# Naval Center for Cost Analysis

## Schedule Estimating Relationship (SER) Development Using Missile and Radar Datasets

**Presented to:**

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# Research Task Overview

- Develop comprehensive schedule and technical datasets for missile and radar acquisition programs

- Develop Schedule Estimating Relationships (SERs) using the datasets

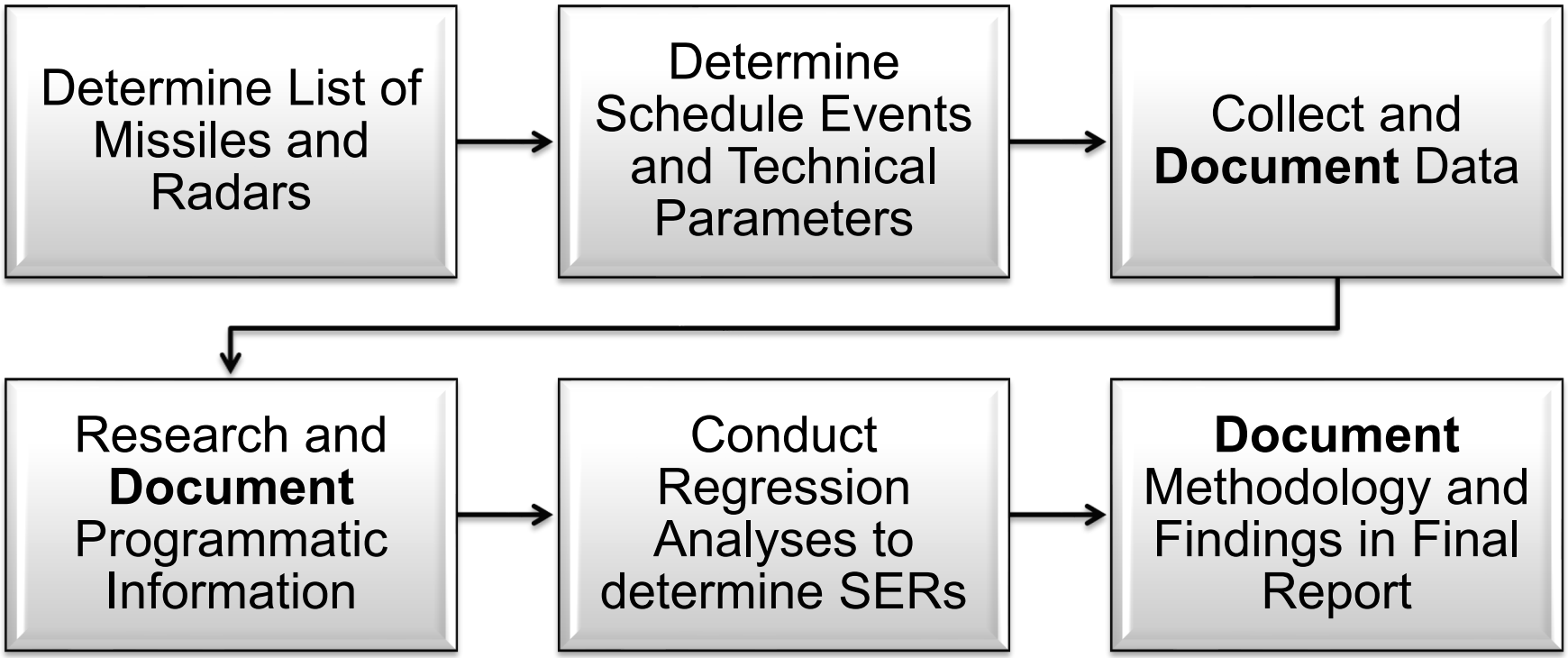




# Introduction

- 38% schedule delay in major defense programs (GAO)
- Schedules need to be de-risked through a data-driven approach
- Development of missile and radar datasets
  - Apply multilevel statistical techniques to determine if schedules can be more accurately predicted
  - Beneficial to Government cost analysts when drawing analogies
  - Descriptive statistics are useful
- No statistically significant SERs due to great variability in schedule durations

# Task Process




*Collaborate with Service Cost Agencies*

# Data Collection

## Schedule Data

| Major Schedule Events |
|---|
| MS A (Decision and Award) |
| MS B (Decision and Award) |
| MS C/Low-Rate Initial Production (LRIP) (Decision and Award) |
| Full-Rate Production (FRP) (Decision and Award) |
| Initial Operational Capability (IOC) |
| **Other Schedule Events** |
| Preliminary Design Review (PDR) |
| Critical Design Review (CDR) |
| Development Test and Evaluation (DT&E) (Start & End) |
| Initial Operational Test and Evaluation (IOT&E) (Start & End) |

## Key Technical Parameter Data

| Missiles | Radars |
|---|---|
| Weight (lbs) | Frequency Band (GHz) |
| Maximum Range (nautical miles [nmi]) | Weight (lbs) |
| Velocity (ft/s) | Antenna Aperture ($ft^2$) |
| Diameter (in) | Number of Elements |
| Length (in) | Number of Transmit/Receive Modules |
| Altitude (ft) | Average Power (KWs) |
| Volume ($in^3$) | Peak Power (KWs) |
| Total Impulse (pounds of force per second) | Minimum Range (nmi) |
| Year of Technology (1962-2010) | Maximum Range (nmi) |

## Data Sources

- Official DoD Sources
  - SARs
  - CARDs
  - Services (History, Briefings, Fact Sheets, Handbooks, Service Cost Organizations)
- Official Studies: RAND, IDA, Tecolote, and Technomics Studies
- Industry
- Forecast International, Deagle, Global Security, Jane's, and others

