# Naval Center for Cost Analysis (NCCA)

## Modeling Schedule and Cost Stochastically

### Time Phasing a Cost Estimate using MS Excel-Based Cost and Schedule Estimating Suite (CaSES)



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# Overview

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# Introduction

- Purpose
  - To demonstrate and provide the cost community with a free, Microsoft Excel-based solution to dynamically time phase cost estimates and accommodate schedule uncertainty and schedule logic throughout a lifecycle cost estimate

- Primary Benefits
  - CaSES time-phasing functions do not require additional software or licensing
  - Functions are easy to implement, regardless of analyst experience levels
  - Functions allow for dynamic time-phasing of cost elements
  - Functions allow schedule logic to be introduced between any cost elements

## CaSES Functions Are Free & Simple To Use

"…the risk-adjusted cost result is too often forced into the point estimate schedule."

– Joint Agency Cost Schedule Risk and Uncertainty Handbook

– Traditional estimates model cost stochastically, while schedule (and Scope) remains deterministic.

– Historical programs have realized schedule delays and cost overruns indicating that there are many cost and schedule combinations.

– A variety of tools exist to model these parameters but can be expensive to procure and difficult to learn.



https://www.ncca.navy.mil/tools/csruh/index.cfm
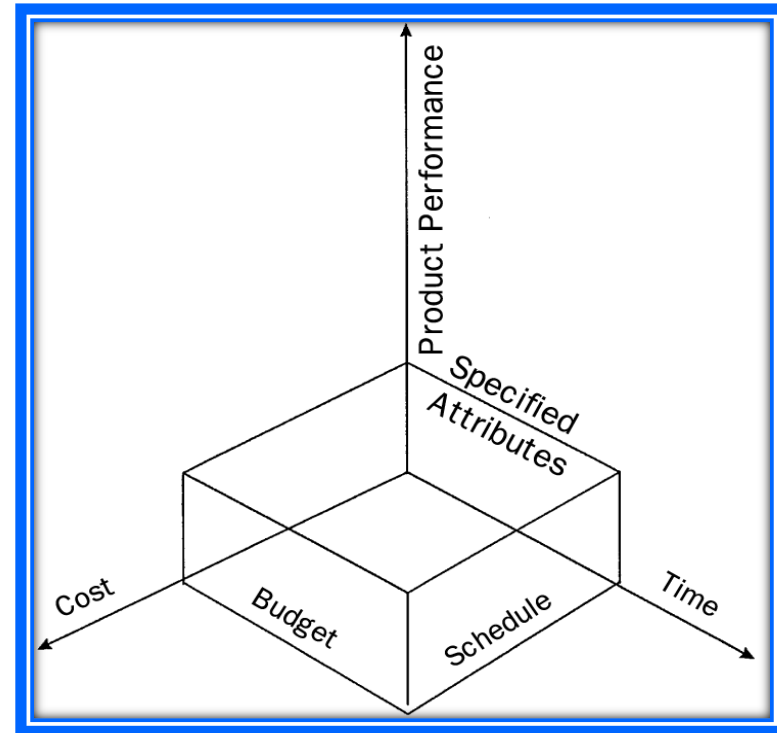
# Introduction
## Background (2 of 3)

- Case studies were developed for 115 of the 320 programs on DOT&E oversight list (as of April 2014).

  - Programs for which case studies were developed:

    - Experienced a delay of 6 months or more and

    - Had a full-rate production decision after 2000

**Schedule Uncertainty in DoD Acquisition (USD AT&L)**



  - Programs for which case studies were not developed:

