Amphibious Combat Vehicle:
Case Study of Using Cost to Generate Operational Requirements

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Purpose and Agenda

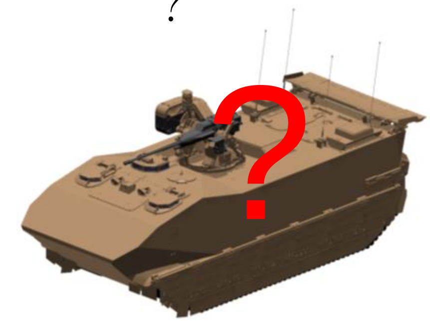
- Purpose:
  - Provide an overview of the Early Phase Systems Engineering process and techniques integrating cost and other technical and logistics factors in deriving operational requirements for the Marine Corps' future Amphibious Combat Vehicle (ACV).
- Agenda
  - Problem Statement
  - SEOPT and Process
  - Integrated Technical and Cost Modeling
  - Capability Selection
  - Tools
  - Results
  - Conclusions and Future Direction

The Problem

1970s | 2010s | 2020s?

Amphibious Assault Vehicle (AAV)

Expeditionary Fighting Vehicle (EFV)



Amphibious Combat Vehicle (ACV)

Current AAV is
- Old, slow and under-armed
- Limited water range
- Too heavy for its original design

Cancelled EFV design was:
- Fast and lethal
- Large water range
- Too expensive to buy and operate.

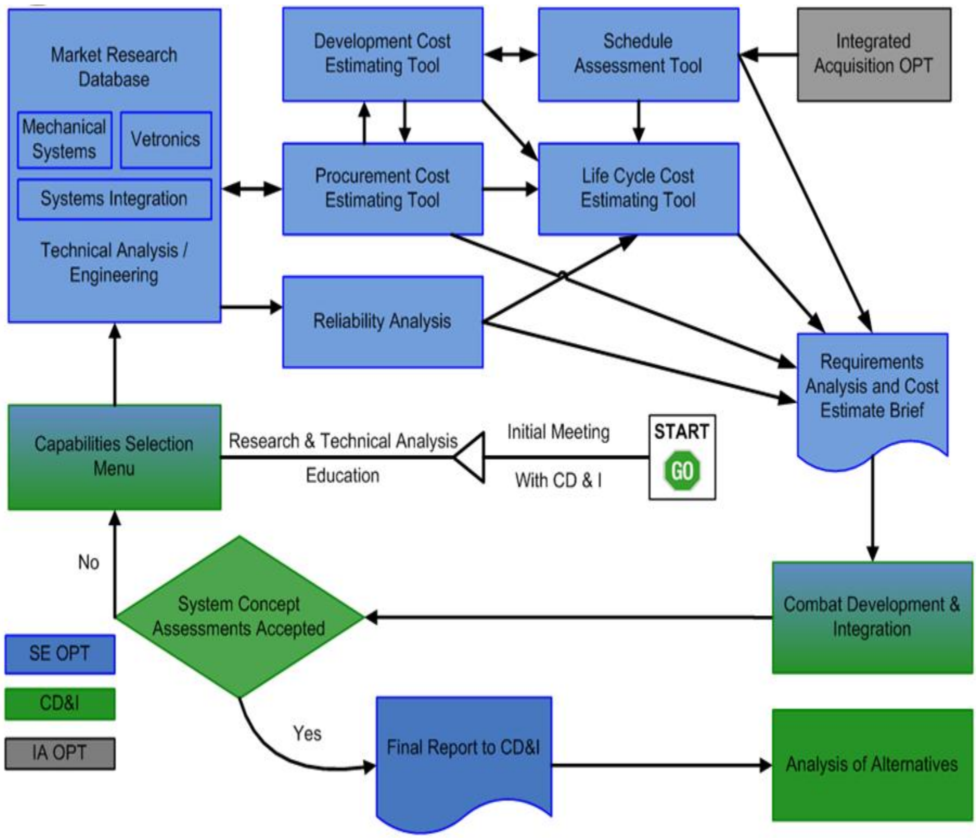
Future ACV needed to support amphibious ops:
- Less expense to buy and operate than EFV.
- Avoid requirements that lead to a vehicle too expensive to buy.

"Despite the critical amphibious and warfighting capability the EFV represents, the program is simply not affordable given likely Marine Corps procurement budgets. **The procurement and operations/maintenance costs of this vehicle are onerous**. After examining multiple options to preserve the EFV, I concluded that none of the options meets what we consider reasonable affordability criteria. As a result, I decided to pursue a more affordable vehicle." (Commandant of the Marine Corps, 2011)

Initial Cost Estimation

- Initial direction was to attempt direct requirement traceability to prime developer cost data to find areas for major cost reduction.
- Summation of requirements costs over 2.5 times the actual cost.
  - Material components supported multiple requirements.
  - Engineering dependencies among material components made substitution of lower cost components more difficult.
- Conclusion:
  - Analysis of requirement costs needed to be done against a holistic set of requirements.
  - Cost estimation and requirements selection needed to evolve into a larger effort of evaluating different system concepts.

SE OPT Process



USMC formed a team called the SE OPT to provide a set of cost-informed requirements for AoA analysis.