Note: All data derived from unclassified, open-sources

## Service Cost Agency Collaboration

Collaborated with key cost organizations to collect and validate schedule and technical data

- NCCA
  - NAVAIR
  - NAVSEA
  - MARCORSYSCOM
- AFCAA
- DASA-CE
- MDA

# Missile Dataset Example

**NCCA DAMIR DATABASE - SAR SCHEDULE DATA EXTRACT**

| SAR Date | Program | SAR Schedule Event | Key Event | Actual Event Date |
|---|---|---|---|---|
| IDA P3014 | **AMRAAM** | Milestone 0 | MS 0 Decision | **Oct-75** |
| 12/25/2015 | **AMRAAM** | Milestone I (DSARC) | MS I Decision | **Nov-78** |
| IDA P3014 | **AMRAAM** | EMD Start/EMD Contract Award | MS II Decision | **Dec-81** |
| 12/25/2015 | **AMRAAM** | Milestone IIIA (DAB) | LRIP Decision | **Jun-87** |
| 12/25/2015 | **AMRAAM** | Milestone IIIB (DAB) (Lot IV Full Go-Ahead Rate Production) | FRP Decision | **Apr-91** |
| 12/25/2015 | **AMRAAM** | IOC Air Force | IOC | **Sep-91** |

**MISSILE SCHEDULE & TECH DATA MASTER**

| 50 programs | Actual Major Schedule Events | | | | | Major Milestone Durations (months) | | | | | Actual Other Schedule Events | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Missile/Ordnance Program | MS A Decision | MS B Decision | LRIP/ MS C | FRP/ MS III | IOC | MS A to B | MS B to LRIP | LRIP to FRP | MS B to FRP | MS B to IOC | PDR | CDR | DTE Start | DTE End | IOTE Start | IOTE End |
| ACM (AGM-129A) | | Feb-83 | Jul-86 | Jul-91 | Jan-93 | | 41.0 | 60.0 | 101.0 | 119.1 | Sep-84 | Mar-85 | | | | |
| ALCM (AGM-86B) | Feb-74 | Jan-77 | Aug-78 | Apr-80 | Dec-82 | 35.0 | 19.0 | 20.0 | 39.0 | 71.0 | Jun-77 | | | | Oct-79 | Feb-80 |
| **AMRAAM (AIM-120A)** | **Nov-78** | **Dec-81** | **Jun-87** | **Apr-91** | **Sep-91** | 37.0 | 66.0 | 46.0 | 112.0 | 117.1 | Sep-82 | Mar-85 | | | Oct-83 | Jun-90 |
| ATACMS-APAM (MGM-140A | Oct-82 | Feb-86 | Jan-89 | Nov-90 | Aug-90 | 40.1 | 35.0 | 22.0 | 57.0 | 54.0 | Sep-86 | Mar-87 | Mar-89 | Dec-89 | Mar-90 | Jun-90 |

**Missile Technical Parameters**

| | Preferred Value | Source Used | Army 2016 Deskbook | AF Fact Sheet - Official | AF MSSRH 2011 | Navy Fact File 2017- Official | Navy Weapons Handbook 2008- Official | Contractor | US Msl Data Book 2011/2001/1997 | Designation-Systems. net | Fed Am Sc - Fas.org | Global Security.org | Jane's 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | **Weight (lbs) - Includes boosters** | | | | | | | | | | | | |
| | Preferred | Source | DB 16 | AF FS | MSSRH | NFF | NWH 08 | Contractor | DSA 11 | Parsch | FAS | GS | Jane's |
| ACM (AGM-129A) | Value 2 | AF FS | Value 1 | Value 2 | Value 3 | | | | Value 4 | Value 5 | | Value 4 | Value 5 |
| ALCM (AGM-86B) | Value 2 | AF FS | Value 1 | Value 2 | Value 3 | | | | Value 4 | Value 1 | | Value 2 | Value 1 |
| AMRAAM (AIM-120A) | Value 2 | AF FS | Value 1 | Value 2 | Value 3 | Value 1 | Value 4 | Value 5 | Value 4 | Value 4 | | Value 2 | Value 4 |
| ATACMS-APAM (MGM-140A Block I) | Value 1 | DB 16 | Value 1 | | Value 2 | | | | Value 1 | Value 2 | Value 2 | | Value 2 |