    - Did not experience a delay of at least 6 months or

    - Had a full-rate production decision in 2000 or before

    - Some programs would have yielded a case study that is classified (small number), and were excluded
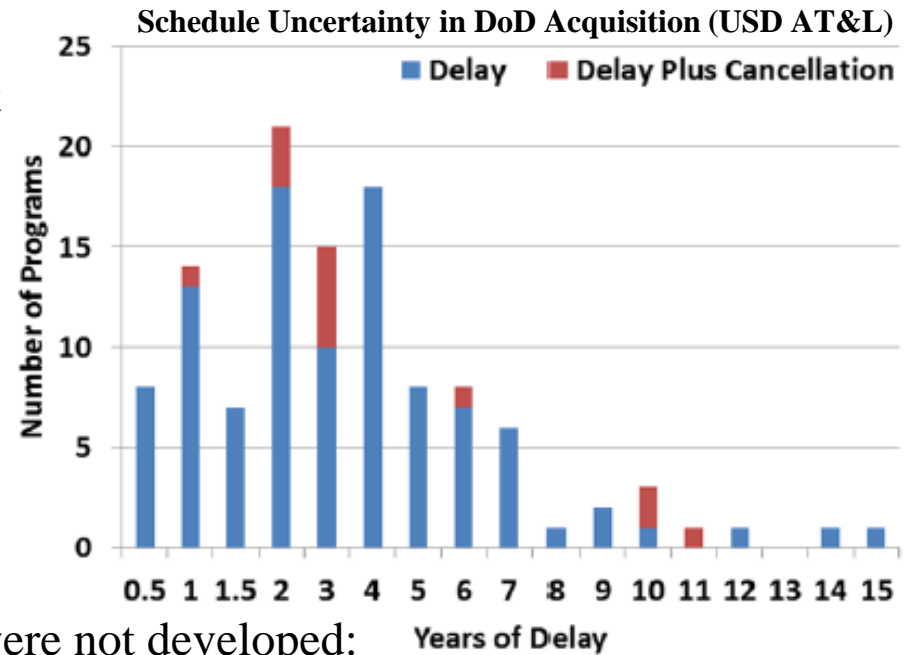
http://www.dote.osd.mil/pub/presentations/jite-32-04-389.pdf

http://www.dote.osd.mil/pub/presentations/ProgramDelaysBriefing2014_8Aug_Final-77u.pdf

# Introduction
## Background (3 of 3)

- Causes of Program delays include:
  1. Manufacturing and development (to include quality control, software development, and integration issues),
  2. Programmatic (scheduling or funding problems),
  3. Performance in Developmental Testing (DT),
  4. Performance in Operational Testing (OT), and
  5. Conducting the test (such as range availability, test instrumentation problems, and test execution problems).

- Marginal cost of testing is a small portion of the overall program budget
  - However, the cost can be a large percentage of the budget in the year(s) in which it occurs.
  - Because the testing occurs at the end of the development process, programs typically have few degrees of freedom (and resources) left to work issues

http://www.dote.osd.mil/pub/presentations/jite-32-04-389.pdf
http://www.dote.osd.mil/pub/presentations/ProgramDelaysBriefing2014_8Aug_Final-77u.pdf

# Introduction
## Solution (Excel Formula vs. VBA Functions)

- Tradeoff between using native excel functions and creating your own.

| Criteria | Excel Formula | VBA User Defined Function |
|---|---|---|
| Readability | Requires multiple cells or long formulas to create complex formulas that are often difficult to read | Concise formula representation |
| Auditability | Do not need to know VBA to audit formula. However, often requires many reference cells | Must understand VBA to audit formula. However, often requires fewer reference cells |
| Complexity | Cannot perform iterative (looping) calculations | Can perform iterative and complex formulas in a single cell |
| Performance (speed) | Varies | Varies |

## Solution: VBA User Defined Function
All VBA macros that are a part of this presentation are available

# Schedule Estimating Basics
## Definitions

**Schedule** is a listing of activities, each with predecessors, a duration and successors. Other common terminology includes:

- **Integrated Master Schedule (IMS)**: The task and calendar based schedule that illustrates the interrelationships among events, accomplishments, criteria, and tasks
- **Predecessors**: A task whose start or finish date determines the start or finish date of its successor
- **Successors**: A task whose start or finish date is driven by its predecessor task(s)
- **Critical Path**: Longest slack-less path to completion
- **Free Slack (float)**: The amount of time an activity can slip without impacting its successor start
- **Hammock**: A special type of task within a schedule that is dependent on external dates for both its start and finish dates and, ultimately, its duration
- **Time Independent (TI)**: elements whose costs are not impacted by the duration of the task they are loaded against (e.g., material cost)
- **Time Dependent (TD)**: elements whose costs are a function of the duration of the task which they are loaded against (e.g., staff cost)
- **Merge Bias**: This occurs when two or more uncertain, parallel paths of activities merge at one milestone. The effect is that the expected completion date for the milestone, in this situation, will be later than the expected completion of the individual paths leading up to it. The number of merging parallel paths and the level of overlap between, and degree of correlation between them (lower correlation between uncertain durations produces greater merge bias) produce an increasing merge bias impact to the schedule.

