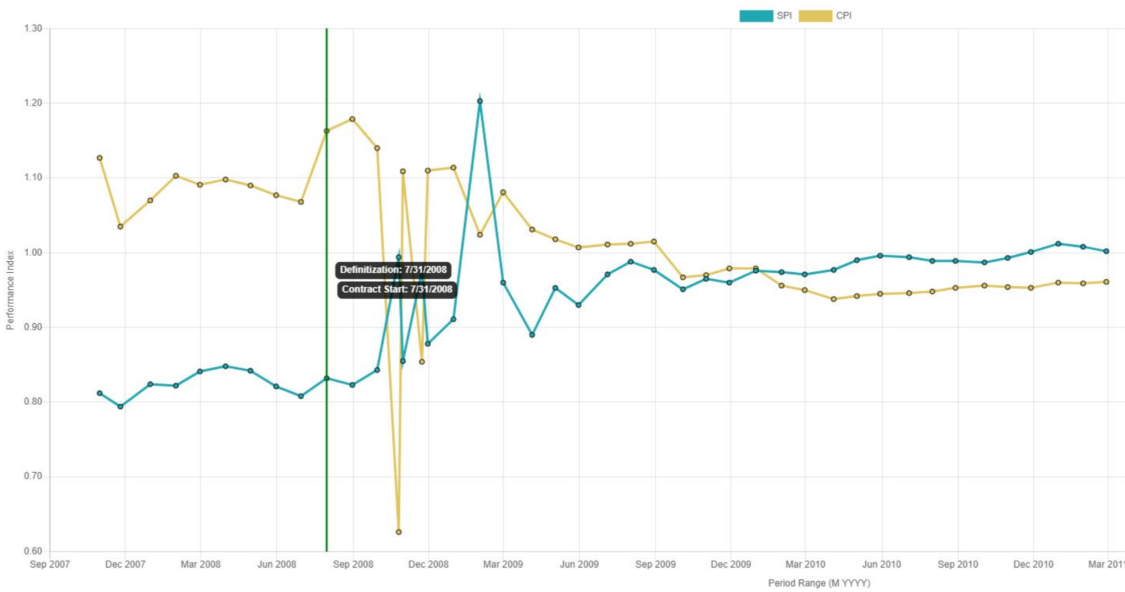


Figure 39. EFV Performance Index, 2007–2011. Source: EVM-CR (2022).

The second index starts following the major restructuring and two critical Nunn–McCurdy breaches. This contract, known as SDD-2 in EVM-CR, also signifies the fourth EFV APB change since the program started. Despite a couple of large CPI and SPI fluctuations in 2008 (distorted data), the general SPI trend reveals a favorable increase, closing at a > 1.0 value. CPI, on the other hand, reports the opposite. Importantly, as cost-efficiency goes down, schedule efficiency goes up. This correlation shows that the service potentially traded cost for schedule given program restructuring. Also, from April 2010 through cancelation, CPI increases, nearing 1.0. Numerous reasons can account for such changes; however, the USMC's decision to decrease units did have a potentially positive effect on total cost savings. Both EVMS graphs reveal excellent markers and triggers for future PMO *proactivity*.

The PMO executed both SDD phases through CPAF contract vehicles. By the end of 2007, GDLS received "78% of the award fee available during each period" and "88% of the fee available for being on schedule and at or under cost" (U.S. House, 2008, p. 6-7). The ratings included *good* and *very good* descriptors. In 2007, U.S. taxpayers paid $2.3 billion on the program, which added weight to the program restructuring argument. Also, in 2007, David Ahern, Deputy Under Secretary for Defense for Acquisition and Technology, stated that GDLS underwent an EVMS recertification effort following the restructuring (HASC, 2007). However, the recertification does not reveal itself in the data. Overall, the EVM-CR data does not align with the work performed, contract dollars spent, or adjectives used in reports.

Additionally, EVM-CR depicts the dollar changes across certain program elements. Figure 40 highlights modifications to both the estimates and budgets at completion. Of note, three critical areas reveal significant negative values, indicating they were traded: SE/PM, spare and repair parts, and system T&E. SE/PM and T&E trades align with previously identified program issues.

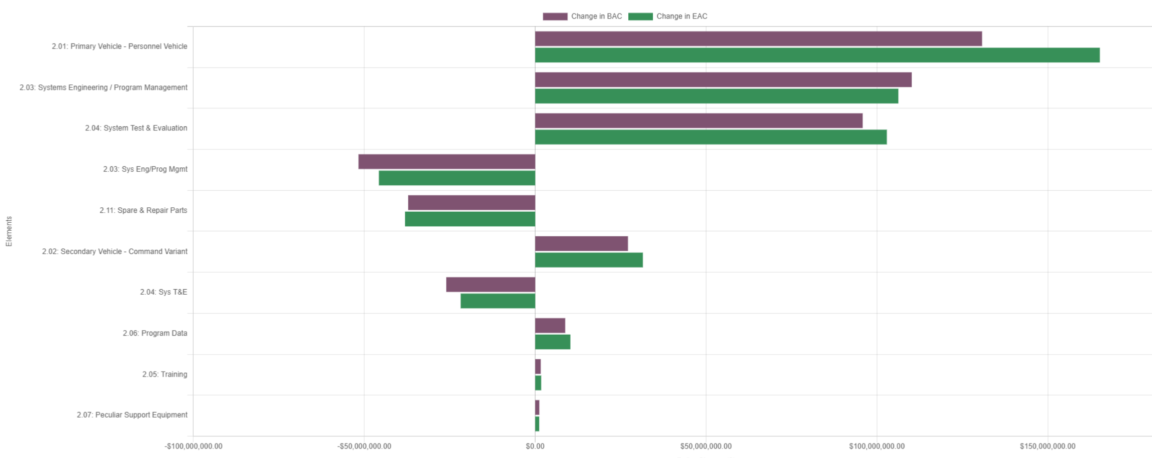


Figure 40. EFV Program Elements / Dollar Change. Source: EVM-CR (2022).

The GAO states that "EVM data should be analyzed and reviewed *at least monthly* [emphasis added] so that problems can be addressed as soon as they occur and cost and schedule overruns can be avoided, or at least their effect lessened" (GAO, 2020a, p. 249). Adequate application of EVM principles would give the PMO expanded data for decisions. Also, the EFV PMO's quality monitoring of EVM data might have directed them not to accelerate T&E, resulting in the poor "test-fix-test" process.

Figure 41 highlights the output benefits of a successfully implemented EVMS. As depicted, EVMSs support program-wide visibility and actions against the plan, or APB. Therefore, I suspect that a common PM tendency is not to broadcast program status due to poor results. Suppose programs remain reactive and do not utilize EVMS to its core purpose, then they risk inaccuracy, and EVMS should not be used for decisions. The PM must stay proactively engaged, provide inputs, and assess outputs for the EVMS to work as intended.