# Radar Dataset Example

## Schedule Data

**Key** | SAR Program | Est Dec/Award (+-3 mos) | Uncertain | Missing Data

| | Programmatic Information | | | | Actual Major Schedule Events | | | | | | | | | | | Actual Other Schedule Events | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Radar Name | Lead Service | Category | Platform | MS A Decision | MS A Award | Platform MS B Decision | MS B Decision | MS B Award | Platform MS C Decision | MS C/LRIP Decision | LRIP Award | Platform FRP Decision | FRP Decision | FRP Award | IOC (Platform for Airborne) | PDR | CDR | DTE Start | DTE End | IOTE Start | IOTE End | First Flight |
| 1 | 3DELRR | Air Force | Ground | Ground | May-09 | Aug-09 | | Sep-14 | May-17 | | | | | | | | Sep-10 | Jun-18 | | | | | |
| 2 | APG-63 | Air Force | Airborne | F-15 | Aug-68 | Nov-68 | Jan-70 | Jan-70 | Sep-70 | Oct-72 | Oct-72 | Jan-73 | Oct-75 | Oct-75 | Jan-76 | Sep-75 | | Apr-71 | | Jun-77 | | Nov-75 | Nov-72 |
| 3 | APG-63(V1) | Air Force | Airborne | F-15 | Feb-94 | May-94 | N/A | Aug-94 | Nov-94 | | | | | Aug-99 | Nov-99 | | May-95 | May-96 | Jul-97 | Jun-98 | Jun-98 | Dec-00 | Jul-97 |
| 4 | APG-63(V2) | Air Force | Airborne | F-15 | Jul-96 | Oct-96 | N/A | Feb-97 | May-97 | | May-98 | Aug-98 | | Dec-98 | Mar-99 | | | Dec-97 | | | | | Feb-99 |
| 5 | APG-63(V3) | Air Force | Airborne | F-15 | | | N/A | Oct-02 | Jan-03 | | Jul-07 | Oct-07 | | | | | | | | | | | May-06 |
| 6 | APG-65 | Navy | Airborne | F-18 | Oct-75 | Jan-76 | Dec-75 | Dec-75 | Aug-76 | Dec-77 | Dec-77 | Mar-79 | Jun-81 | Jun-81 | Sep-81 | Mar-83 | | Jun-77 | | Mar-82 | Oct-80 | Jan-81 | Mar-78 |
| 7 | APG-66 | Air Force | Airborne | F-16 | Sep-74 | Dec-74 | Apr-75 | Apr-75 | Nov-75 | Dec-76 | Dec-76 | Mar-77 | Oct-77 | Oct-77 | Jan-78 | Jun-80 | Apr-76 | Jun-76 | | Jan-79 | Dec-76 | | May-77 |
| 8 | APG-68 | Air Force | Airborne | F-16 | | | N/A | Jan-81 | May-81 | | | | | | | | | | | | | | |
| 9 | APG-68(V9) | Air Force | Airborne | F-16 | | | N/A | Oct-99 | Jan-00 | | | | | | | | May-00 | Sep-00 | | | | | Aug-01 |
| 10 | APG-70 | Air Force | Airborne | F-15E | | | N/A | Nov-82 | Feb-83 | | | | | | | | | Dec-84 | | | | | Jan-85 |
| 11 | APG-73 | Navy | Airborne | F-18 | | | Jan-76 | Mar-89 | Jun-90 | | Mar-91 | Jun-91 | | Jul-95 | Oct-95 | | Aug-90 | Nov-91 | | Mar-94 | | | Mar-92 |
| 12 | APG-77 | Air Force | Airborne | F-22 | | | Jun-91 | Jun-91 | Aug-91 | Aug-01 | Aug-01 | Sep-01 | Mar-05 | Mar-05 | Nov-06 | Dec-05 | Apr-93 | Jun-95 | | | | | Nov-97 |
| 13 | APG-77(V1) | Air Force | Airborne | F-22 | | | N/A | Feb-02 | Feb-02 | | Aug-06 | Nov-06 | | | | | Dec-02 | Apr-03 | | | | | Mar-04 |
| 14 | APG-78 | Army | Airborne | Apache | | | Dec-90 | Dec-90 | Dec-90 | Sep-94 | Sep-94 | Dec-94 | Oct-95 | Oct-95 | Dec-95 | Nov-98 | | | | | Jan-95 | Mar-95 | |
| 15 | APG-79 | Navy | Airborne | F-18 E/F | Jan-00 | Apr-00 | N/A | Feb-01 | Feb-01 | | Jul-03 | Oct-03 | | Feb-07 | Jan-07 | Nov-06 | Dec-00 | Aug-01 | Apr-02 | | Feb-03 | | Feb-03 |