**Cost and schedule Model Types (JA CSRUH)**

- **CISM**: The Cost Informed by Schedule Method is a cost uncertainty model that has some level of duration uncertainty built into it such that duration uncertainty influences the cost simulation results.
- **FICSM**: The Fully Integrated Cost/Schedule Method is typically a cost loaded schedule model with cost/schedule risks and uncertainty addressed.
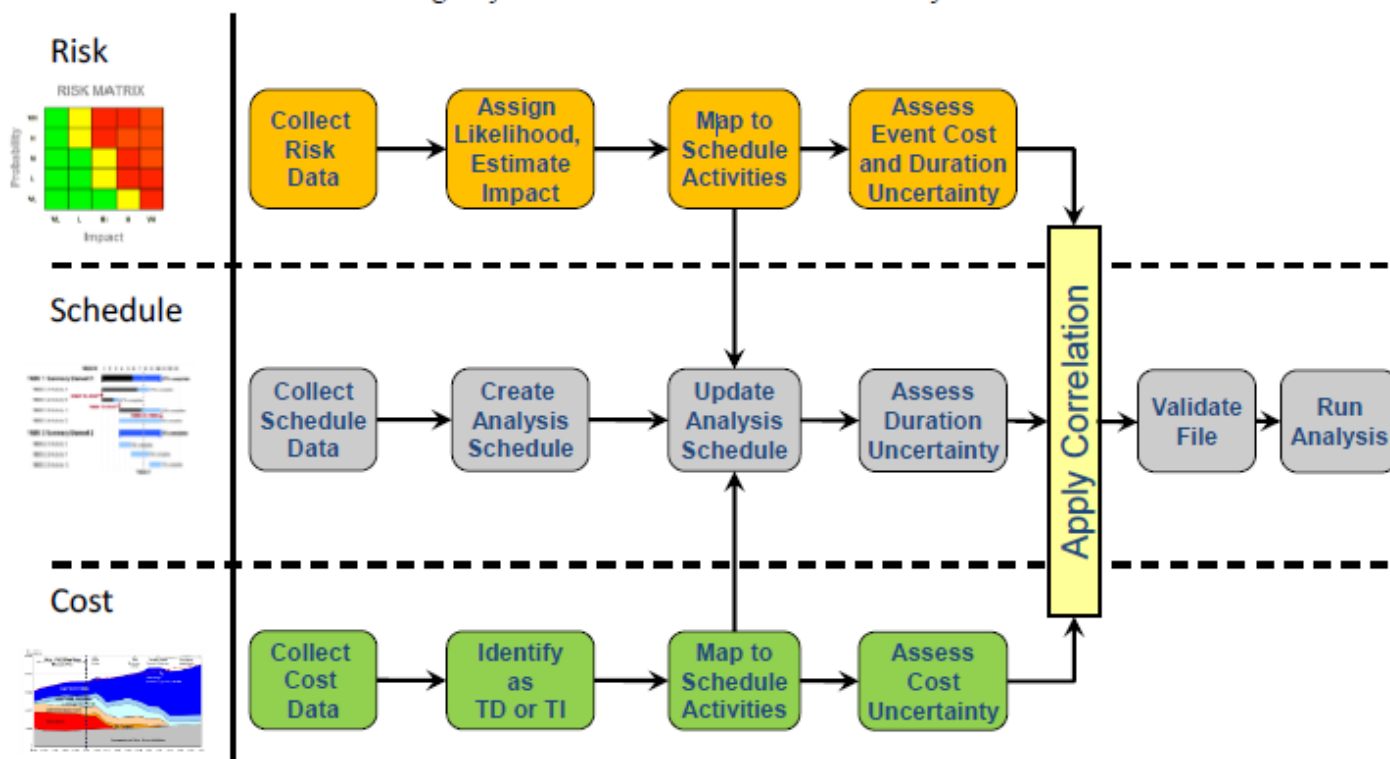
# Schedule Estimating Basics
## Best Practices