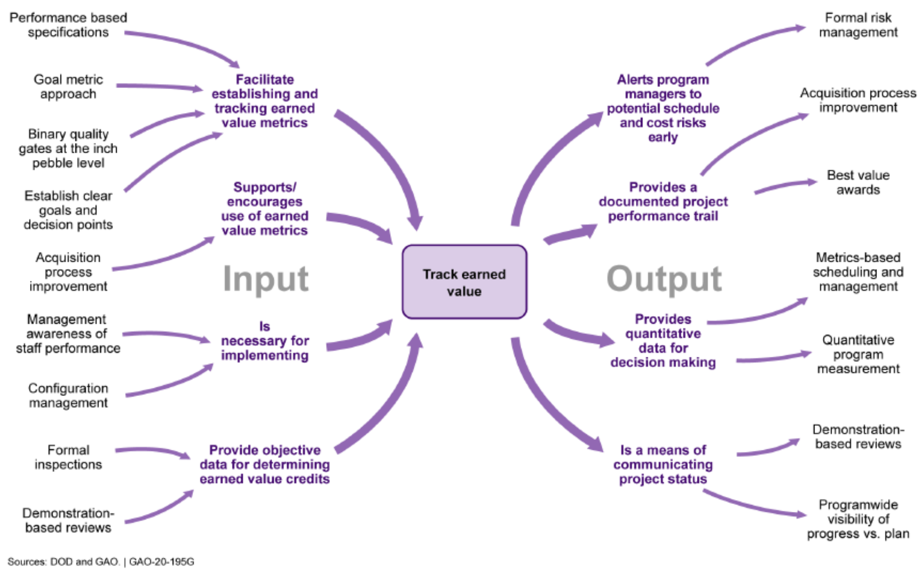


Figure 41. Inputs and Outputs for Tracking Earned Value. Source: GAO (2020a, p. 215).

The December 2019 ACV SAR stated,

> The Program Office received a *waiver of EVM* [emphasis added] on March 19, 2015, prior to MS B based on the limited duration of work to be performed in which EVM would apply. The cost of certifying an EVM System at multiple sites versus the benefit achieved due to the low level of residual risk after the application of alternative management controls was not beneficial nor did it produce actionable results. However, the Program Office receives monthly Integrated Program Management Reports (IPMR) including Schedule Risk Assessments, Cost Schedule Data Reports (CSDR), and Contract Funding Status Reports (CFSR) from the prime contractor in order to track and manage cost, schedule, and performance. (DAMIR, 2022)

A 2017 GAO report on the ACV cost estimates analyzed the ACV FoV non-EVMS approach. Although required by statute, the GAO found that the "program's alternative approach for overseeing contractor performance aligned with relevant best practices identified in the GAO Cost Estimating and Assessment Guide" (p. 21). Specifically, the GAO lists three actionable traits: "(1) establishment a comprehensive system, (2) ensuring performance data are reliable, and (3) *utilizing performance data* [emphasis added] in making decisions" (GAO, 2017, p. 21). The GAO found that the ACV program utilizes a detailed WBS, and they eliminate data anomalies to guarantee consistent data and engage contractors for performance data.

Although the ACV PMO does not report EVMS-specific data, it regularly submits IPMRs to EVM-CR to fulfill CDRL requirements. EVM-CR separates ACV FoV acquisition efforts into the EMD and P&D phases. For example, the contract number, M67784-16-C-0006, reveals both FPI and CPFF contract types (EVM-CR, 2022). The ACV submissions are detailed and contain various schedule and production risk assessments, critical paths, the integrated master plan, schedule, and PM assessments and actions. Overall, I agree with the GAO and the "alternative approach." However, a certified ACV EVMS would provide broader, more valuable metrics for the PMO track risk, especially given the EFV history.

The ACV data includes summary program schedules (see Figures 42 and 43). Comparing the first and last ACV 1.1 summary schedules, September 27, 2018, and March 14, 2022, respectively–show an approximate 1-year slip for all FRP deliveries. For example, Figure 43 indicates that the first FRP ACV-P delivery occurred in the second quarter (Q2) of FY2022, at the end of the 2018 FRP 1 option in Figure 42. This schedule indicates that the contractor will deliver the first FRP ACV-C in Q4 FY2023, the first ACV-30 in Q2 FY2026, and the first ACV-R in Q2 FY2027. Therefore, one can see that the PMO and BAE–Iveco are focusing manufacturing on the personnel and command variants before the 30mm and recovery variants. Figure 43 also includes future delivery dates of the ACV 1.1 mission variants.

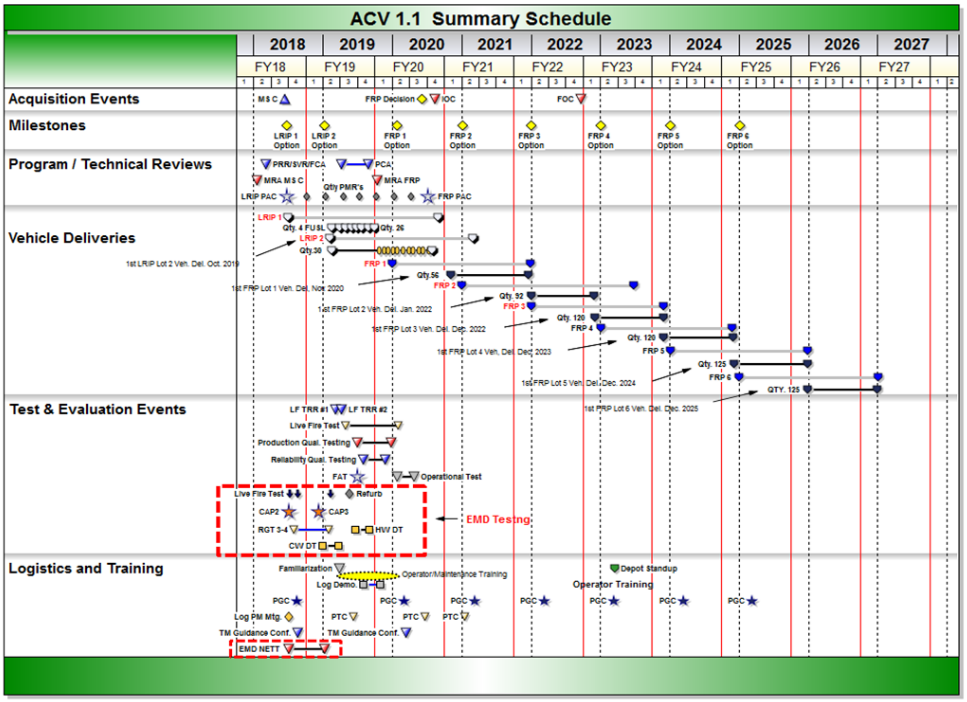


Figure 42. ACV 1.1 Summary Schedule, Dated September 27, 2018. Source: EVM-CR (2022).

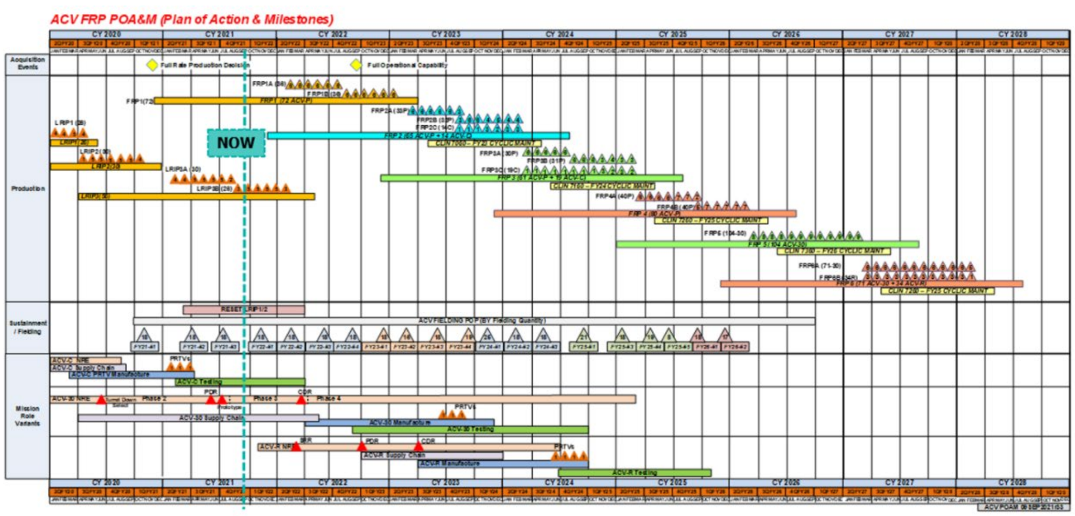


Figure 43. ACV 1.1 Summary Schedule, Dated March 14, 2022. Source: EVM-CR (2022).