The Iterative Process:

- Work with the operational requirements customer (CD&I) on the initial range of capabilities.
- Form a set of selected capability options.
- Conduct market research on possible material components.
- Conduct multi-dimensional trade space analysis – iterative material selection, first vehicle cost and vehicle attribute estimates.
- Estimate possible schedules and acquisition strategies.
- Conduct developmental cost and reliability estimates.
- Feed all data into LCCE tool.
- Redo process as needed with adjusted customer capability selections

Capability Options

To Move – Maintain appropriate speeds on land or water as specified in mission orders.
Water mobility
Land Mobility
Range
Operating Environment (without kit)
Towing (Land & Water)
Navigation
Thermal vision (other than gun sight)
Silent Watch (functions)
Weight growth Allowance

To Shoot – Demonstrate weapons station and armament functionality (sight, traverse, elevate, fire). (P-Variant)
Firepower
Target Acquisition
Reloading Capability
Mixed Fleet Weapon Systems

To Communicate – Maintain minimum essential communications for safe and effective operations. (P-Variant)
Voice Communications
Data
Blue PLI distribution
Software Hosting
Internal Communications
FIST Team Support

To Carry – Transport Marines from ship-to-objective and deliver them in fighting condition. (P-Variant)
Crew
Troop carrying capacity
Troop Loads
On-Board Equipment Material (OEM) Storage
Water Survival Equipment
Environmental Controls
Additional Days of Supply (per # of Troops & Crew)
Other Mission Essential Equipment (lbs)
Cargo (without troops)
Litter Kit
MK154 Line Charge Kit
Lighting
Camie Nets (ULCANS)

Transportability - To be transportable by truck, U.S. rail, air, and sea.
Amphibious Shipping
Landing Craft
Maritime Prepositioning Shipping
Rail
Truck (lowboy)
Air
Crane Lift (structure/appurtenances)
DOT Compatible (Roads)
Ground pressure

SUSTAINMENT - 'Design for Support, Design the Support, Support the Design'
Materiel Availability (JCIDS KPP) M_A = Number of End Items Operational/Total Population
Design For Reliability (JCIDS KSA)
MTBRR (Mean Time Between Remove & Replace in hours)
MR (On-Board Intermediate) = Maintenance Manhours/Op hour
MCMT (On-Board Intermediate) = Corrective Maint Time/Total Number of Maint Actions
Diagnostics
Depot maint support
Intermediate maint
Operator maint
Supply Chain/PHS&T
Technical Data
Computer Resources
Software Support
Support & Test Equipment
Operational Site Activation (Portfolio?)

System Training
Transition
Initial
Refresher
Concurrency
Unit

To Protect – Protect crew and embarked Marines against threat forces and weapons.
Direct fire survivability
Indirect fire survivability
Mine survivability
IED Protection
EFP Protection
Directed energy
Signature requirements (Visual, Acoustic, Thermal, RCS)
AFSSS
RPG
Rapid Obscuration
Smoke Generation
Combat Identification
NBC Protection

Mission Performance (Traceable to OMS/MP)
Operational Availability A_O
System Reliability

NOTE: ITEMS IN RED ARE RELEVENT TO LOGISTICS.

System Concepts

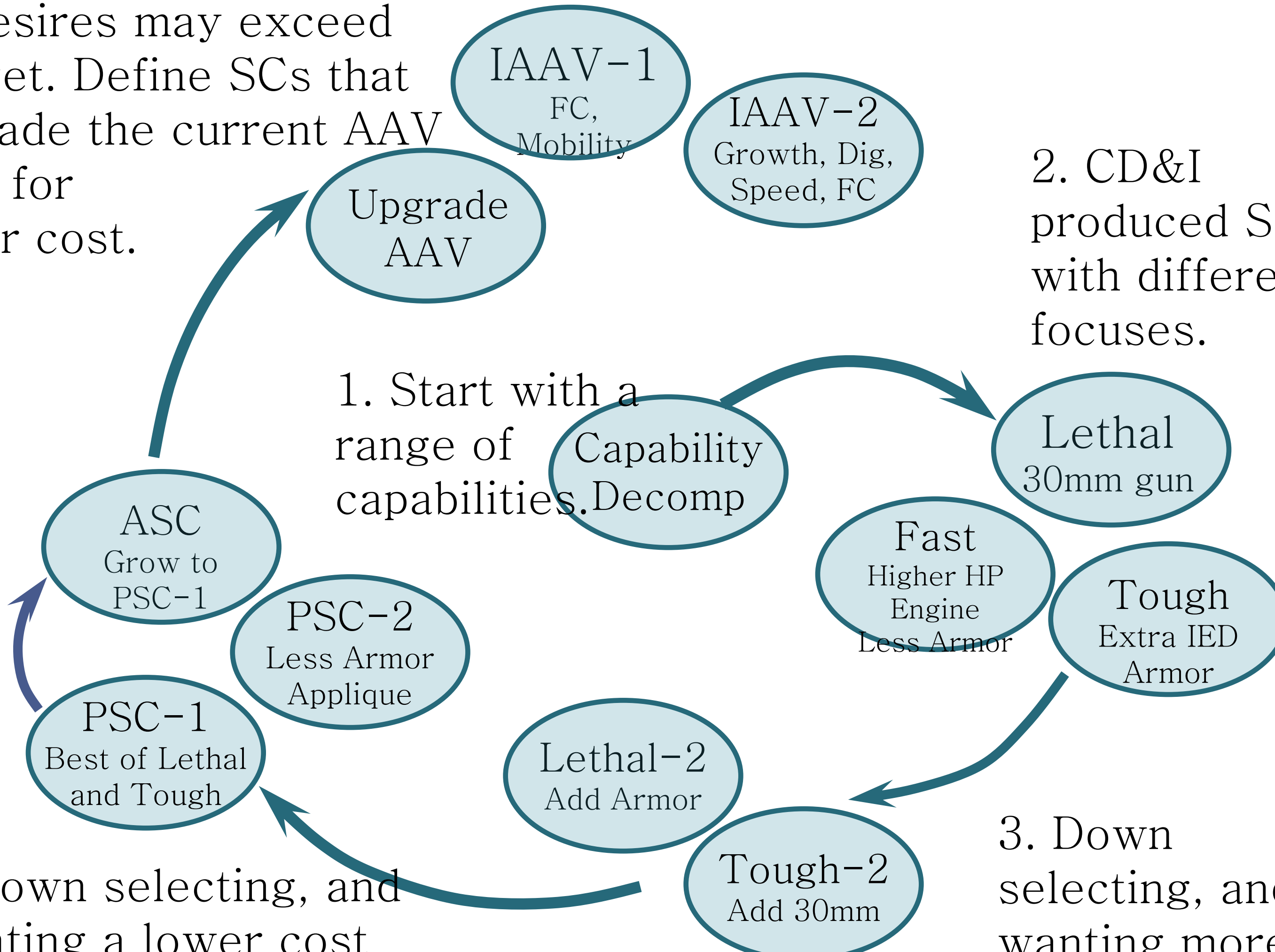
1. Start with a range of capabilities.