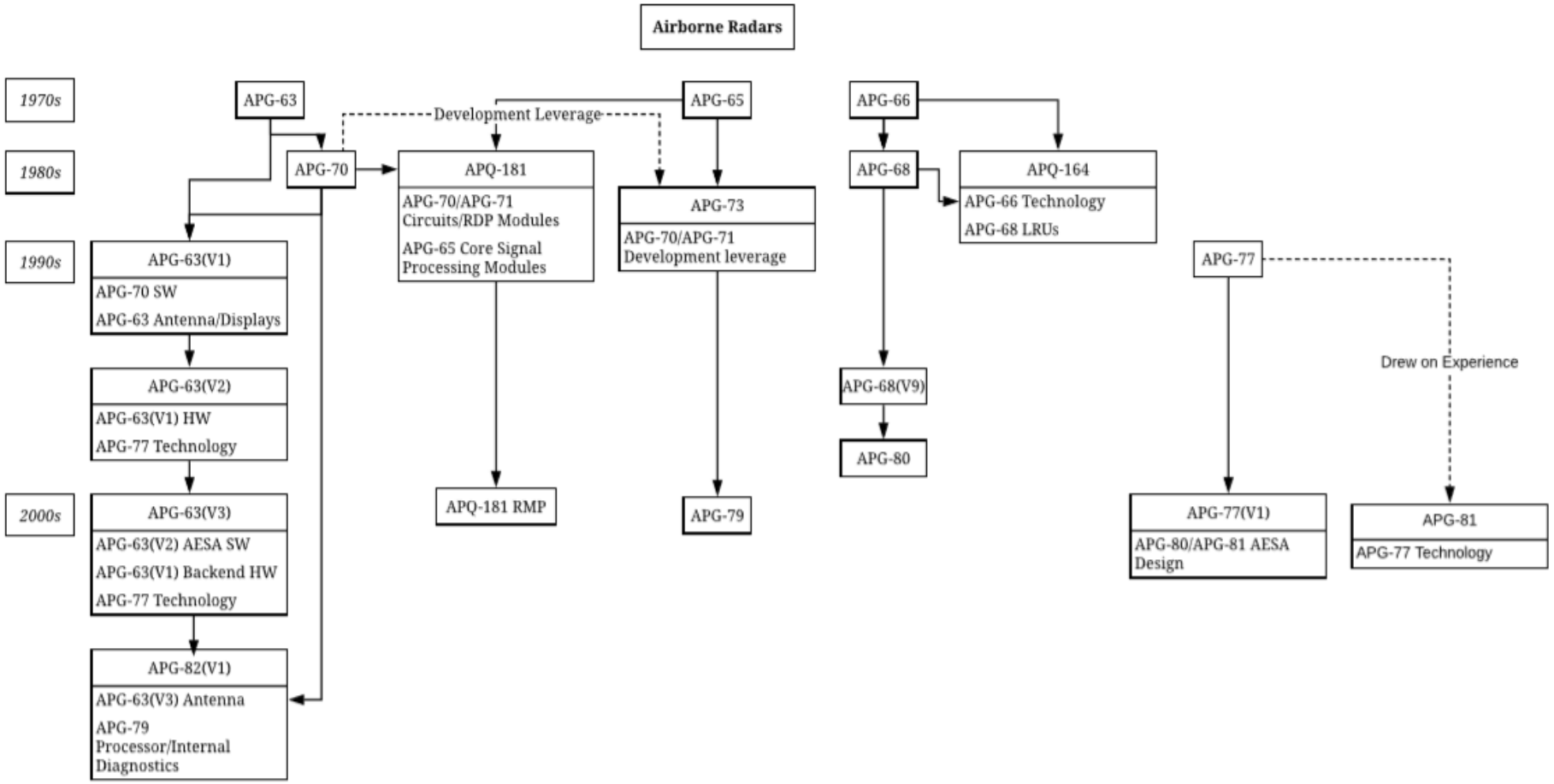
## Technical Data

| | Programmatic Information | | | | Technical Characteristics | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Radar Name | Lead Service | Category | Platform | Array Type | Frequency Band | Freq. Range in GHz | Avg. Freq. in GHz | % New Design | Weight (Lbs) | Antenna Aperture ($Ft^2$) | No. of Elements | Transmit/ Receive Modules | Avg Power (KWs) | Peak Power (KWs) | Min Range (Nmi) | Max Range (Nmi) | Software Size (KLOC) |
| 1 | 3DELRR | Air Force | Ground | Ground | AESA | C | Value 1 | Value 1 | | Value 1 | Value 1 | Value 1 | Value 1 | | | | | |
| 2 | APG-63 | Air Force | Airborne | F-15 | Mech. Scan | I/J (includes X) | Value 2 | Value 2 | | Value 2 | Value 2 | | | | Value 1 | | Value 1 | |
| 3 | APG-63(V1) | Air Force | Airborne | F-15 | Mech. Scan | I/J (includes X) | Value 2 | Value 2 | | | Value 3 | | | | | | Value 2 | |
| 4 | APG-63(V2) | Air Force | Airborne | F-15 | AESA | X | Value 2 | Value 2 | | | Value 4 | | | | | | Value 3 | |
| 5 | APG-63(V3) | Air Force | Airborne | F-15 | AESA | X | Value 2 | Value 2 | Value 1 | Value 3 | Value 5 | Value 2 | Value 2 | | | | Value 4 | |
| 6 | APG-65 | Navy | Airborne | F-18 | Mech. Scan | X | Value 2 | Value 2 | | Value 4 | Value 6 | | | | | | Value 5 | |
| 7 | APG-66 | Air Force | Airborne | F-16 | Mech. Scan | X | Value 2 | Value 2 | | Value 5 | Value 7 | | | Value 1 | Value 2 | Value 1 | Value 6 | |
| 8 | APG-68 | Air Force | Airborne | F-16 | Mech. Scan | X | Value 2 | Value 2 | | Value 6 | Value 8 | | | | | | Value 7 | |
| 9 | APG-68(V9) | Air Force | Airborne | F-16 | Mech. Scan | X | Value 2 | Value 2 | | Value 7 | Value 9 | | | | | | Value 8 | Value 1 |
| 10 | APG-70 | Air Force | Airborne | F-15E | Mech. Scan | I/J (includes X) | Value 2 | Value 2 | | Value 8 | Value 10 | | | | | | Value 9 | |
| 11 | APG-73 | Navy | Airborne | F-18 | Mech. Scan | X | Value 2 | Value 2 | | Value 9 | Value 11 | | | | | Value 1 | Value 10 | |
| 12 | APG-77 | Air Force | Airborne | F-22 | AESA | X | Value 2 | Value 2 | Value 2 | Value 10 | Value 12 | | Value 3 | | Value 3 | | Value 11 | Value 2 |
| 13 | APG-77(V1) | Air Force | Airborne | F-22 | AESA | X | Value 2 | Value 2 | Value 3 | Value 11 | Value 13 | Value 3 | Value 4 | | Value 4 | | Value 12 | Value 3 |
| 14 | APG-78 | Army | Airborne | Apache | Mech. Scan | Ka | Value 4 | Value 4 | | | Value 14 | | | | | | Value 13 | |
| 15 | APG-79 | Navy | Airborne | F-18 E/F | AESA | X | Value 2 | Value 2 | Value 4 | Value 12 | Value 15 | Value 4 | Value 5 | | | | Value 14 | Value 4 |