1. Create Analysis Schedule: FICSM begins with a model of the schedule logic
2. Map Cost to Analysis Schedule: Determine TI and TD tasks
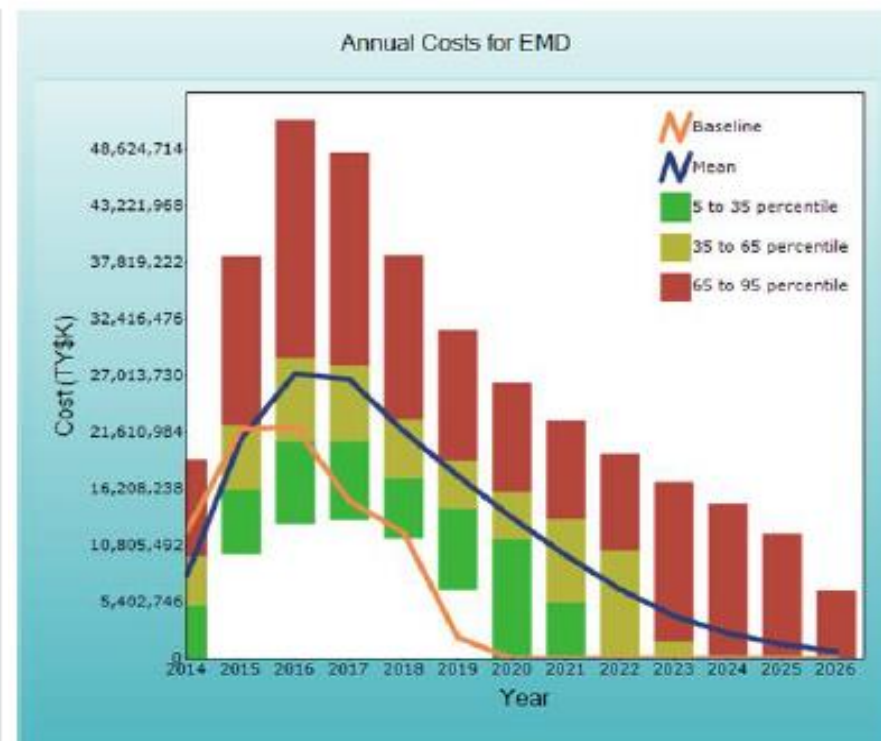3. Map risk register events into the network



Joint Agency Cost Schedule Risk and Uncertainty Handbook

- This presentation assumes cost, schedule and risk analysis has been completed.
- This presentation will demonstrate how to combine these analyses into one Microsoft Excel-based model