2. CD&I produced SCs with different focuses.

3. Down selecting, and wanting more.

4. Down selecting, and creating a lower cost ASC that can become a PSC.

5. Desires may exceed budget. Define SCs that upgrade the current AAV fleet for lower cost.



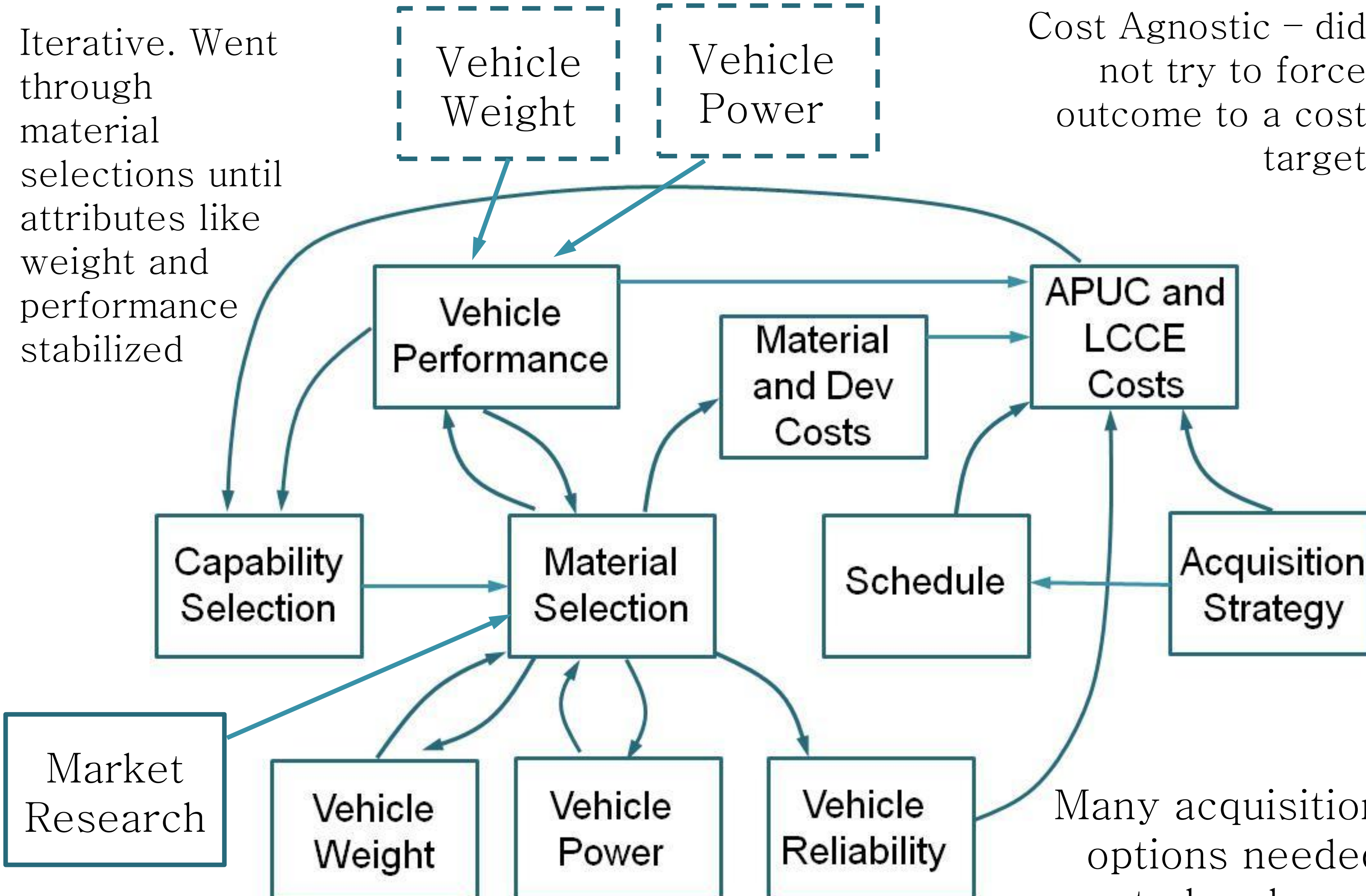
Cost Estimation Conducted

- A variety of cost estimation techniques were used to assess probable cost ranges of different system concepts:
  - Actual costs for currently available material components (WBS level 4 and 5)
  - Cost Estimating Relationships (CERs) for estimating develop-ment costs from material costs.
  - Analogous cost estimation techniques for impact of production learning curve, contracting strategy savings, and operations and support costs based on the older AAV.
- Cost estimates produced, each with a three-point cost range of low, most likely and high:
  - Average Procurement Unit Cost (APUC)
  - Development costs
  - Life Cycle Cost Estimates (including MILCOM, Training, O&S, and disposal)
  - Cost profiles for R&D, PMC, and O&M funding for 30 years
- Above products were produced for each system concept and the permutation of the following variables:
  - Production size
  - Production period
  - Pessimistic, most likely and optimistic schedules

Integrated Cost and Performance Modeling

Iterative. Went through material selections until attributes like weight and performance stabilized

Cost Agnostic – did not try to force outcome to a cost target



Many acquisition options needed to be chosen early.