D. DECISION SCIENCE PERSPECTIVES

When analyzing the EFV and ACV programs, one must strive to understand the USMC’s decision-making regarding the paradigms governing the workforce. This section ties in closely to the KBA and the attainment of KPs. For example, if one operates within an unbounded environment, KPs are irrelevant because the APB and its milestones do not matter. In a sense, the DSS bounds the USMC and its knowledge. Paradigms like RCM, BRM, and HBP help us comprehend our actions and complex interdependencies. By identifying the rules that govern thinking, PMs can better posture themselves for change and work to improve future acquisition programs. This section argues for decision science, while attempting to correlate examples within each program.

1. Realism versus Rationality

The DSS process remains the structure for effective decision-making, and leaders using this model cannot possibly consider every piece of information to form a rational path forward. Still, analysis of EFV program performance characteristics over time reveals that the EFV changed 60% of the requirements. The presumption that requirements remain solid requires stakeholders to remain steadfast, including the USMC, Congress, industry, and even the taxpayer. Therefore, I observed that EFV officials experienced tremendous conflict when deciding whether to keep original requirements or enable the myriad of stakeholders to continue adding to and influencing the program. This conflict fueled other conflicts, which drove the PMO to the boundaries of the rational DSS and beyond. The program stressed the "Big A" model to its limits, which prevented the reconciliation of reliability, T&E, and SE issues. Despite multiple assessments and audits suggesting realistic trade-offs, the Marine Corps disregarded the model's boundaries.

ACV RCM cognitive barriers surround missed opportunities. For example, technical performance metrics should have included cold weather operation, interior space, seats, and egress concerns. However, even though the program was executed with limited knowledge in areas, the program managed a prescriptive path consistent with a KBA. Therefore, at times decisions are seen to contrast with the rational standard yet remain logical. Charles Lindblom stated that "issues are often characterized by partisan debate and compromise rather than a more overall-rational process" (Davis et al., 2005, p. 9).

2. Constraints and Restraints

The analysis shows the enormous number of top-down constraints and restraints placed upon DOD acquisition via statutes, regulations, knowledge, and internal controls that bound the system. Constraints are requirements that *dictate* action. Alternatively, restraints *prohibit* action. For instance, both restrict freedom of movement and containerize acquisition. However, their application and absolute limits differ, like Nunn–McCurdy (restraint) and descriptive triggers, like KPs (constraint).

The EFV and ACV programs experienced the same overarching acquisition constraints, with minor changes over time. The main difference lies in their restraints. The DOD did not seem to prohibit much of anything. For example, when the contractor was paid award fees despite the deficient performance, they remain unrestricted to continue the same standard—the continued rebaselining highlights the continuous adjustment of internal constraints instead of adhering to the restraints. Similarly, internal reliability triggers could have triggered SE reviews and process updates much earlier. However, program boundaries remained elastic throughout execution.

The ACV requirements highlight a significant point related to RCM and BRM and objective/threshold values. For example, the phraseology contained in the November ACV APB Change 1 uses *should* and *shall.* These words depict normative and positive situations, respectively. The EFV program requirements only included KPP values without clarification, for example, 56/43.5 objective/threshold hours for MTBOMF reliability. In contrast, the ACV requirements explain the need and incorporate objective/threshold restraints through *should* and *shall.* This minor expansion solidifies the significance of ACV requirements from the beginning. This restrained clarification works, in a sense, to establish the decision-making paradigm of the stakeholders. Requirement language bounds the USMC and foreshadows impending restrictive aspects of the capability, time, and resources. Therefore, when analyzing requirements, the ACV program operates within a more confined environment, narrowing future trade-offs and streamlining knowledge.

3. Industry Boundaries

Cost, schedule, and performance are the primary boundaries typically referred to as the *triple constraint*. At the time, the EFV program worked these targets with a new form of teaming. During the early CED/V phase of the EFV, program officials initiated some of the first integrated product teams (IPTs). In 1998, the assistant AAAV/EFV PM mentioned that the 1996 GDLS contract award required "an integrated product team structure … General Dynamics then developed their own 'Concept Board' against that requirement" (Johnson, 1998, p. 4). This new IPT arrangement required the contractor to collocate into a single facility with government officials. When conducting IPTs, the PM, confirmed that most of the decisions were made by IPT members but "on occasion, he share [d] a 'tiebreaker'" (Johnson, 1998, p. 4). Although there are benefits to collocation, including rapid planning, approvals, and overall communication, there are also downsides.

For instance, the for-profit industry and the for-capability DOD cannot always see eye-to-eye. In this regard, IPTs resemble a more rational decision process that describes how individuals *should* make decisions vice how they are *actually* made (Davis et al., 2005, p. 81). While establishing this innovative teaming approach, the PMO and industry were governed by different paradigms and incentives. These cognitive barriers created the potential for ambiguous or unclear goals. In 1998, the PM alluded the need for IPT training and the significance of adhering to the same set of rules among team members (Johnson, 1998, p. 12). Overall, the EFV IPT trials are considered questionable in their effectiveness. In today's acquisition environment, IPTs remain a widespread best practice. Yet, each IPT is vulnerable to the preferences and incentives of each entity. This realization should force leaders to train under a standard governing paradigm or, at a minimum, work to understand the relevant differences between each.

The USMC settled on an incremental approach for acquiring the ACV 1.1, 1.2, and 2.0. The combination of 1.1 and 1.2 increments created a self-deploying amphibious vehicle similar in water speed and range to the AAV. This approach reduces the complexity and concerns surrounding HWS knowledge. However, even though ACV 1.1 incorporates substantial upgrades compared to the legacy AAV, such as a V-shaped hull and suspended seats for survivability (Judson, 2020), the Marine Corps enticed industry into 1.2 requirements. By incentivizing contractors to meet self-deploying 1.2 needs, the Marine Corps complicated their future decision-making. Thus, ill-defined growth goals might have misled potential clients. Yet, this decision effectively bounded industry's knowledge and resources to the 1.2 requirements, or less, whatever the existing BAE-Iveco design could muster. Therefore, the programs seem to "muddle through" these relationships. Although the ACV is more bounded than the EFV, the relaxation of 1.2 requirements is viewed negatively when performance outweighs cost and schedule.

4. Attempts at Synergy

Synergy relates to the combination of RCM and BRM or the acknowledgment of rules and choices. Through this lens, the EFV program tried to synergize through its attempt to bend the DSS to its will. By this logic, the USMC attempted to fit the system to the acquisition, vice the acquisition to the system. For example, SE efforts became reactive to increase reliability and performance without a stable and mature design. Multiple assessments identified SE as an issue. Due to an inability to implement controls, the program disregarded certain constraints. In a sense, the program's response to the system's poor performance outweighed foundational design issues. Prioritizing stakeholder demands and undervaluing internal metrics combined to create a reactive culture. I characterize this process as an *over-extension* or over-reliance on industry. Due to inadequate oversight, synergies favored industry and conflicted with the DOD's mission to support the warfighter.

In contrast, the ACV program set up an initial strategy to leverage maturity and synergize within the system, even to the detriment of performance. For example, the GAO identified three program factors, notably reducing program ambiguity and interpretation between stakeholders.

> 1. "Recognition that the ACV would spend much of its time on land,
> 2. Shortfalls in the AAV's ability to meet protected land mobility requirements once on shore, and
> 3. Technical and affordability challenges that preclude the development of HWS vehicle in the near term" (GAO, 2015b, p. 6).