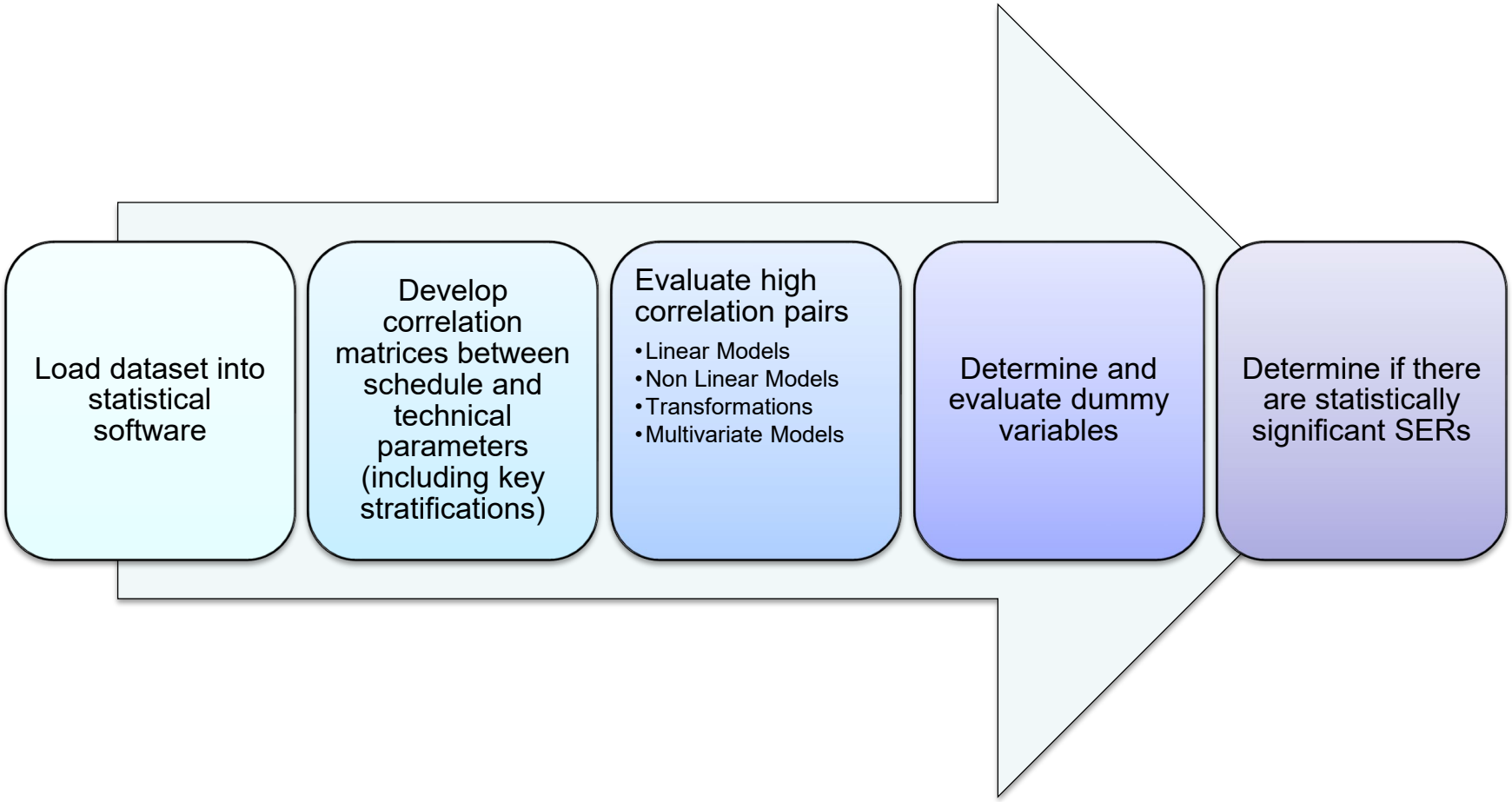
# Programmatic Information (Radar Example)

| Radar Short Name | Radar Overview | Radar Affiliation | Radar Schedule Impacts |
|---|---|---|---|
| **APG-66** | Fire control radar, coherent, multi-mode, digital fire control sensor designed to provide all-weather air-to-air and air-to-surface modes with advanced dogfight and weapon delivery capabilities. | Upgrade to APQ-120 | Schedule durations were shorter since development started through IR&D that resulted in developing a prototype of the system before a requirement was stated. |
| **APQ-164** | 1970s era first ever PESA radar with a beam steering controller and real time processor that allowed simultaneous SAR and Terrain Following (TF) imagery. | Technology from APG-66 and common LRUs with APG-68. | None Identified |
| **AWACS RSIP** | Supported air defense and tactical operations by providing extended, all-altitude radar surveillance over land and water. Improved target identification and resistance to radar jamming. | None Identified | Development schedule delays resulted from software development problems and integration slippage. Delays in IOT&E due to a mishap that damaged radar components. |