Procurement and Development Cost Tool

Base Vehicle #6: 12.7 Protection/8 Knot Speed

Go Back to Front Page | Go Back to Options Page

Weight	55,199
Weight (Min)	50,455
Weight (Max)	60,119
Hardware Cost (Procurement)	$6,004,909.79
Hardware Cost (Min)	$5,408,319.20
Hardware Cost (Max)	$6,652,832.91
NRE Cost (Most Likely)	$245,236,811.17
Reliability	36
Power (hp)	1,399
Power (hp) - Min	1,272
Power (hp) - Max	1,500
Power (Electric)	9,131
Power (Electric) - Tolerance	0
Power (Electric) - Peak	32
Power (Hydraulic)	52
Power (Hydraulic) - Min	47
Power (Hydraulic) - Max	58
DRA	4

CWBS	Subsystem (Level III)	Component (Level IV)	Min Weight (lbs)	Most Likely Weight	Max Weight (lbs)	Hardware Cost (FY07) (Min)	Hardware Cost (FY07) (Most Likely)	Hardware Cost (FY07) (Max)
2.01								
2.01.01	Hull / Frame Structure (1.1.1)		25303	27878	30452	$2,667,227	$2,945,994	$3,224,760
2.01.01.01		Hull Weldment (1.1.2)	13,434	14,927	16,420	813,384	$903,760	994,136
2.01.01.02		Hull Hatches & Panels (1.1.3)	2,426	2,526	2,626	$452,915	$503,239	$553,563
2.01.01.03		Hull Armor (1.1.4)	5,043	5,604	6,164	524,975	$583,306	641,636
2.01.01.04		Hull Accommodations (1.1.5)	1120	1171	1222	$240,000	$245,749	$251,497
2.01.01.05		On-Vehicle Equipment (1.1.6)	800	861	921	$44,053	$44,053	$44,053
2.01.01.06		Other Hull Parts (1.1.7)	2480	2790	3100	$591,900	$665,888	$739,875
2.01.01.07		Hull Integration, Assembly, Test & Checkout (1.1.8)						
2.01.01.08		Hull Systems Engineering/Program Management (1.1.9)						
2.01.02	Land Suspension System (1.1.2)		12,119	13,249	14,380	$420,881	$460,543	$500,204
2.01.02.01		Track System (1.1.2)	5,447	6,140	6,834	$102,397	$103,724	$105,052
2.01.02.02		Suspension System (1.1.2)	3,297	3,663	4,030	$270,000	$300,000	$330,000
2.01.02.03		Road Wheels (1.1.2)	2,380	2,380	2,380	$6,948	$6,948	$6,948
2.01.02.04		Sprocket Carriers (1.1.2)	372	375	377	$24,069	$31,629	$39,189
2.01.02.05		Support Rollers (1.1.2)	232	300	368	$7,467	$8,241	$9,015
2.01.02.06		Track Tensioning System (1.1.2)	391	391	391	$10,000	$10,000	$10,000
2.01.02.08		Other Land Suspension Parts and Systems (1.1.2)						
2.01.02.09		Land Suspension System Integration, Assembly, Test & Checkout (1.1.2)						
2.01.02.10		Land Suspension Systems Engineering/Program Management (1.1.2)						
2.01.03	Hydrodynamic Appendages and Steering (1.1.1)		645	787	929	$118,546	$137,954	$157,361

- Estimation of material and development costs, and Vehicle Attributes using a small set of factors (e.g. weight, power)
- Manual selection of material choices to fulfill capability selections.
- Reused EFV WBS/CBS. Included18 subsystems, and their components plus PM/SE, Integration, Testing, initial spares, and training costs.
- Dynamically calculated costs and vehicle attributes.
- “Ford.com” model – pick a base vehicle and add options from there.
- Tools helped identify material issues, but human insight still needed.

WBS is the central structure between the tools.