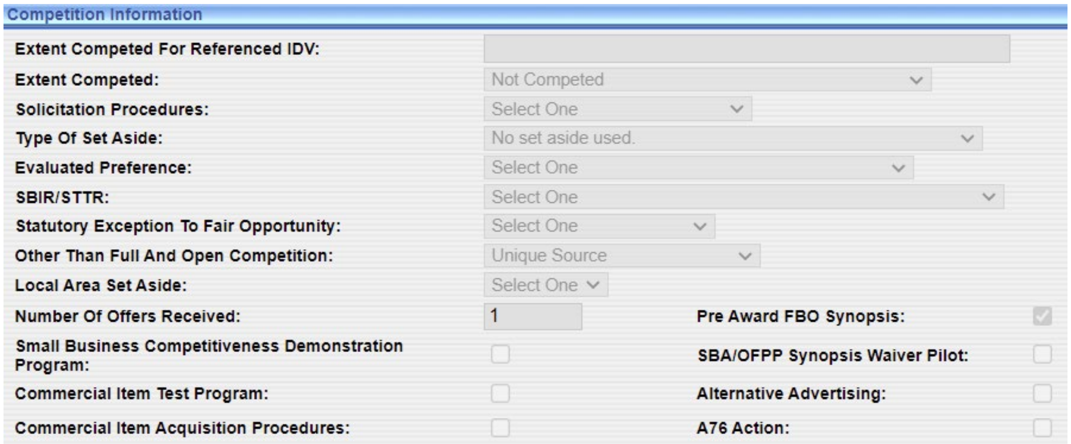
On the other hand, the ACV program used proven technology and information to synergize upfront and early with the BAE-Iveco design. The decision to modify this existing system gave decision-makers a baseline for variation and a benchmark of consistency. Through this approach, decision-makers focused their efforts within the objective/threshold requirement window without fearing a foundational design failure. However, future HWS requirements will undoubtedly require significant design changes, which will require stakeholders to review their established decision-making paradigm.

5. DSS Abnormalities

Starting in concept development, GDLS beat out BAE in 1990 to design the EFV. Reports suggest that the GDLS and BAE proposals were highly similar. However, one critic argues that the source selection process deviated from the norm in that

> the choice had to be made on some basis other than the technical merits of the ideas. So, the winner was selected based on three criteria that buttressed traditional contracting paradigms: (1) the willingness of the contractor to co-locate an R&D facility and key personnel (engineers from General Dynamics had to move to Washington, DC, to be in the same location as each other and the government customer); (2) performance on previous government contracts; and (3) the willingness of the contractor to share in the cost of the development. (Srivastava, 2019, p. 69)

GDLS was the prime contractor, and following the initial concept development award, full and open competition for future awards seems to have been limited within industry. The time between the first and second SDD rebaselining was almost 2 years. Before the second SDD rebaselining in June 2001, the DOD awarded GDLS a CPAF contract to develop an alternative EFV drivetrain without competition. On the signed contract, under the category of "other than full and open competition," GDLS is mentioned as a "unique source" (Federal Procurement Data System [FPDS], 2008).



Competition Information

Extent Competed For Referenced IDV:			
Extent Competed:	Not Competed		
Solicitation Procedures:	Select One		
Type Of Set Aside:	No set aside used.		
Evaluated Preference:	Select One		
SBIR/STTR:	Select One		
Statutory Exception To Fair Opportunity:	Select One		
Other Than Full And Open Competition:	Unique Source		
Local Area Set Aside:	Select One		
Number Of Offers Received:	1	Pre Award FBO Synopsis:	☑
Small Business Competitiveness Demonstration Program:	☐	SBA/OFPP Synopsis Waiver Pilot:	☐
Commercial Item Test Program:	☐	Alternative Advertising:	☐
Commercial Item Acquisition Procedures:	☐	A76 Action:	☐

Figure 44. EFV Alternate Drivetrain Contract Award M6785401C0001. Sources: FPDS (2008); Srivastava (2019, p. 70).

FAR Part 6.3 (2022) specifies scenarios where other than full and open competition can be allowed. Justification relating to this specific award remains unclear. However, it is probable that by co-locating their R&D facilities and critical personnel, GDLS provided the "unique capability of the source to provide the particular research services proposed" (FAR 6.3, 2022). This route is technically allowed per FAR Part 6.302-1(a)(2)(i)(A). However, this gave GDLS priority over other potential vendors and subsequently locked the government into the relationship over 4 more APB cycles. Concerning HBP, from the outset, the selection of GDLS can be mildly associated with an availability bias (AB) on behalf of the DOD, which potentially hindered full and open competition.

One positive ACV deviation from the typical acquisition life cycle surrounded the use of DARPA and their FANG challenges. After decades of market research, the Marine Corps branched out because they understood that current industry technology did not allow for a HWS amphibious vehicle. Through partnerships and a combined vision, DARPA looked to enable "classified programs to leverage open innovation widely" (Srivastava, 2019, p. 54). However, FANG did not provide the results the service wanted. (Srivastava, 2019, p. 54). The Marine Corps quickly understood that R&D projects rarely move quickly nor enable broad innovation due to secrecy constraints. Ultimately, based on design characteristics and multiple APB changes, the Marine Corps chose not to continue with FANG. One reason could be that the FANG-1 design winner scored only a 63% on its final submission (Srivastava, 2019, p. 52).

Looking forward to ACV 2.0, the Marine Corps should reevaluate the constraints placed upon industry surrounding 2.0 HWS research. For example, the recency effect, a shared decision-making trap, gives excessive weight to current information. If the Marine Corps acknowledges its bias towards ACV 1.1 performance, they could potentially reinvigorate innovation for 2.0 utilizing an updated DARPA challenge. Figure 45 shows the three proposed DARPA FANG challenges. Only the first was promoted, scored, and awarded.

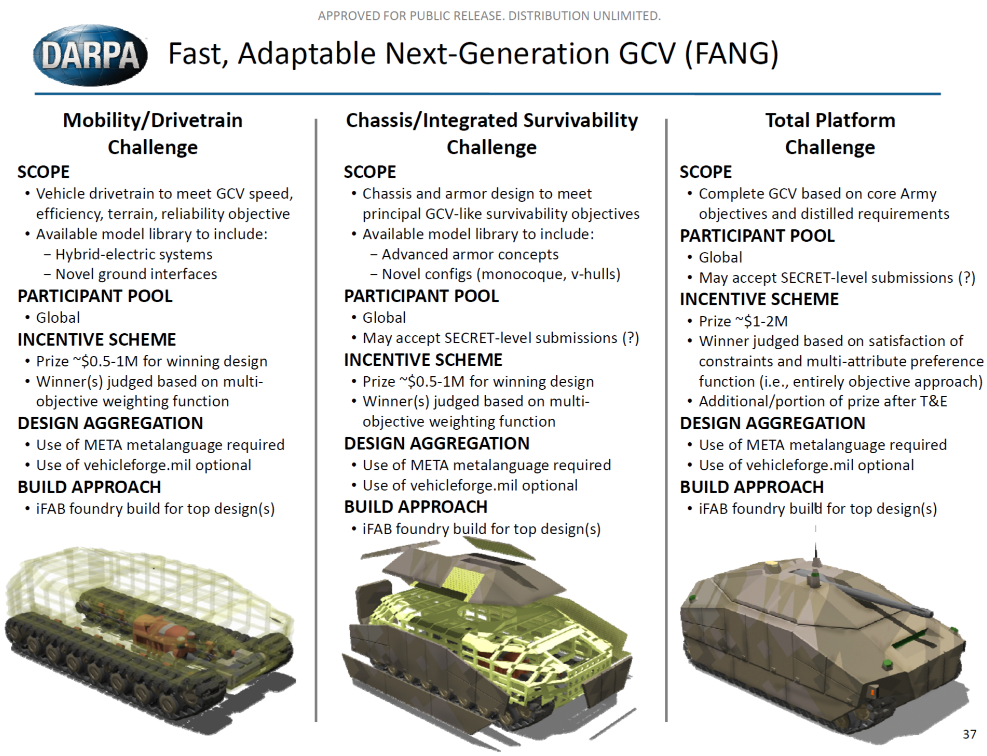


Figure 45. DARPA FANG Tiered Challenges. Sources: Eremenko and Wiedenman (2010, p. 37); Srivastava (2019, p. 53).