# Program Genealogy (Airborne Radar Example)



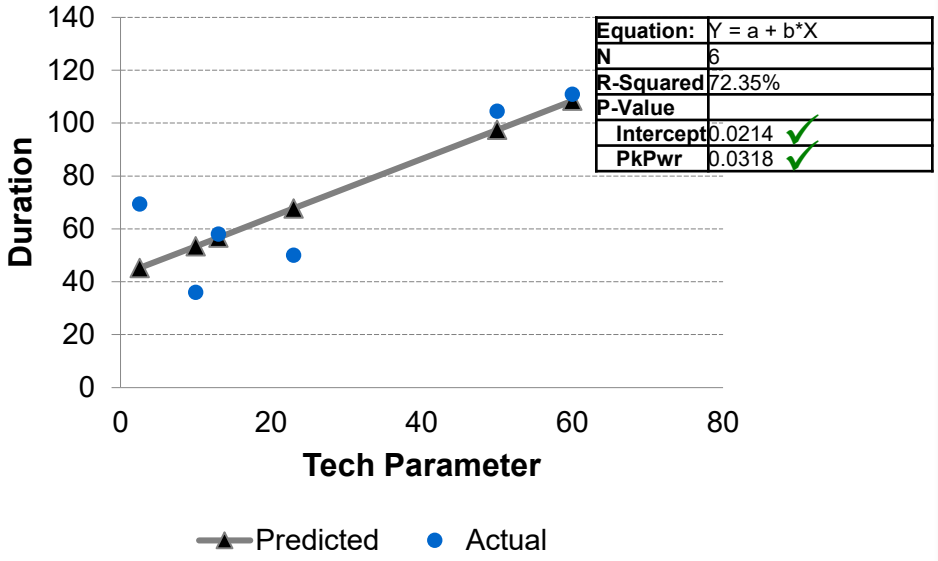
# SER Analysis Process



# Radar Regression Analysis Examples

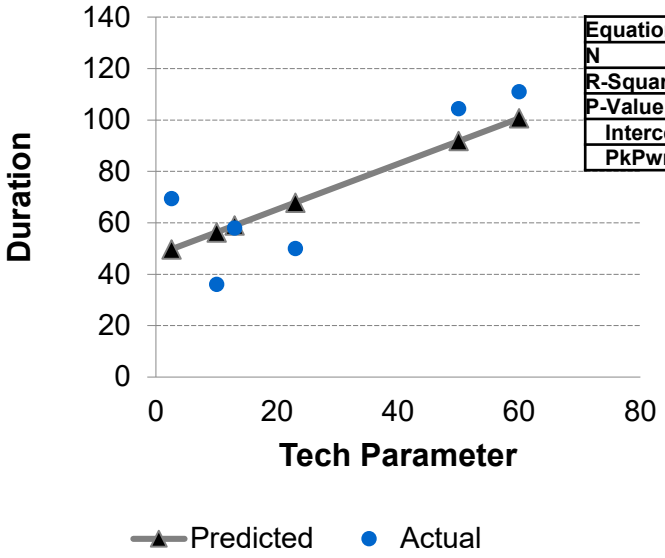
## Linear OLS

Best Model



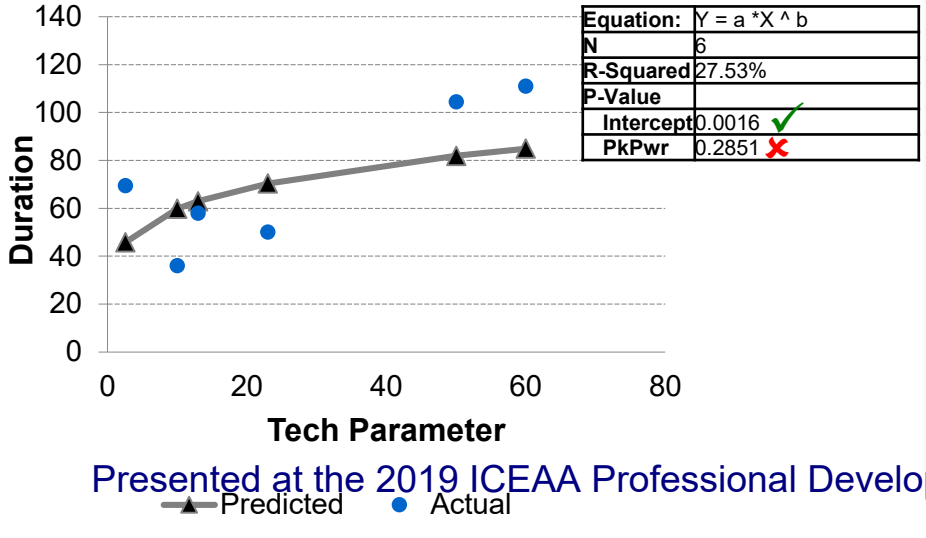

| Equation: | Y = a + b*X |
|---|---|
| N | 6 |
| R-Squared | 72.35% |
| P-Value | |
| Intercept | 0.0214 ✓ |
| PkPwr | 0.0318 ✓ |

## Linear MUPE



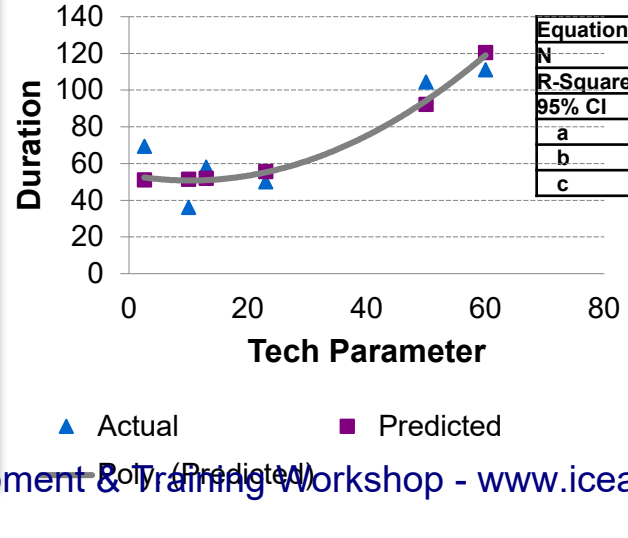

| Equation: | Y = a + b*X |
|---|---|
| N | 6 |
| R-Squared | 46.42% |
| P-Value | |
| Intercept | 0.0149 ✓ |
| PkPwr | 0.1360 ✗ |