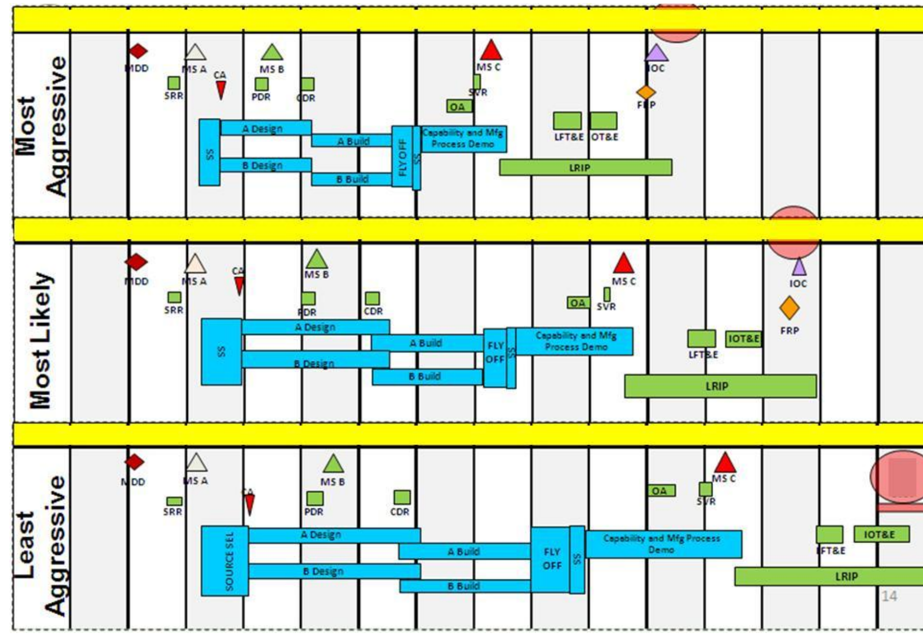
Vehicle Attributes

Attribute	Value	Description/Methodology for Calculating Value
First Vehicle Procurement Cost	Min: $9102799 Most Likely: $9896604 Max: $10746441	Value calculated from the Options page - summation of all first vehicle procurement costs from the base vehicle and options selected.
Development Cost	Min: 294935284 Most Likely: 316048523 Max: 341537658	Value calculated from the Options page - summation of all development costs from the base vehicle and options selected. Dependent on the procurement costs.
Weight: Curb	Min: 64155 Most Likely: 69664 Max: 75131	Value calculated from the Options page - summation of all weights from the base vehicle and options selected, with the addition of fuel weight (300 gal at 7.1 lbs per gal). Most likely weight is displayed.
Weight: Combat equipped	Min: 76727 Most Likely: 82236 Max: 87704	Calculated from the curb weight plus fully equipped crew and passengers. Assuming 20 Marine, 95 percentile weight (195 lbs), and combat load averaging 400 lbs per person.
Ground clearance	16	Initial ground clearance is assumed to be 16". This may then be reduced based on selection of optional underbody armor for IED protection.
Ground Pressure	11.01	Assuming tracked vehicle. Using Most Likely Vehicle Combat loaded weight. Assuming 21" wide tracks with 17' length touching the ground on both sides.
Turning radius	0	Based on capability selected by CD&I. If pivot capabiltiy is selected, then turning radius will be 0. Assuming a tracked vehicle system.
Survivability: Direct	None	Determined by which base vehicle is selected in the options page, and any applique that may be selected as an option.
Survivability: NBC	NBC: Collective Protection; ; Integrated Detection	Based on the optional components selected in the Options page.
Max Speed (Land) (mph)	Min: 60 mph Most Likely: 60 mph Max: 51.1 mph	Being calculated as a function of available engine horsepower and vehicle weight. Vehicle Combat Weight is being used. HP comes from the base vehicle selected.
Max Speed (Water) (knots per hour)	Min: 8 knots Most Likely: 8 knots Max: 8 knots	Being calculated using equations derived from a regression analysis using performance charts from NSWC Carderock. Vehicle Combat Weight is being used. HP comes from the base vehicle selected.
Miles per Gallon (Land)	0.78	Assuming JP8 diesel fuel. Uses assumed vehicle average cruising speed. Uses vehicle combat weight.
Nautical Miles per Gallon (Water)	0.11	Assuming JP8 diesel fuel. Vehicle going at max water speed - highest engine fuel consumption rate. Uses vehicle combat weight.
Range	214.909090909091 Miles on land after traveling 12 nautical miles from shore. 300 miles on land travel only, assuming level road and cruise speed of 25 mph.	Uses chosen distribution of water and land miles chosen by CDI. Calculates fuel consumption over water first, then range over land. Assuming fuel tank size, using JP8 diesel fuel. Vehicle going at max water speed - highest engine fuel consumption rate. On land vehicle goes at cruising speed over road. Uses vehicle combat weight.
DRA	Min: 3.6	Uses TRLs for all components of base vehicle and options chosen. If a component does not have a explicit TRL listed, it is assumed to be TRL 8.
Crew Size	3	Assumed to be three - going in SE OPT assumption.
Troop Load	17	Assuming a 17 Marine troop load.
Reserve Buoyancy	Min: 12.4% Most Likely: 15.3% Max: 18%	Dividing volume of water = vehicle combat weight by volume of vehicle. Uses assumed vehicle dimensions (subtracting turret portion of height.

- Based on the data from:
  - Base vehicle attributes (overall weight, power, TRL, etc.)
  - Options selected
  - SE OPT assumptions (such as vehicle being EFV dimensions)
- Tool will provide a subset of the configured vehicle attributes.
- Key Attributes
  - Combat and curb weights
  - Reserve buoyancy
  - Land range/fuel tank size

Schedule Input to LCCA

- Each SC had three different schedules constructed out to IOC
  - Most Aggressive
  - Most Likely
  - Least Aggressive
- The schedules included several programmatic assumptions or decisions normally found in an acquisition strategy:
  - Milestone targets
  - Contracting strategy
  - Number of prototypes (affects testing schedule)
  - Length of development



LCCE Tool

- Inputs
  - First vehicle costs.
  - Non-recurring Engineering costs
  - Recurring Engineering costs
  - Fuel consumption (land and water, ratio)
  - Crew size
  - Weapons systems
  - Reliability
  - Acquisition Assumptions:
    - Schedule (various activities, in months)
    - Number of prototypes
    - Number of vendors
    - Production rate
    - Total Production target
    - Contract type and competition savings
- Products and Assumptions (per element of Logistics)
  - Total Life Cycle Systems Mgt: Cost all activities, including costs budgeted by other programs and agencies.
  - Procurement: Business factors such as overhead, profit margin of contractors.
  - Development: learning curve percentages, manpower needed and their costs.
  - MILCON: Analogy to existing AAV infrastructure.
  - Operations and Sustainment (O&S): Analogy to existing AAV fleet.
    - 20 year service life.
    - Three levels of maintenance.
    - 437 hours/year operation.
    - Unit Operations: Analogy to AAV transportation costs, ammunition costs.
    - Maintenance: Analogy to equipment service life, maintenance equipment cost, replacement costs at all three levels.
    - Manpower: Crew size, known force structure for maintenance and training, and expected pay rates.

New Technique: Complexity for Estimating Reliability

Reliability impacts LCCE, yet how can reliability be estimated at such an early stage?

For new SCs:

- Modified an existing functional block diagram (from EFV) to work reliability estimates for new concepts.

For SCs based on existing AAV vehicles:

- Little data on existing components.
- Used complexity as a parameter to estimate reliability.
  - Used a modified-Boothroyd-Dewhurst (Mod-BDM) complexity metric
  - Boothroyd-Dewhurst metric requires knowing the number and types of parts, and their number of interfaces. Not realistic for SCs.
  - Mod-BDM uses a categorical estimate of parts per major subsystems.
- Analysis showed that this parametric worked well compared to FBD-based reliability estimates for new SC vehicles.