6. Problem Set Barriers and Effects

The following heuristics and biases are explored and associated with each program. Most of the connections overlap with prior analysis and other decision science principles. The section attempts to understand each organization’s behavior by correlating certain program actions to common cognitive barriers. The analysis proved difficult and should not be used as a unilateral decision aid.

a. Problem 1: Too Much Information

Availability Heuristic/Bias (AH)/Bias. The EFV began on the heels of the prior tracked amphibious vehicle acquisition efforts and attempted to solve a joint forcible entry requirement. At the time, the forcible entry requirement was not up for debate or challenge. Thus, a tracked vehicle was primed in decision-makers' minds, which prevented them from exploring other alternative solutions. AH did not affect the ACV program as they broke free from the OTH requirement for ACV 1.1. However, the Marine Corps combined 1.1 with the 1.2 tracked variant. Here, a producible 1.1 increment might have caused the USMC to invalidate the 1.2 entirely, revealing a bias toward current performance.

Confirmation Bias (CB): Following the poor OA in 2006, General Hagee, CMC, stated that

> yes, [the EFV] *is going to be able to* [emphasis added] come from 30 miles at sea at speeds that are unbelievable. But it is a tremendous vehicle ashore also. Today, except for a couple of minor exceptions, we do not have a good vehicle that can operate on a contaminated battlefield. The EFV can, in fact, *do that* [emphasis added]. (Castelli, 2006)

Here, leaders continued to advocate for EFV performance despite widespread, conflicting evidence. Though this statement does not encapsulate the entire EFV viewpoint, it highlights the predominant CB evident at the time. Likewise, the HWS requirement remains on the table for the ACV, albeit not as advertised as in the past. Given new force design initiatives, it is in the Marine Corps' best interest to acknowledge the potential for CB concerning HWS technology. They can then leverage HWS studies and research before ACV 2.0 development.

Anchoring Bias (AB). Multiple agencies awarded the EFV PMO for superior performance before establishing the APB in 2000. From 1996 to 1998, the EFV program was awarded

- The 1996 Stratospheric Ozone Protection Award from the Environmental Protection Agency
- The 1996 and 1997 Department of the Navy Environmental Security Award

- The 1996 and 1997 Department of Defense Environmental Security Award
- The 1997 David Packard Award for Excellence in Acquisition
- The 1997 Secretary of Defense Superior Management Award
- The 1998 Department of Defense Value Engineering Honorary Achievement Award (Johnson, 1998, p. 14).

These awards established an initial successful reference point for program management, paralleling OB discussed later. Following an award, follow-on execution remains uncertain. Thus, awards can also be seen as an anchor point, implying future success to stakeholders. Given the duration of a EFV program life cycle and management turnover, it is evident that success can deteriorate over time. Therefore, early on program awards present a potential undue anchor point in a program's life cycle, which do not secure future success. However, I did not find any direct evidence of this anchoring. Additionally, I did not find any evidence of ACV AB. I believe the ACV program resists AB associated with past development efforts through its continued reliance on mature, proven technology.

b. Problem 2: Not Enough Meaning?

Hindsight Bias (HB). Firstly, I acknowledge that this report embodies hindsight bias (HB) regarding EFV development. Still, it is conceivable the EFV program misjudged the past LVA, LVT(X), and AAV results as being more predictable than expected. Additionally, the 23-year duration of the EFV acquisition increased the retrospective timeline each baseline iteration. Still, following the December 2002 audit and 2006 OA, program officials acknowledged reported problems yet did not effectively reevaluate SE or change design processes. These miscalculations reinforce the need for more meaning or information at the time, which could have reset perceptions. For the ACV, the program avoids HB by acknowledging past failures and applying a disparate acquisition approach. In the future, ACV officials must recognize that requirements can creep into design variants and should remain defensively postured against them.

Halo Effect (HE). I see the halo effect (HE) describing built-in assumptions. Business decisions can be ascribed to HE, such as the source selection process. For example, GDLS produced the M1A1 and still supports the LAV for the Marine Corps.

Thus, the Marine Corps' relationship with them may have impacted their "amphibious tank" contract awards (U.S. House, 2008, p. i). During EFV development, the HE potentially infiltrated senior leadership during high-level decisions and meetings, especially with the shrinking industrial base. For example, many companies manufactured the original LVT amphibious vehicle during World War II, including FMC. UDI acquired FMC in 1997, which was acquired by BAE Systems Land & Armaments in 2005. Therefore, the Marine Corps reverted to its original LVT manufacturer concerning ACV selection, notwithstanding significant company reorganization. Again, similar to AB, the last positive impression of a company does not guarantee future success. It is relevant to note that both GDLS and BAE, as two major amphibious vehicle development companies, have been competing against each other for a long time. This longstanding competition can impede smaller companies from entering the industry. The ACV program experiences minor HE by choosing BAE, but BAE's teaming with Iveco reduces the impact.

c. Problem 3: Need to Act Fast?

Actor-Observer Bias (AB). AB resembles circular reasoning in that a decision-maker tries to justify their decisions without fully acknowledging the underlying situational or environmental context. For example, concerning the EFV, "In interviews with Committee staff, Marine Corps and General Dynamics officials stated that the 'test-fix-test' approach was adopted as the best way to meet the program's schedule after Congress underfunded the SDD phase" (U.S. House, 2008, p. 4). Here, the Marine Corps attributes EFV issues to external, congressional action. Congress, on the other hand, wants a different internal explanation. This example is an oversimplification of the EFV events. Yet, it highlights a bias that could fuel poor program data or descriptions of failure. Therefore, managers must recognize all sources of knowledge, both external and internal, that affect their programs.

The ACV program seems to have explained its strategy more thoroughly through its risk ownership. However, the increment combination resembles a form of circular reasoning. For example, the Marine Corps stated that ACV 1.1 met 1.2 requirements while still not acknowledging the tracked requirement (Lee, 2019). This reversion back to the original requirements again reveals favor toward cost and schedule over performance.

False Consensus Effect (FCE). I view the FCE within the multiple EFV rebaseline attempts, specifically when viewed as a standard practice or norm. For example, in March 2005 and June 2007, the EFV program experienced its third and fourth APB changes. These critical junctures occurred after multiple Nunn–McCurdy breaches and should have given the decision-maker pause. Still, a PM cannot terminate the program and must revert to the service's decision to cancel or continue. Therefore, the PM's risk calculation relies on accurate communication with decision-makers. PMs must fight the urge to over-advocate during these times and instead entertain ideas of those typically dismissed. I observed more advocacy than inquiry during the EFV testimony and public statements, which potentially raised a false consensus among stakeholders.

The ACV originated after the canceled EFV created an opportunity to revitalize the MPC. Initially, the MPC program retained only a "limited amphibious capability" without a ship-to-shore requirement (GAO, 2015b, p. 7). Then, the MPC and ACV melded their requirements. Here, the USMC supported a quick transition by leveraging prior programmatic efforts. After sufficient market research, the MPC became the ACV. In this case, FCE applies when considering a post-EFV future. Although an innovative idea and in line with GAO best practices, senior leaders decided upon an incremental approach, thus preventing new development and potentially a better capability. No one can forecast when technology will meet the required maturity levels for a new program. However, acquisition professionals must acknowledge prior innovation and refrain from dismissing previous efforts based purely on termination. Therefore, although successful, the FCE potentially limited alternatives to ACV development.

