Time Phasing Cost Estimates in MS Excel Models

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- ***The views expressed in this paper and in our remarks are our own and do not imply endorsement by the Office of the Director of National Intelligence (ODNI) or any other US Government agency***

Introduction

Overview

- **Goals**
  - Review and update tools and techniques used by the ODNI CAIG to phase space and ground cost estimates
  - Develop a workbook that acts as a central repository for enhanced time phasing methods for application in ODNI/CAIG cost models and estimates
- **Process**
  - Phase One
    - Review existing methods and applications
    - Simplify complex functions
    - Consolidate tools and methods
    - Explore additional applications
  - Phase Two
    - Enhance functions and replace macros
    - Build-out constraint mechanism
    - Simplify user interface
  - Phase Three
    - Update phasing functions
    - Improve cost model integration & usability
    - Examine schedule achievability

Existing Methods

- **Space/Ground Phasing Model**
  - Developed by Eric Burgess for the NRO CAIG in 2003 using cost data from 30 NRO, Air Force, and NASA programs
  - Utilizes a two-step process to phase acquisition costs for space and ground systems
    - Step One: Create an expenditure curve based on historical outlays
    - Step Two: Employ an outlay profile and inflation index to convert the expenditure curve into a budget profile
  - Model has been updated multiple times since 2003 (most recently in 2009)
    - Basic structure has remained static, but phasing equations have been refined
- **Constraint Mechanism**
  - Developed by Matt Reiley for the ODNI CAIG in 2004
  - Allows cost estimators to perform trades inside of MS Excel cost models to account for budgetary limitations/constraints
    - Step One: Adjust annual estimates based on user-specified constraints (e.g., fixed budget profiles
    - Step Two: Determine the cumulative impact of the annual constraints
    - Step Three: Re-phase the delta across the remainder of the cost estimate

Space/Ground Phasing Model

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Expenditure-Phasing Model

Space Segment
version 2003

$E(t) = (R^*t+1-\exp(-at^b))/(R+1-\exp(-a))$

E(t) = Cumulative percent of cost expended at time t
t = Fraction of total duration from contract award to last launch
a = -.4138 + .0729*(#units) + .0488*(months duration) + .0145*(%NR)
b = 1.79
R = .001477*(months duration)

6	# Units	a =	4.193
78	Months duration (to last launch)	R =	0.115
25	% NR (0-100)		
6/1/2006	ATP date		
12/1/2012	Last Launch on Contract		
1000	Total Space Segment Cost (BY$)	Checksum	
2007	Base Year	$ 999.9954	

Fiscal Year	% time (=100% at last launch)	% BY cost (=100% at last launch)	Annual Cost (BY$)	
2006	5%	2.4%	$ 23	These are contract expenditures, not budget dollars. See conversion to budget below.
2007	20%	21.9%	$ 193	
2008	36%	48.1%	$ 258	
2009	51%	70.7%	$ 222	
2010	67%	85.9%	$ 150	
2011	82%	94.7%	$ 87	
2012	97%	99.4%	$ 47	
2013	108%	101.4%	$ 20	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	

Note: Expenditures are incurred through last launch plus 6 months.

Expenditure-Phasing Model

Ground H/W and S/W Acquisition
version Feb2005

Use this model if analogy or build-up data not available

$E(t) = (R^*t+1-\exp(-at^b))/(R+1-\exp(-a))$

E(t) = Cumulative percent of cost expended at time t
t = Fraction of total duration from contract award to first supported launch
a = 4.9091
b = 2.53
R = 0.4247

6/1/2006	ATP date		
12/1/2009	First Supported Launch		
12/1/2012	Last Supported Launch		
42	Months duration (to 1st launch)		
78	Months duration (to last launch)	Checksum	
500	Total Cost (BY$)	$ 500	

Fiscal Year	% time (1st Launch =100%)	% BY cost (=100% at 1st launch)	Annual Cost (BY$)	
2006	9%	3.7%	$ 18	These are contract expenditures, not budget dollars. See conversion to budget below.
2007	38%	35.8%	$ 153	
2008	67%	78.3%	$ 203	
2009	95%	98.1%	$ 95	
2010	114%	104.7%	$ 31	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	
0	0%	0.0%	$ -	

Note: Expenditures are incurred through IOC plus 6 months.