# Schedule Estimating Basics
## Reports
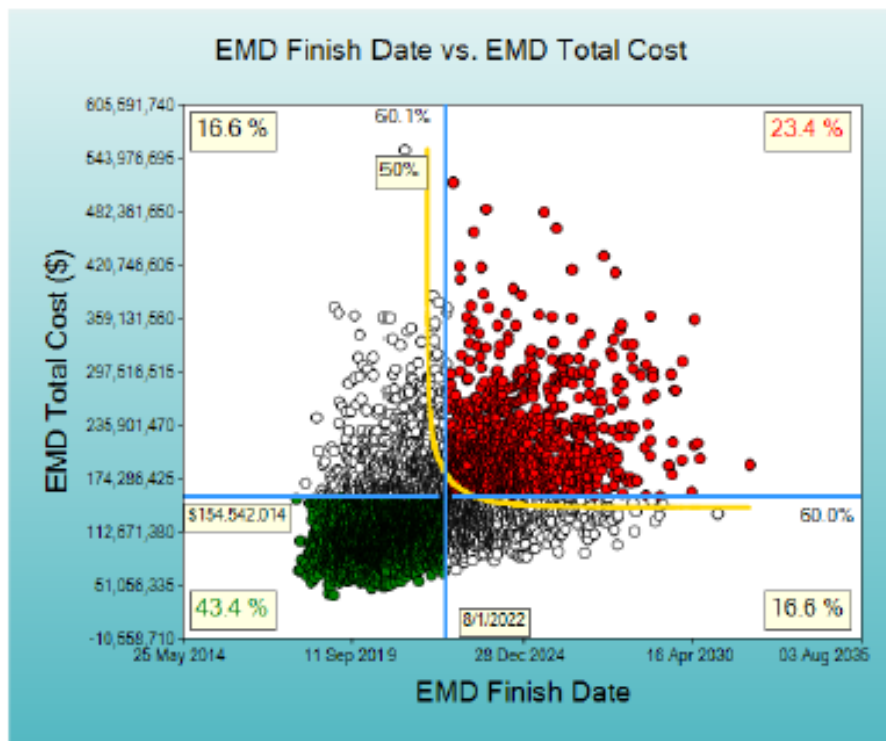


The **Joint Confidence Level** (JCL) is the probability of achieving both cost and schedule targets.

The **Annual Cost** chart displays the yearly uncertainty bands and is useful to compare to the budget.

# Common Phasing Distributions
## Notes (1 of 2)

- **Cumulative Distribution Function (CDF) Phasing**: represents estimates that phasing profile can be described by a function
  - Schedule slips directly affect total costs
    * Must create functional relationship between cost and duration
  - Schedule slips do not directly affect total costs
    - Software
    - Engineering efforts
- **Custom Phasing**: represents estimates that have a fixed phasing profile and not easily defined by a CDF
  - Schedule slips directly affect total costs
    - Staffing profile (FTE)
    - Burn rate (Systems Engineering Burn Rate)
  - Schedule slips do not directly affect total costs
    - Material costs
    - Full funding requirements (Procurement)
    - Fielding profile (O&S)

# Common Phasing Distributions
## Excel User Defined Functions (VBA)

| Excel User Defined Function | Description | Notes | Parameter 1 | Parameter 2 | Parameter 3 | Parameter 4 | Parameter 5 | Parameter 6 | Parameter 7 |
|---|---|---|---|---|---|---|---|---|---|
| **BetaPhasing** (Start Date, Duration, Cost, Alpha, Beta, Fiscal Year) | Returns a specified phasing profile based on the modified beta distribution by Richard Whitlock of NASA | Should be based on analogous programs, COSTAT allows a fit of actual data | **Start Date:** Estimated Start Date of task | **Duration:** Estimated Duration of task | **Cost:** Estimated Cost of task | **Alpha:** Shape Phasing parameter | **Beta:** Scale Phasing parameter | **Fiscal Year:** First Fiscal Year of estimate | |
| **RayleighPhasing** (Start Date, Duration, Cost, Delta, Fiscal Year) | Returns a specified phasing profile based on the Rayleigh distribution | Labor intensive programs (not well suited for material costs) | **Start Date:** Estimated Start Date of task | **Duration:** Estimated Duration of task | **Cost:** Estimated Cost of task | **Delta:** area under the cumulative rayleigh curve that is unused | **Fiscal Year:** First Fiscal Year of estimate | | |
| **WeibullPhasing** (Start Date, Duration, Cost, Beta, Lambda, Fiscal Year) | Returns a specified phasing profile based on the Weibull distribution | when beta = 1: exponential 2: Rayleigh | **Start Date:** Estimated Start Date of task | **Duration:** Estimated Duration of task | **Cost:** Estimated Cost of task | **Beta:** Shape Phasing parameter | **Lambda:** Scale Phasing parameter | **Fiscal Year:** First Fiscal Year of estimate | |
| **UniformPhasing** (Start Date, Duration Cost, Fiscal Year) | Returns a specified phasing profile based on the Uniform distribution | | **Start Date:** Estimated Start Date of task | **Duration:** Estimated Duration of task | **Cost:** Estimated Cost of task | **Fiscal Year:** First Fiscal Year of estimate | | | |
| **CustomPhasing** (ExSD, ExDur, Estimated Start Date, Estimated Duration, Cost, Slip, Fiscal Year) | Returns a specified phasing profile based on a custom (user defined) distribution | Ideal for phasing distributions that cannot be described by a single equation | **Expected Start Date** | **Expected Duration** | **Estimated Start Date** | **Estimated Duration** | **Cost:** Estimated Cost of task (can be a range of cells, or a single cell) | **Slip:** Cumulative time at which schedule slip occurs | **Fiscal Year:** First Fiscal Year of estimate |