Analyzed how Mod-BDM compared to the use of the defined

Data Preparation

- Raw Data
  - 26,000 EFV parts list, assigned to vehicle subsystems.
    - Gives hierarchal association
  - MTBF estimates from Raptor for 7 ACV system concepts.
- Complexity Metrics
  - Boothroyd-Dewhurst Method (BDM)
    - Famous for Design For Assembly (DFA)
    - Three elements – N_p: # parts, N_t: # part types, and N_i: # interfaces
    - Problem: What if you don't have parts information?
- New Complexity Metric
  - Modified Boothroyd-Dewhurst Method
    - Ordinal instead of ratio values.
    - Subdivided into major subsystems.
    - Solves BDM problem – less specific info needed.
- Data Processing
  - Estimate BDM numbers for vehicles from system concept material definitions
    - Estimate the #interfaces per part type.
    - Process raw parts data using Excel.
    - Tailor a parts list per system concept.
  - Expert assignment of ordinal values to Modified BDM table.

WBS ELEMENT CODE	WBS REPORTING ELEMENTS	EFV			ACV-Lethal			ACV-Fast			ACV-Tough			PSC 1			PSC 2			Alt SC		
		Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)	Np (# of Parts)	Nt (Part Types)	Ni (# of Interfaces)
2.01	Primary Vehicle																					
2.01.01	Hull/Frame Structure	2.5	2.0	2.0	2.5	2.0	2.0	2.5	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.5	2.0	1.5	2.0	2.0	1.5	1.5
2.01.02	Land Suspension System	3.0	2.5	2.0	1.5	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0	2.0	1.5	1.5	1.5	1.0	1.0	1.5	1.5	1.5
2.01.03	Hydrodynamic Appendages and Steering	2.0	2.0	1.5	1.5	1.5	1.0	2.0	1.5	1.5	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0
2.01.04	Engine System	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0
2.01.05	Automotive Drive Train System	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0	3.0	3.0	2.0
2.01.06	Marine Drive Train System	2.5	2.5	1.5	2.0	2.0	1.0	2.5	2.5	1.5	2.0	2.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0	2.0	2.0	1.0
2.01.07	Auxiliary Automotive Systems	3.0	3.0	2.0	3.0	2.5	2.0	3.0	2.5	2.0	3.0	2.5	2.0	3.0	2.5	2.0	3.0	2.5	2.0	3.0	2.5	2.0
2.01.08	Turret Assembly	2.0	2.0	1.0	3.0	2.0	2.0	1.5	1.5	1.5	1.5	1.5	1.5	3.0	2.0	2.0	3.0	2.0	2.0	1.5	1.5	1.5
2.01.09	Fire Control System	3.0	2.0	2.0	3.0	2.0	2.0	2.0	1.5	1.5	2.0	1.5	1.5	3.0	2.0	2.0	3.0	2.0	2.0	2.0	1.5	1.5
2.01.10	Armament	2.0	1.5	1.0	2.0	1.5	1.0	2.0	1.5	1.0	2.0	2.0	2.0	2.0	1.5	1.0	2.0	1.5	1.0	2.0	1.5	1.0
2.01.11	Automatic Loading (Ammo Feed System	2.5	2.0	1.5	2.0	2.0	2.0	1.5	1.0	1.0	1.5	1.0	1.0	2.5	2.0	1.5	2.5	2.0	1.5	2.5	2.0	1.5
2.01.12	Nuclear, Biological and Chemical	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0	2.0	1.0	1.0
2.01.13	Special Equipment	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2.01.14	Navigation Systems	2.0	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0	1.5	1.0	1.0
2.01.15	Communications System	2.0	2.0	2.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0	1.5	1.5	1.0
2.01.16	Primary Vehicle Application Software	3.0	1.0	2.0	1.5	1.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.5	1.0	2.0	1.5	1.0	2.0	1.0	1.0	1.0
2.01.17	Primary Vehicle System Software	3.0	2.0	2.5	1.5	1.5	2.0	1.5	1.5	2.0	1.5	1.5	2.0	1.5	1.5	2.0	1.5	1.5	2.0	1.5	1.5	2.0
2.01.18	Vetronics	3.0	2.0	3.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0	3.0	2.0	2.0
		44.5	35.5	31.0	38.5	31.5	28.0	36.0	30.0	26.0	35.5	30.0	26.0	40.0	32.0	28.5	38.5	31.0	27.5	35.5	30.5	25.5

Data Analysis

- Variables
  - Independent – Complexity. Two different Complexity Measures to be evaluated:
    - BDM
    - Modified BDM
  - Dependent – Reliability (MTBF)
- Equations

$$BDM = \sqrt{N_p + N_t + N_i}$$

$$Mod\_BDM = \frac{1}{3}\left(\sum_{i=1}^{n} Np_i + \sum_{i=1}^{n} Nt_i + \sum_{i=1}^{n} Ni_i\right)$$

$$T_2 = (r_{jk} - r_{jh})\sqrt{\frac{(N-1)(1+r_{kh})}{2\left(\frac{N-1}{N-3}\right)|\mathbf{R}| + \bar{r}^2(1-r_{kh})^3}},$$

$$|\mathbf{R}| = (1 - r_{jk}^2 - r_{jh}^2 - r_{kh}^2) + (2r_{jk}r_{jh}r_{kh})$$

$$\bar{r} = \tfrac{1}{2}(r_{jk} + r_{jh})$$

Calculated independent and dependent variable values for seven system concepts.