Self-Serving Bias (SSB). I did not interview management during this research; therefore, I did not ask if officials were personally or professionally biased concerning their careers. However, I am confident that individuals, whether consciously or subconsciously, consider success and promotion as a driving force within a hierarchy. Therefore, any person working inside a PMO must set aside time to understand this bias.

During successful endeavors, stakeholders should remain humble and, during adversity, capitalize on the workforce’s moral qualities. Therefore, I did not analyze this bias.

Optimism Bias (OB). Following the program awards from 1996 to 1998, EFV leaders drastically accelerated the schedule. They conducted the CDR in January 2001, just one month after the first SDD contract award in December 2000. This decision, against best practices, reveals significant OB. Another recognizable OB event occurred in February–March 2007. Following the Nunn–McCurdy breach, the Navy and USMC admitted that they must relax EFV requirements after realizing that a combat-loaded EFV could not swim on–plane. Instead of termination, they proposed and approved the fifth SDD revision with scheduled IOC/FOC dates set for 2015/2025. Today, 34 years later, in 2022, the EFV would still not be FOC. SECDEF Gates seemed to have recognized this creeping bias and canceled the program in 2011. In 2020, the GAO stated that “many cost estimating challenges can be traced to over-optimism” (GAO, 2020a, p. 10). In the GAO’s last EFV *Assessments of Selected Weapons Programs*, the Marine Corps chose not to comment on the result, stating that “the Marine Corps was provided a draft of this assessment and did not offer any comments” (GAO, 2012, p. 146).

The ACV program signaled low-level OB when they combined 1.1 and 1.2 increments. By accommodating 1.1 R&D into 1.2 requirements, the Marine Corps marked hopeful trade-offs by accepting a wheeled vehicle instead of a tracked one. A 2017 GAO report stated,

> While the Marine Corps is *optimistic* about its approach and believes risk is minimized by the ACV’s relatively stable design, we see parallels between the risks facing the ACV program—given the concurrency between testing and production—and those that faced the previously canceled amphibious vehicle program. (GAO, 2017, p. 17)

A program’s optimism should be *balanced* against its constraints. The services can prevent creeping optimism by accepting successes and fighting the desire to capitalize on supposed beneficial changes. Rarely should temporary success justify enhanced or additional requirements; risks do not disappear after a goal is achieved. Program life cycles require a constant level of sustainment to remain successful. Eventually, OB and unrealistic assumptions must disappear from Figure 46, an ever-too-familiar depiction that overweighs challenges against mitigations. Realizations of bias, like OB, can help balance a one's expectations with reality.

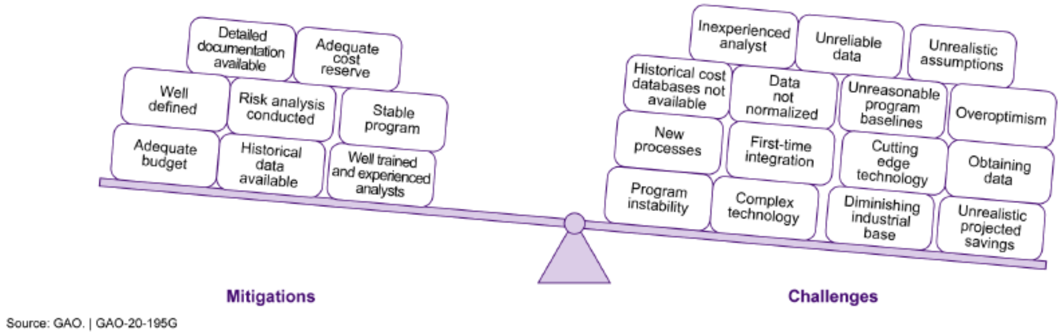


Figure 46. Cost-Estimating Challenges and Mitigations. Source: GAO (2020a).

d. Problem 4: What Should Be Remembered

Misinformation Effect (ME). The EFV program seems to have experienced the ME. For example, once failure information, such as bow flap failures, reach a decision-maker's desk, the potential for undue filtering increases. EFV management might have realized these failures earlier through the design process; however, it failed to identify them, leading to extensive and costly prototyping. Therefore, technical communications play a large part in the ME. Programs cannot succeed if individuals fear retribution or embarrassment because of the information they possess. Therefore, open, and honest communication of all relevant information remains a prerequisite for success.

During the USMC's struggle to keep the EFV program alive, Congress seemed not to receive the whole picture. For example, the House Oversight Committee found that GDLS "received 106% of the available bonus for being on cost and schedule" (U.S. House, 2008, p. 7), potentially resulting from a government-contractor misinformation. During the same period, program officials witnessed the poor delivery performance, stating that "the contractor did not meet the contractual delivery date" (U.S. House, 2008, p. 7). Yet, again, award fee payouts to GDLS indicated acceptable performance, whether intentional or unintentional.

The ME also concerns safety and culture. One tragic example of the ME connects the ACV program to an AAV sinking off the coast of California in July 2020, where one sailor and eight Marines lost their lives. After investigating the incident, investigators found that poor material readiness caused the incident. In response, General Gary Thomas stated, "If we can, with our education system and reporting systems, create an environment where people are comfortable, I think we'll make a lot of headway towards the safety culture we need" (Kaufman, 2021). This serious connection highlights the importance of the ME. The ACV program can study these incidents to prevent future ME-related bias.

Specific to the ACV, I found potential misinformation surrounding the OTH requirement from the 2012 MPC and early ACV development. For example, following the ACV MSA phase, the program removed the OTH requirement, deciding on sea connectors. Then, the subsequent ACV 2.0 variant returned HWS, which remains historically connected to the OTH capability. This conflicting requirement can increase technical and tactical ambiguity and risk. In this regard, one finds that consistent requirements remain a crucial component in combating ME-related issues.

In general, stakeholders encounter most of these common cognitive barriers during the program start, where it remains vital that decision-makers recognize how these biases, and many others can affect their decisions. Table 24 summarizes the HBP comparison based on the discussion and resources. However, I could not gain high-level HBP fidelity without interviews or surveys. Therefore, I am unable to effectively analyze bias within each program conclusively.

Table 24. Summary of Observed HBP Problem Sets on Program Performance.

	AH	CB	AB	HB	HE	AB	FCE	SSB	OB	ME
EFV	+	+	/	+	/	+	+	N/A	+	+
ACV	+	-	-	-	/	+	/	N/A	-	/

Minor effect annotated with (-), moderate effect (/), and more meaningful effect (+).

V. CONCLUSION

At the end of the 1998 article titled "AAAV–At the Brink of Prototype," the PM offered an extremely accurate observation.

> If I had to say one thing that particularly stands out in my experiences here and throughout the 5 years I've been associated with this program and others, it would be that defense acquisition has always been, is now, and I believe will remain in the future, *principally a human endeavor.* And while we can create a lot of processes, use a lot of tools by which to improve and speed up our work, *all the important things sooner or later come down to people*, their intellectual abilities, and their capability to work with other people. Those out there who think that it's otherwise have something to learn. (Johnson, 1998, p. 16).

I recommend that acquisition professionals apply this outlook by including decision science aspects in their programs. The comparison of the programs made clear that relationships are at the heart of each decision. Currently, automation fails to encompass the full spectrum of decision-making. Therefore, humans must recognize their inherent biases, adjust their paradigms accordingly, and remain flexible during each interaction. I observe that most program issues stem from natural human variability instead of illogical or poorly designed decision aids. Both programs involved different aids and people, yet the model remained relatively consistent. Therefore, the EFV/ACV comparison leans more toward failures of human interaction and less on process and procedure.