Cost-to-Budget Conversion

Version: Final v2b June 2003

Purpose:

(1) Compute annual budget required to support the space and ground expenditures computed above.
(2) Apply budget constraints as necessary
(3) Compute resulting deviation from underlying model

Linked Inputs:

	Space		Ground
2006	Fiscal-year start		2006
2013	Fiscal-year end		2010

Expenditures in base-year dollars (BY$): BY 2007

Fiscal Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Space	23	193	258	222	150	87	47	20	0	0	0	0	0	0	0
Ground	18	153	203	95	31	0	0	0	0	0	0	0	0	0	0

Outlay rates:

1	2	3	4	5
58.56%	34.53%	4.07%	1.71%	1.13%

Note: AF 36000 outlay rates used for all NRO programs, regardless of choice of raw inflation index.

Computations:

Raw Inflation indices:

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2007	0.971	1.000	1.031	1.062	1.096	1.131	1.168	1.207	1.249	1.291	1.335	1.381	1.429	1.478	1.529
NRO															

Weighted Inflation indices:

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
2007	0.986	1.016	1.047	1.079	1.114	1.150	1.188	1.228	1.270	1.314	1.359	1.406	1.454	1.504	1.556
NRO															

Real-dollar expenditures:

	TOT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Space	1058.70	22.62	192.56	266.34	236.23	164.54	97.88	54.85	23.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ground	514.58	17.23	153.11	209.34	100.44	34.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Intermediate Calculations:

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Space	38.63	306.06	271.66	220.82	122.21	65.91	34.62	7.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ground	29.42	244.12	211.49	28.98	19.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Results:

Total Obligation Authority Required:

MODEL: FOR REFERENCE

Space	TOT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
% Time		5.1%	20.5%	35.9%	51.2%	66.6%	82.0%	97.4%	107.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TY$ (Annual)	1058.70	**38.63**	**306.06**	**271.66**	**220.82**	**122.21**	**65.91**	**33.42**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
TY$ (Cum)		38.63	344.68	616.34	837.16	959.37	1025.28	1058.70	1058.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BY$ (Cum)		39.18	340.51	600.01	804.58	914.32	971.64	999.77	999.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	999.77	39.18	301.33	259.49	204.57	109.74	57.32	28.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	999.77	39.18	301.33	259.49	204.57	109.74	57.32	28.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Budget (Cum)		3.6%	32.6%	58.2%	79.1%	90.6%	96.8%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

MANUALLY CONSTRAINED: LINK TO THIS

Goal for constraining budgets is usually to keep within σ =10% of the model cum. budget at 40-50% time.

	TOT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TY$ (Annual)	1058.70	38.63	306.06	271.66	220.82	122.21	65.91	33.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cum difference (%)		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
BY$ (Annual)	-0.23	39.18	301.33	259.49	204.57	109.74	57.32	28.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BY% (Annual)	100%	3.9%	30.1%	25.9%	20.5%	11.0%	5.7%	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

MODEL: FOR REFERENCE

Ground	TOT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
% Time		9.5%	38.0%	66.6%	95.2%	114.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
TY$ (Annual)	514.58	**29.42**	**244.12**	**211.49**	**28.98**	**0.57**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
TY$ (Cum)		29.42	273.54	485.03	514.01	514.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BY$ (Cum)		29.85	270.19	472.21	499.06	499.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	499.58	29.85	240.35	202.02	26.85	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	499.58	29.85	240.35	202.02	26.85	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
% Budget (Cum)		5.7%	53.2%	94.3%	99.9%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

MANUALLY CONSTRAINED: LINK TO THIS

Goal for constraining budgets is usually to keep within σ =13% of the model cum. budget at 40-50% time.

	TOT	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
TY$ (Annual)	514.58	29.42	244.12	211.49	28.98	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cum difference (%)		**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
BY$ (Annual)	-0.42	29.85	240.35	202.02	26.85	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BY% (Annual)	100%	6.0%	48.1%	40.4%	5.4%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

- Provide inputs for phasing equations (e.g., start date, launch date)
- Create phased expenditure profile using Eric Burgess' phasing equations
- Apply inflation indices and Air Force 3600 outlay rates to create budget profile/estimate
- Manually adjust phased estimate to re-align constant year dollars

Enhanced Model

Highlights

- **Phase One**
  - Simplified Structure
    - Overall spreadsheet size reduced (82 vs. 156 Excel rows)
    - Redundant tables eliminated
    - Hidden/Special cells removed
  - Manual requirements eliminated
  - Consistent formatting applied to identify user-inputs, calculations, etc…
  - Additional functionality introduced
    - Custom outlay profiles (vs. Air Force 3600)
    - Constraint mechanism
- **Phase Two**
  - Streamlined and flexible structure
    - Multiple systems can be estimated in a single spreadsheet
    - Inputs (phasing parameters, outlay rates, and constraints) for each system are independent
  - Functions are traceable and employ user-friendly input mechanisms
  - Phasing results can be output as either dollars or percentage-of-effort (via toggle)
  - Constraint mechanism supports more comprehensive application to a full CES/WBS