# Algorithm
## CDF

define t = cumulative elapsed time during current period / Duration

define t - 1 = cumulative elapsed time during previous period / Duration

defined only in the interval 0 <= t <= 1

Do until t = 1

1. calculate CDF(t) : end of time period
2. calculate CDF(t - 1): beginning of current time period
3. calculate PDF(t) = CDF(t) – CDF(t - 1)
4. calculate Cost(t) = PDF(t) * Cost

Loop

**Special Considerations**

– Continuous distributions are undefined at CDF(1)

  • Must define the cumulative probability at which time the CDF is complete

    – Default for Rayleigh distribution completes the distribution at the 97th percentile (leaving 3% in the tail)

  • Must normalize "cost" to account for amount of probability in the tail that will not be achieved

    – Cost = Cost / CDF percentile complete

    – Default for Rayleigh: Cost / .97

# Algorithm
## Custom

define t                    as the current time period (discrete) corresponding to the array of costs

define NormCost( )          as the array that contains the normalized cost for each period

define CostResult( )        as the array that contains the Estimated cost for each period (taking into account duration uncertainty

Normalize each period costs to a full year

- Start Date and End Date are potentially partial periods
- Start Date and End Date may have different fractions of a period depending on how much slip has occurred
- May need to add extra year of cost based on where the schedule slip has occurred  (i.e. cost in the last period slips into the next period)

For t =  1 to # of periods

- If t = 1 then CostResult (t) = NormCost(1) * Start Date Fraction
- If t = End Date then CostResult(t) = NormCost(End) * End Date Fraction
- If t <= Slip Period then CostResult(t) = NormCost(t)
- If t > Slip Period AND t <= (Slip Period + add duration) then CostResult(t) = NormCost(Slip Period)
- If t > (slip Period + added duration) then CostResult(t) = NormCost(t – added  duration)

Next t

**Special Considerations**

–   Cost is an array of values (each value in the array represents the discrete cost for a particular time period)

# Common Phasing Distributions
## Notes (2 of 2)

- Start Dates can either be excel dates or whole number periods
  - Excel Dates are simply a continuous count of days and fractions since January 1, 1900
    - The formulas accept dates as inputs, however they are converted to Fiscal Year format YYYY.QTR
    - October 1, 2015 = 2016.00 ; FY16 QTR 2 = December 31, 2015 = 2016.25 ; June 22, 2016 ≈ 2016.72
  - Whole number time periods can range from 0 to 4000
- Duration can be any time period as long as each period is equal in duration (i.e. Year, Quarter, Months)
  - If your start date is an excel date then duration is in years by default
  - Remember to be consistent with your start date
  - Current limit is 100 time periods (columns) user imposed limit
- Phasing distribution functions are array based formulas
  1. Highlight the range of cells in which you want to enter the array formula

     (Number of columns selected is equal to the number of periods to return)
  2. Type the formula that you want to use

     (Choose phasing distribution and insert correct parameters)
  3. Press ctrl + shift + enter

     (Creates the array formula)

**Important**: Any time you edit the array formula, the braces ({ }) disappear from the array formula, and you must press Ctrl+Shift+Enter again to incorporate the changes into an array formula and to add the braces.