This section considers the entirety of the research conducted above. First, I answer my initial research question and then recommend areas for future research. I acknowledge hindsight bias and realize that my closing thoughts do not encapsulate the programs in their entirety, including nuance, external pressures, and organizational relationships.

> **How did the EFV and ACV programs compare concerning the following key defense acquisition areas? (1) mandatory requirements, (2) DOD Decision Support System (DSS) model, (3) Program Management (PM) tools, and (4) decision science principles.**

Table 25 shows the results of the analysis. Through my research and observations, it is clear that the ACV program performs better than its EFV predecessor. During the comparison, I labeled each subsection of the programs either green (better), yellow (marginal), or worse (red). The results represent a qualitative outlook based on the data. They do not represent a complete representation of each criterion. While the EFV performance was subpar to a large degree, the ACV program does leave room for improvement and can continue to learn from the EFV until its end-of-life cycle. Due to the low fidelity of Rechtin's heuristics and the Problem Set Barriers, I could not effectively compare the programs there. I found that open source and government reports do not provide enough data to determine those effects.

Table 25. EFV/ACV Summary Comparison of Analysis Criteria

	COMPARISON	
Mandatory Requirements	**EFV**	**ACV**
Acquisition Program Baseline Data Change	*Significant changes*	*Minor change*
Selected Acquisition Report Change	*Multiple breaches*	*Increasing breaches*
Nunn-McCurdy Breaches	*Critical breaches**	*None*
Level of Market Research and Effect on Program[1]	*Mediocre*	*Extensive*
DOD Decision Support System	**COMPARISON**	
Joint Capability Integration and Development System	**EFV**	**ACV**
Effect of Changes in Key Performance Parameters	*60% change*	*Minor change*
Effect of Changes in Strategic Guidance	*V-Shaped Hull (IEDs)*	*Strategic alignment*
DOD Decision Support System	**COMPARISON**	
Defense Acquisition System: Little "A"	**EFV**	**ACV**
Acquisition Approach[2]	*Standard*	*Incremental**
Schedule Change	*Years*	*Months*
Change to the Number of Units[3]	*Large decrease*	*Increase*
DOD Decision Support System	**COMPARISON**	
Planning, Programming, Budgeting, Execution	**EFV**	**ACV**
Price per Copy (APUC)[4]	*$202.8 million (final)*	*$6.6 million (current)*
Cost Trade-off Decisions	*Increased Cost*	*Balanced*
Program Management Tools	**COMPARISON**	
Knowledge-Based Acquisition	**EFV**	**ACV**
Adherence to Knowledge Points	*Large gaps*	*Minor gaps*
Evidence of Program Trust	*Accurate costing*	*Reneged on 1.2 plan*
Decision Paradigm: Scope of Knowledge	*Increasing scope*	*Limited scope*
Program Management Tools	**COMPARISON**	
Systems Engineering	**EFV**	**ACV**
Application of Rechtin's Heuristics	*Unable to effectively compare/contrast*	
Design Change Process[2,5]	*Poor implementation**	*Existing Platform**
Program Management Tools	**COMPARISON**	

	COMPARISON	
Mandatory Requirements	**EFV**	**ACV**
Risk Management	**EFV**	**ACV**
Critical Technology Risk	*HEU, bow flap, etc.*	*Variant Subsystems**
Risk Mitigation Activities	*Unbalanced trade-offs*	*Coherent trade-offs*
Program Management Tools	**COMPARISON**	
Test and Evaluation	**EFV**	**ACV**
Expected Outcome vs. Test Results	*Highly disconnected**	*Better performing*
Program Management Tools	**COMPARISON**	
Earned Value Management System	**EFV**	**ACV**
EVMS Utilization[6]	*Poor implementation*	*Waived; IPMR data*
	COMPARISON	
Decision Science	**EFV**	**ACV**
Realism versus Rationality[7]	*Unrealistic*	*Logical*
Constraints and Restraints	*Elastic*	*Bounded*
Industry Boundaries[8]	*Poor IPT training*	*Relaxation of 1.2 req.*
Synergistic Elements	*Over-extension*	*Baseline for variation*
DSS Abnormalities	*Limited competition*	*DARPA collaboration*
Problem Set Barriers and Effects[9]	*Unable to effectively compare/contrast*	
Better (green)	0	12
Equal (yellow)	8	12
Worse (red)	16	0

[1] EFV market research data limited.

[2] ACV abandoned 1.2 increment.

[3] ACV unit increase result of 1.1 increment combination with 1.2.

[4] Data from EFV December 2010 SAR and ACV FoV September 2021 SAR (DAVE, 2022a & 2022b).

[5] Change processes from ACV 1.1 to 2.0 remain unknown.

[6] Minimal EVMS data was researched for comparison.

[7] Criteria based on limits to rational solutions.

[8] Different metrics. Comparison considers ACV performance over cost and schedule.

[9] Low fidelity; EFV experiences more harmful effects, while ACV experiences minor effects.

* Indicates the top three risks experienced by each program.

I do not believe the EFV started with a predetermined outcome of failure. Based on the research, unbalanced cost and schedule increases overpowered the EFV performance goal, leading to cancelation. The ACV program performs better in every area except four where they equally compare: SAR change, evidence of program trust, acquisition approach, and industry boundaries. Figure 47 shows my interpretation of the performance of each program. Each constraint compares the goal against the reality. The marker representations outside the acquisition environment speak to the EFV program's unbounded nature. The illustration shows that the EFV cost and schedule goal disparities significantly exceed the ACV FoV. In the future, I forecast ACV 2.0 performance goals cresting the abilities of the acquisition environment.