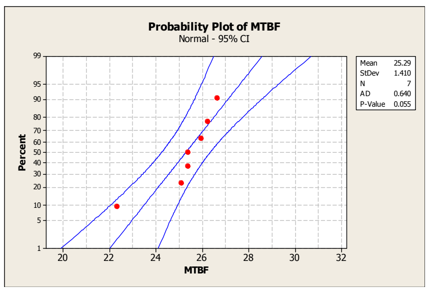
		EFV	FAST	LETHAL	Tough	PSC-1	PSC-2	ASC
Indep	BDM	539.9	482.3	518.5	483.8	523.9	520.3	487.2
Indep	Modified BDM	37.00	30.67	32.67	30.50	33.50	32.33	30.50
Dependent	MTBF	22.34	25.96	25.37	26.64	25.10	25.37	26.24

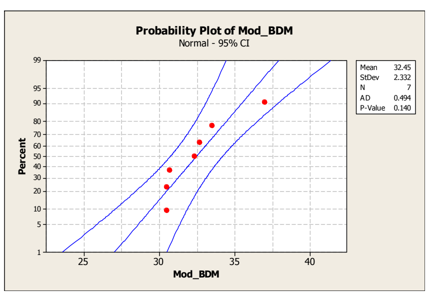
- Analysis Steps to determine the possible correlation between complexity and MTBF.
  - Calculate Data Table
  - Visually inspect for linearity
    - Determine linear vs nonlinear fit.
    - Check for homoscedasticity
  - Calculate Correlation and Regression for each complexity measure vs. MTBF.
    - Used Pearson. Both independent and dependent variables were ratio-based (even though raw data in Modified BDM was ordinal)
    - Linear regression used.
  - Conducted Hypothesis Tests (95% Confidence) to ensure the existence of a significant correlation.
  - Conduct Williams T_2 Test to determine if the two different correlations on a common dependent variable are significantly different.

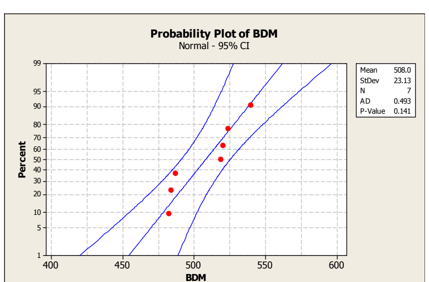
- Steiger, J. H. (1980) Tests for Comparing Elements of a correlation Matrix. Psychological Bulletin, 87(2).
- Neil, J.J. and Dunn, O.J. (1975) Equality of Dependent Correlation Coefficients. Biometrics, 31(2).

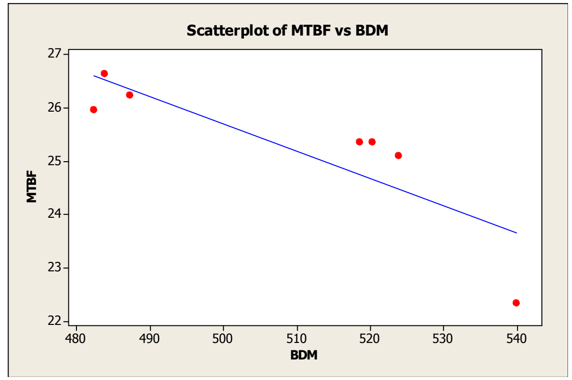
Analysis Results

- Checked for normality of the data, as hypothesis tests will be used both on the individual correlations and to compare them.
- All variables roughly fit a normal distribution.









Regression Analysis: MTBF versus BDM

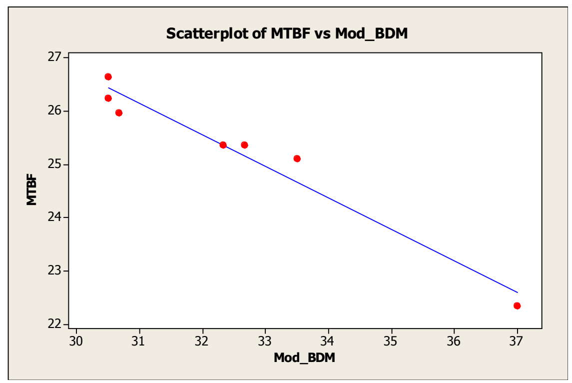
```
The regression equation is
MTBF = 51.39 - 0.05137 BDM

S = 0.830773   R-Sq = 71.1%   R-Sq(adj) = 65.3%

Analysis of Variance

Source      DF       SS       MS      F      P
Regression   1   8.4744  8.47436  12.28  0.017
Error        5   3.4509  0.69018
Total        6  11.9253
```

Pearson correlation of BDM and MTBF = -0.843



Regression Analysis: MTBF versus Mod_BDM

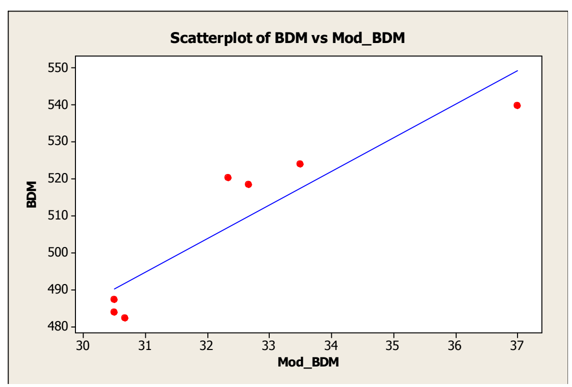
```
The regression equation is
MTBF = 44.47 - 0.5910 Mod_BDM

S = 0.323598   R-Sq = 95.6%   R-Sq(adj) = 94.7%

Analysis of Variance

Source      DF       SS       MS       F      P
Regression   1  11.4017  11.4017  108.88  0.000
Error        5   0.5236   0.1047
Total        6  11.9253
```

Pearson correlation of Mod_BDM and MTBF = -0.978



Pearson correlation of Mod_BDM and BDM = 0.915

H_0: corr1 = corr2 Conduct William T_2
H_1: corr1 != corr2 Test, alpha = 0.05

$T_{(.025, 4)} = 2.7765$ dof = N – 3

William T_2 = 4.07, so we reject the $H_{0.}$

Statistical Results

- Based on the Williams T_2 Test
  - There is statistically significant evidence that the correlation between BDM and MTBF vs. Mod-BDM and MTBF are different.
    - Mod-BDM and MTBF showed a higher correlation.
  - The correlation between Modified-BDM and MTBF is a better relationship to use for predicting reliability for the amphibious vehicle domain when estimating vehicle concepts than the Boothroyd-Dewhurst Method.
    - Quicker estimation method than figuring out vehicle part counts and interfaces.
    - Resolves issue concerning a lack of detailed parts data.