# Common Phasing Distributions
## Incremental Funding vs Full Funding

- Choosing the correct phasing distribution depends on the type of funding
  - Apply **incremental funding** to Research, Development, Test and Evaluation efforts:
    - Funding requirement to finance contract effort for a specific fiscal year
    - Period of performance = effort planned in the first fiscal year of the appropriation
    - Budgets are based on annual requirements which are appropriated on a single year basis
    - Plan for obligation in first year but may have to obligate in the second year of availability

  - **Full Funding** applies to Procurement and MILCON Appropriations
    - Each year's appropriation request must contain funds required to cover the total cost incurred in completing delivery of a given quantity of usable end items, such as aircraft, ammunition, missiles and all other items of equipment.

# Example
## Program X Cost Summary

**Excel Demonstration**:

1. Show analysis schedule
2. Show how to insert each function (talk to each parameter)
3. Show a few iterations of a simulation with graph of cost by fiscal year)
4. Show JCL and Annual Cost charts

| ID | WBS Element | Point Estimate (BY) | Point Estimate (TY) | Units | BY | Inflation | Phasing Method | Expected Start | Expected Duration | Estimated Start | Estimated End | Estimated Duration | Cost Input |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **X Program** | $ 1,800.0 | $ 2,126.9 | | | | ROLL UP | | | | | | |
| 2 | **Development** | $ 800.0 | $ 872.0 | | | | ROLL UP | | | | | | |
| 3 | Prime Mission Product | $ 270.0 | $ 289.9 | | | | ROLL UP | | | | | | |
| 4 | TD | $ 30.0 | $ 30.8 | $M | 2016 | RDTEN COMP | ETC | | | 2016.00 | 2017.50 | 1.50 | $ 30 |
| 5 | EMD | $ 240.0 | $ 259.1 | | | | ROLL UP | | | | | | |
| 6 | Hardware Procurement | $ 20.0 | $ 21.0 | $M | 2016 | RDTEN COMP | UNIFORM | | | 2017.50 | 2019.00 | 1.50 | $ 20 |
| 7 | Hardware NRE | $ 150.0 | $ 161.6 | $M | 2016 | RDTEN COMP | BETA | | | 2017.50 | 2023.50 | 6.00 | $ 150 |
| 8 | Software | $ 70.0 | $ 76.5 | $M | 2016 | RDTEN COMP | RAYLEIGH | | | 2017.50 | 2023.50 | 6.00 | $ 70 |
| 9 | SEPM | $ 320.0 | $ 350.9 | | | | ROLL UP | | | | | | |
| 10 | Contractor | $ 180.0 | $ 198.1 | $M | 2016 | RDTEN COMP | CUSTOM | | | 2016.00 | 2025.00 | 9.00 | $ 20 |
| 11 | Government | $ 140.0 | $ 152.8 | $M | 2016 | RDTEN COMP | CUSTOM | 2016.00 | 2023.50 | 2016.00 | 2023.50 | 7.50 | $ 120 |
| 12 | Profit | $ 63.0 | $ 68.6 | $M | 2016 | RDTEN COMP | FORMULA | | | | | | 15% |
| 13 | ECO | $ 42.0 | $ 45.7 | $M | 2016 | RDTEN COMP | FORMULA | | | | | | 10% |
| 14 | Test | $ 105.0 | $ 116.9 | $M | 2016 | RDTEN COMP | CUSTOM | 2019.00 | 2023.00 | 2019.00 | 2023.00 | 4.00 | $ 105 |
| 15 | **Production** | $ 1,000.0 | $ 1,254.9 | $M | 2016 | APN | CUSTOM | | | 2023.00 | 2029.00 | 6.00 | $1,000 |

# Final Thoughts

Limitations

1. Excel sometimes requires a full calculation to "refresh" formulas
2. Complex formulas cause simulation runtime to increase significantly
3. Schedule logic is not intuitive or easily manipulated in excel

Future Projects

1. Add more phasing distributions (Exponential, Factor)
2. Schedule Logic for Excel
3. Suite of tools
   a) Functions: Learning Curve, Inflation, etc.
   b) Work Breakdown Structure (indenture, summing)
4. Analysis of historical cost, schedule and performance metrics (triple constraint)
5. Suggestions?

# Contact Information

- Thank you for attending and if you would like more information regarding CaSES time phasing functions, please contact:

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