## Log Linear OLS



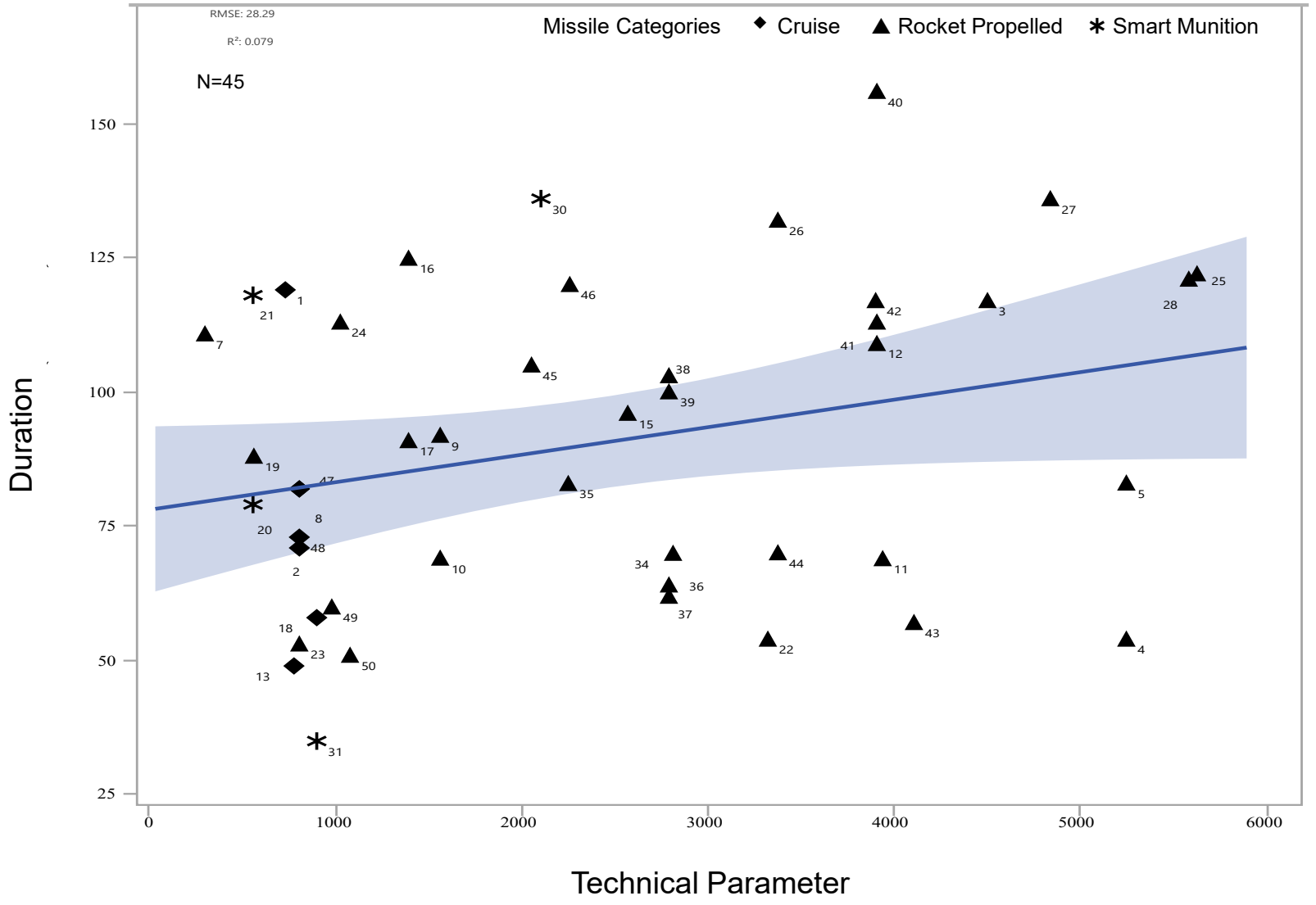

| Equation: | Y = a *X ^ b |
|---|---|
| N | 6 |
| R-Squared | 27.53% |
| P-Value | |
| Intercept | 0.0016 ✓ |
| PkPwr | 0.2851 ✗ |