SE OPT Products

- Generated 11 different system concepts (SCs) over a 12 month period with Requirements Organization involvement
- Each SC had a technical performance and attribute profile.
  - Max land speed, max water speed, reserve buoyancy, land/water range, protection, weapons capability/lethality, MTBF, and weight (curb, combat).
- For each SC, generated 27 different permutations of 3-point cost estimates (low, most likely, and high)
  - 3 different Acquisition Objectives (AOs)
  - 3 different production runs
  - 3 different schedules
- Each 3-point cost estimate permutation included the following:
  - APUC, total development, and total LCCE
  - R&D, PMC, and O&M yearly cost profile.
  - LCCE cost profile broke out development, procurement, MILCON, and disposal.

System Concept Estimated Performance Attributes

	Capabilities Selected	AAV	AAV Concepts									ACV Concepts						EFV
		Requirements	AAV Upgrade			Improved AAV-1			Improved AAV-2			ASC ***			PSC 1			Requirements
			Low	Most Likely	High	Low	Most Likely	High	Low	Most Likely	High	Low	Most Likely	High	Low	Most Likely	High	
Max Water Speed (knots)	8, 10 (FAST)	7	7			7			8			8			8			25
Weight Growth Allowance (lbs)	1500	0	0			0			1500			1500			1500			1500
Primary	40mm(AAV-Upg), .50cal(IAV-1, 2))	40mm	40mm			.50 cal			.50 cal			40mm			30mm			30 mm
Secondary	.50 cal (AAV-Upgrade)	.50 cal	.50 cal			None			None			.50 cal			7.62mm			7.62mm
Stowed	Readyx5(AAV-Upg), x3 (IAV-1, 2)	Ready x 5	Ready x 5			Ready x 3			Ready x 3			Ready x 3			Ready x 2			Ready x 1
Crew	3	3	3			3			3			3			3			3
Survivability, Direct Fire	Varies	7.62 (Inherent) / 14.5 (EAAK)	7.62 (Inherent) / 14.5 (EAAK)			7.62 (Inherent) / 14.5 (EAAK)			7.62 (Inherent) / 14.5 (New Appliqué)			12.7 (Inherent)			12.7 (Inherent) / 14.5 (App 360 degress) **			14.5mm (Inherent)
Survivability, Blast Protection	Varies	Level 1	Level 1 (Inherent) / Level 3+ (App)**			Level 1 (Inherent) / Level 3+ (App)**			Level 1 (Inherent) / Level 3+ (App)**			Level 2 (Inherent)			Level 2 (Inherent) / Lev 4+ (App)			Level 1
Troops	17	21	17			17			17			17			17			17
Days Of Supply (DOS)	2	1	2			2			2			2 *			2 *			1
Curb Weight (1000 lbs) (Land)	N/A	48	54.2	56.0	58.4	52.6	54.5	57.4	55.1	58.4	62.8	62.0	67.5	73.4	67.4	73.2	79.0	69.5
Combat Weight (1000 lbs) (Land)	N/A	61	64.4	66.3	68.6	62.8	64.8	67.6	67.5	70.7	75.2	74.6	80.0	86.0	77.6	83.2	89.1	79.2
Reserve Buoy (No IED Armor)	25%	14%	12.2%	10.9%	9.6%	14.4%	13.0%	11.0%	**18.0%**	**15.1%**	**11.4%**	28.4%	23.2%	17.5%	25.5%	20.2%	14.5%	24.00%
Max Land Speed (mph)	45	45+	45			45			45			45			45			45
Cruising Land Speed (mph)	25	25	25			25			25			25			30			25
Op Range (Wtr/Lnd) (nm/mi)	12 / 200	3 / 128	3 / 286			12 / 245			12 / 222			12 / 200			12 / 200			12 / 180
Range - Land only	300 mi	200	300			300			300			300			300			267
Horse Power (hp)	N/A	525	600			600			1050 - 1200			1050 - 1250			1100 - 1260			2701
MTBF	20 hrs	N/A	38.18	34.71 (Parametric Only)	31.24	37.29	33.88 (Parametric Only)	30.49	33.17	30.15 (Parametric Only)	27.14	28.86	26.24	23.62	27.61	25.1	22.59	N/A

Conclusions and Future Direction

- The USMC ACV program gives insight to the actual use of integrated cost and technical modeling during pre-MDD to inform requirements. Specifically:
  - Form core team of acquisition, cost estimation, domain and SE experts agnostic to the cost estimation result.
  - Focus on known technologies as much as possible.
  - Used the Blanchard LCCA process and multi-dimensional trade space to analyze possible operational requirements sets, while also including schedules, contracting, and other acquisition strategy issues to affect the cost.
  - Used various cost estimation techniques, but it was integrated with the technical modeling and gathering of key data (market research of component costs, weights, power consumption, and reliability).
  - Used a system dynamics approach to reaching cost and technical estimates while trying to reach capability targets. Many requirements cannot be cost estimated in isolation (i.e., linearly)
  - Multiple system concepts need to be evaluated. The final

Conclusions and Future Direction

- Seems to be the first attempt to conduct multi-dimensional trade space and cost estimates at this level of detail to generate operational requirements in DoD. (Looking for other examples!)
- Trusted Source. Going to this level of detail, and not invested in program itself, made this a trusted set of estimates.
- Future:
  - Doing this for the complete portfolio (MPC as well as ACV, AAV).
  - Change the acquisition process to do this for Milestone A.
    - Program budget based on SEOPT cost profile.
    - Develop handbook
  - Transition from SE OPT group to the actual program office. (Estimate useful only if the assumptions and decisions made in SE OPT are carried out by PM)

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