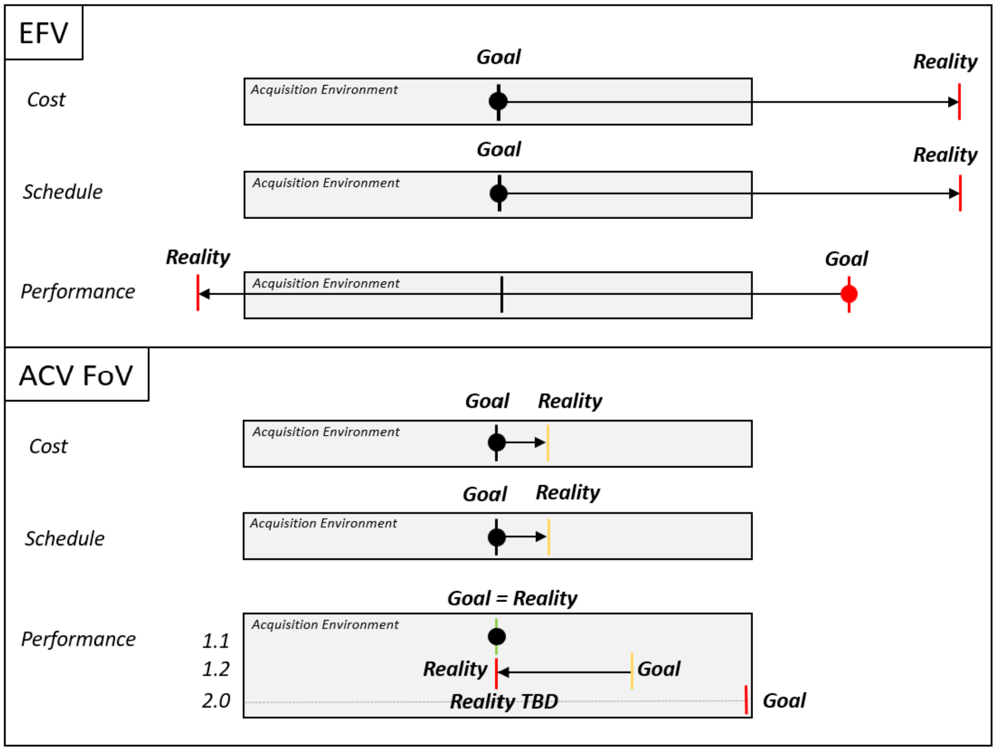


Figure 47. EFV/ACV Summary Depiction of Program Success

Concerning top risks, I found that the EFV termination stemmed from its Nunn–McCurdy beaches, poor SE management, and poor T&E planning. As a result of these increased risks, the EFV spiraled out of control while its costs and schedule became unsustainable. Here, internal cost triggers and proper EVMS processes can help managers spot cost issues before they reach Nunn–McCurdy levels. The 2008 DCMA audit mentioned that "processes and procedures are below standard and do not provide the requisite definition and discipline to properly plan and control complex, multibillion-dollar weapon systems acquisition programs" (U.S. House, 2008, p. 6). Additionally, DCMA stated that "work is being performed that has not been authorized in accordance with any processes" (U.S. House, 2008, p. 6). These statements speak directly to SE management, which significantly contributed to program termination.

Additionally, T&E faded into an unusual "test-fix-test" approach. Although similar to the current iterative software practices, PMOs cannot effectively develop hardware in this manner based on the analysis. Each engineering change is critical, flowing down and affecting various subsystems. The EFV program struggled and chose to accept risk through its T&E approach, costing the program. The EFV PMO worked within a stricter rational paradigm by attempting to unravel and incorporate every stakeholder requirement under the DSS model while also overly weighing GDLS input. As mentioned in the analysis, these dynamics caused the EFV program more conflict and stressed "Big A" boundaries. As a result, the program strayed away from DSS guidelines and delayed the warfighter critical equipment by attempting to rationalize design and requirements changes.

The analysis indicates that leaders' prioritization of cost drove the ACV procurement. The program leveraged the DSS, and, interestingly, the ACV does not convey vast capability increases over the current AAV concerning requirements. By accepting AAV-level performance, the ACV symbolizes a more BRM-centered paradigm. By acknowledging program boundaries such as technical maturity limitations (KBA), reasonable requirements, and Nunn–McCurdy thresholds, the ACV program shows successful execution in comparison. The ability to quickly field a system with similar or less performance to the AAV supported the decision. However, increasing costs and creeping requirements drove the program to abandon its incremental approach. When combined with force design divestitures, the result produced performance equal to or less than the AAV. I suspect this level of capability enables the Marine Corps to spend money elsewhere while retaining the statutory amphibious capability.

Top ACV risks surround technical risks associated with variant subsystems, SE implementation, and future 2.0 HWS efforts. Although the ACV program combined increments to reduce risk, the Marine Corps cannot alleviate risk within its variant progression. If these risks grow, they could postpone or outright cancel the 2025 HWS ACV increment. Similarly, if the budget shifts toward ACV 2.0 development, the last ACV-R variant may not receive appropriate funding. The planned future HWS 2.0 effort will require extensive design changes. Likewise, HWS remains an enormous challenge, requiring a fair sum of developmental and operational assumptions. EFV EMD shows that HWS capability is not just an add-on; it is extraordinarily complex. The engine, drivetrain, and subsystems must be reevaluated and engineered. In a sense, the HWS

ACV 2.0 will be a completely new vehicle. The Marine Corps must now decide whether to proceed with this massive investment through a comprehensive capability-based assessment, DOTMLPF-P review, and thorough AoA.

Overall, the ACV program did leverage lesson learned from the learn where the EFV program. The poor EFV acquisition history left a fantastic opportunity for improvement. The ACV program recognized the value of knowledge-based best practices and mature technology. Despite abandoning the 1.2 increment, their initial approach proved beneficial. For example, one initial lesson learned deals specifically with the unit numbers. In 2007, as EFV costs continued to rise, the program decided to decrease units by 42%. Consequently, EFV TOC increased to over 60% in 12 years. Based on the ACV 1.1s proven technology, the 2019 decision to consolidate increments and increase quantities makes sense. However, unlike the EFV, the USMC chose to conspicuously reduce units. DOT&E stated,

> The planned acquisition objective of 632 ACVs will replace the legacy AAVs fielded to the Assault Amphibian battalion within the Marine Division. The last acquisition objective of 1,122 has been reduced in accordance with Marine Corps Force Design 2030 modernization efforts. (DOT&E, 2021, p. 121)

Therefore, one can see other strategic forces at work. The consequence of combining increments and decreasing procurement quantities has yet to be determined. Still, the Corps accepts the non-tracked vehicle with water speeds equal to the AAV in the interim. The GAO reported that after the early "July 2012 AOA, [the] Marine Corps … determined HWS was technically feasible but not without unacceptable trade-offs" (GAO, 2015b, p. 5). Unlike the EFV, the ACV program reconciles real-world problems (ambiguity, time pressure, politics, interpersonal conflict, biases) with the virtual ones (known structures, variable level of complexity, controlled experiments, implementation failure; Davis et al., 2005, p. 53).

In closing, I concluded that the EFV failed due to an over-reliance on the rational DSS model and an inability to trade performance. Although the program seemed to experience more bias than the ACV, I cannot attribute failure to the prevalence of bias. Bias tendencies remain insidious factors that are hard to acknowledge and correct.

Table 26 highlights some management interventions to prevent them from affecting your decisions and mission. The ACV favored reduced cost and schedule over performance. Additionally, the ACV operates within a boundedly-rational model, exercising limited, logical tradeoffs within the current acquisition environment.

Table 26. Feasible Decision-Making Interventions. Adapted from Walden University (2022).

Strive for strong quantitative and qualitative evidence.
Avoid generalizations.
Remain objective while acknowledging the subjectivity of knowledge points
Encourage inquiry over advocacy.
Consider the sensitivity of data, including the people in the decision process.

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APPENDIX: ACV COMBINATION MEMORANDUM

Figure 48. ADM: ACV FoV Combination. Source: DAVE (2022).

THE ASSISTANT SECRETARY OF THE NAVY
(RESEARCH, DEVELOPMENT AND ACQUISITION)
1000 NAVY PENTAGON
WASHINGTON DC 20350-1000

JAN 0 8 2019

MEMORANDUM FOR PROGRAM EXECUTIVE OFFICER LAND SYSTEMS

SUBJECT: Amphibious Combat Vehicle Acquisition Decision Memorandum

Reference: (a) ASN(RDA) memo Amphibious Combat Vehicle Milestone C Acquisition Decision Memorandum dtd June 19, 2018
(b) DoD Instruction 5000.02 dtd August 10, 2017

On January 3, 2019, Program Executive Officer Land Systems (PEO LS) and Amphibious Combat Vehicle (ACV) program manager provided a brief on combining the currently approved ACV 1.1 program and the future ACV 1.2 program into one Major Defense Acquisition Program (MDAP). The recommendation was based on the demonstrated performance of the ACV 1.1 program meeting the requirements for the ACV 1.2.

I approve combining of the two programs into one ACV Family of Vehicles MDAP and provide the following for action:

- I direct the USMC to continue efforts of the ACV Mission Role Variant development as previously denoted in reference (a).

- In accordance with reference (b), updated acquisition documentation reflecting an ACV Family of Vehicles program shall be provided as part of the Full Rate Production Decision for the ACV Personnel Variant.

- I authorize the development of a Business Case Analysis for a Multi-Year Procurement for the future ACV Full Rate production contract.

My point of contact for this effort is Mr. Richard Ellis, ODASN ELM (703) 614-4582, Richard.p.ellis@navy.mil.

James F. Geurts

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