## Non Linear (Triad)

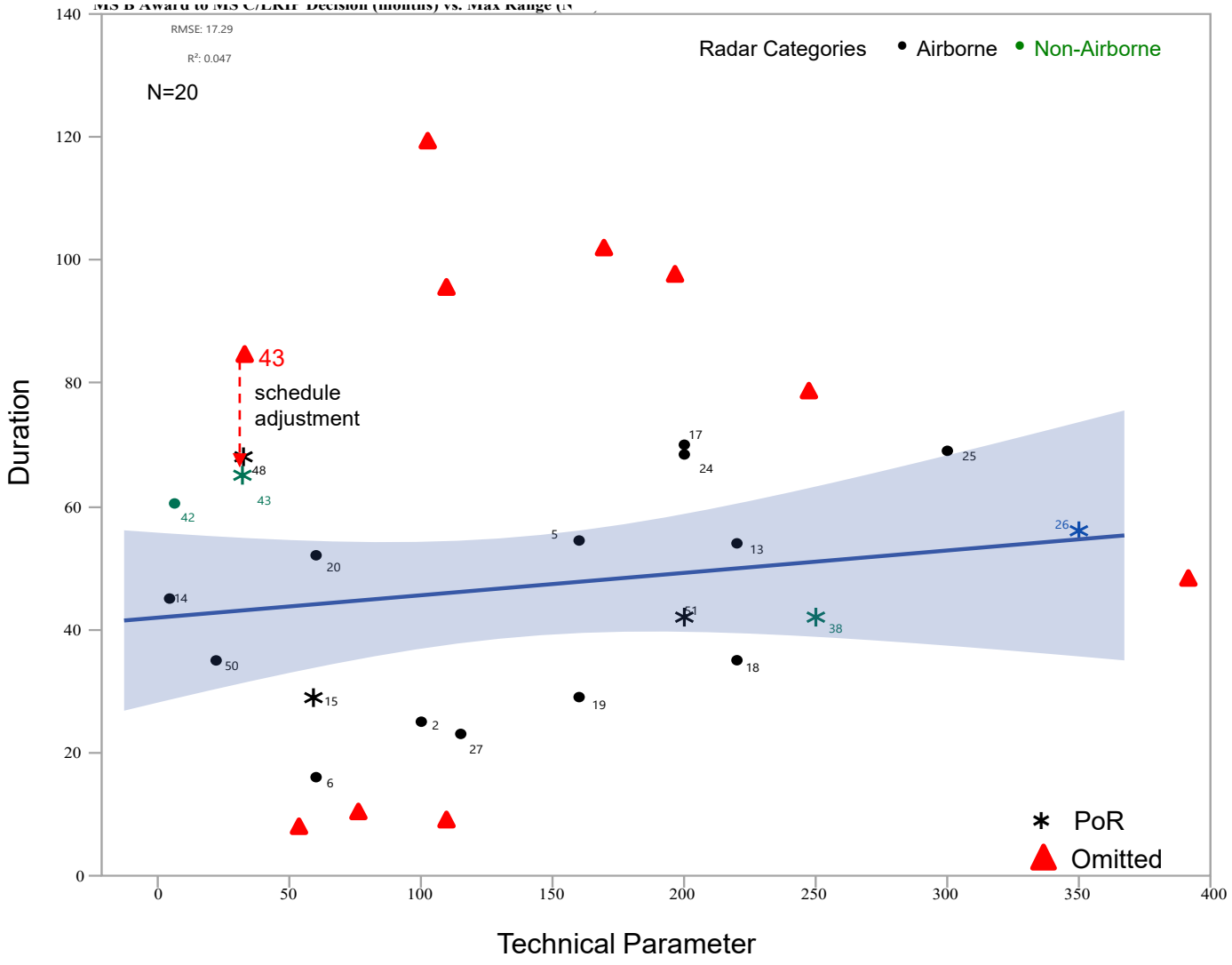



| Equation: | Y = a + b*X ^c |
|---|---|
| N | 6 |
| R-Squared | 71.74% |
| 95% CI | |
| a | (20.1297,82.0685) ✓ |
| b | (-0.026,0.0271) ✗ |
| c | (-8.7982,14.5241) ✗ |

# Missile Regression Example



# Radar Regression Example



# Descriptive Statistics

## Missiles

| | MS A to B | MS B to LRIP | LRIP to FRP | MS B to FRP | MS B to IOC |
|---|---|---|---|---|---|
| **Number of Observations (N)** | 26 | 45 | 38 | 43 | 45 |
| **Mean** | 35 | 56 | 29 | 82 | 91 |
| **Standard Deviation** | 14 | 22 | 20 | 30 | 29 |
| **Coefficient of Variation** | 40% | 39% | 67% | 36% | 32% |
| **Maximum** | 64 | 105 | 111 | 147 | 156 |
| **Median** | 35 | 56 | 24 | 81 | 88 |
| **Minimum** | 11 | 13 | 3.9 | 24 | 35 |

## Radars

| | MS A to B | MS B to PDR | MS B to CDR | MS B to MS C | MS B to FRP | MS B to IOC |
|---|---|---|---|---|---|---|
| **Number of Observations (N)** | 12 | 19 | 27 | 21 | 16 | 16 |
| **Mean** | 24 | 12 | 20 | 47 | 67 | 80 |
| **Standard Deviation** | 22 | 7 | 11 | 17 | 22 | 22 |
| **Coefficient of Variation** | 88% | 54% | 57% | 36% | 33% | 28% |
| **Maximum** | 69 | 26 | 46 | 70 | 111 | 121 |
| **Median** | 16 | 13 | 18 | 51 | 60 | 78 |
| **Minimum** | 3 | 2 | 2 | 16 | 36 | 52 |

*Statistics indicate great variability in the durations and must be used with caution when evaluating future program schedules*

# Lessons Learned

- Data source hierarchy needed where there is conflicting data for the same program
- Both MS Decision and MS Award useful in estimating durations
  - Work begins at MS Award
  - One known date can estimate the other
  - Average 2- to 3-month delay
  - Protests and contract negotiations cause longer delays
- Programmatic information key to understanding duration outliers and program commonality
  - Technical problems (major redesign)
  - Extended testing
  - Funding cuts
- Understand missing MS Decisions
  - Some programs do not have a MS C or FRP Decision
  - Some programs do not follow traditional acquisition process (DoDI 5000.02)
- Radar subsystems of an aircraft or ship platform often driven by platform schedules

# Conclusion

- Developed comprehensive schedule and technical datasets for missiles and radars
- No SERs were statistically significant
- Regression plots help understand the relationship between schedule durations and technical parameters
- Government can use scatter plots, programmatic history, and genealogies to determine analogies for future programs
- Descriptive statistics are useful in evaluating future program schedules

*Unless further data collection can establish SERs, use descriptive statistics and analogies to evaluate schedules*

# Questions/Comments

Schedule Estimating Relationship (SER) Development Using Missile and Radar Datasets

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