Enhanced Model

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Phasing Inputs

System	Phasing Method	ATP Date	Launch	Base Year	Total Cost (BY$)	Number of Units	% NR (0-100)	Expense Lag	System Type	Follow-On (Ground)
System 1										
Space	Space	10/17/2006	8/13/2017	2007	100.00	6	25	6		
Ground	Ground	10/17/2006	7/31/2010	2007	50.00			6	No	No

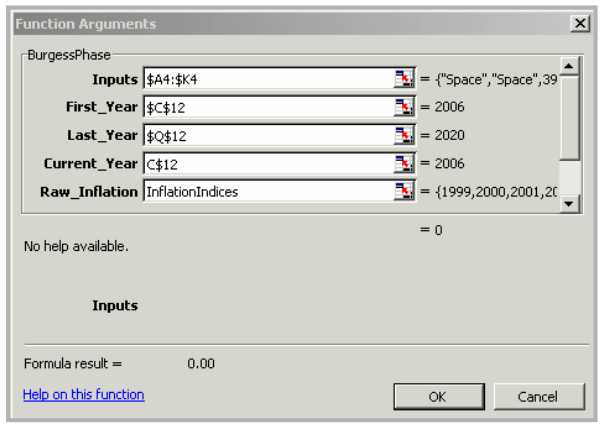
Format

Dollars

Phase Estimate (CY07) — **Dollars**

System	Total	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
System 1																
Space	100	0.00	14.03	20.61	19.55	15.89	10.90	7.05	4.25	2.77	1.99	1.68	1.29	0.00	0.00	0.00
Ground	50	0.00	14.04	17.89	13.12	4.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

- Current model requires only 10 rows in MS Excel
- Function interface simplifies user requirements
- Multiple systems may be estimated in a single sheet
- No manual adjustments required



Enhanced Model (cont'd)

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- **Users can easily model multiple systems and perform trades using custom outlay profiles**

Outlay Rates

Available Profiles	Year 1	Year 2	Year 3	Year 4	Year 5
1	58.56%	34.53%	4.07%	1.71%	1.13%
2	80.00%	20.00%			

Phase Estimate (CY07)

System	Total	2007	2008	2009	2010	2011	2012
AF 3600 Outlay							
1.1	100	29.66	34.18	22.19	11.28	2.69	
1.2	50	14.78	17.34	13.04	4.85	0.00	
80 / 20 Outlay							
1.1	100	21.91	32.47	24.40	14.03	6.72	0.48
1.2	50	10.90	16.39	13.68	8.42	0.60	0.00

- **Constraints may be applied to an estimate, and costs re-phased over any time period**

Re-phase period

Budgetary constraints

Constraint(s)

WBS	Constrain	Phase Method	Phase Start	Phase End	Total	2007	2008
1.1	Yes	Proportional	2010	2011	45.00	25.00	20.00
1.2	Yes	Uniform	2010	2011	22.00	10.00	12.00

Constrained Estimate Summary

WBS	Total	2007	2008	2009	2010	2011
1.1	100.00	25.00	20.00	22.19	26.49	6.32
1.2	50.00	10.00	12.00	13.17	10.25	4.58

Constraint

Original Estimate

Re-phase

Next Steps

Phase Three

- **Expand constraint/re-phase mechanism**
  - Introduce into lower levels of cost element structure
  - Allow modelers to control how re-phasing is handled at lower levels (i.e., fixing certain elements
- **Improve model integration**
  - Develop a graphical user interface to guide users through the entire process
  - Generate tables and functions automatically based on user inputs
  - Verify models include all necessary components (e.g., code modules)
- **Introduce Schedule Achievability**
  - Develop bounds for realistic constraints and re-phasing effort
  - Develop methods to determine impact of constraining a budget on schedule

Sources

Sources

- **Burgess, E., "Time Phasing Methods and Metrics," Presented at the 37th Annual DoD Cost Analysis Symposium, Williamsburg, VA, February 2004.**
- **Lee, David A., Hogue, Michael R., and Gallagher, Mark A. "Determining a Budget Profile from a R&D Cost Estimate," Journal of Cost Analysis, 1997.**