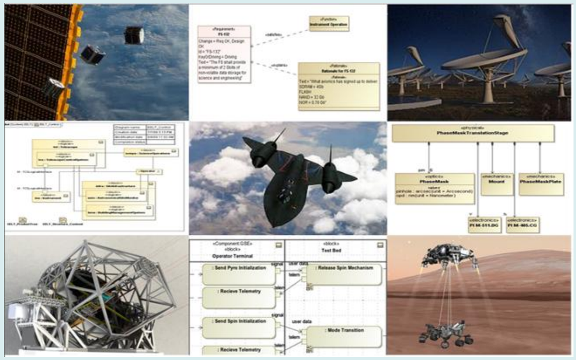


Return on Investment for Complex Projects Utilizing Model Based Systems Engineering (MBSE)

Michael E. Gooden (Ph.D. Candidate)
School of Engineering and Applied Science
George Washington University
Washington, DC 20052
mikegooden@gwu.edu
michael.e.gooden@gmail.com

Return on Investment for Model Based Systems Engineering (MBSE)

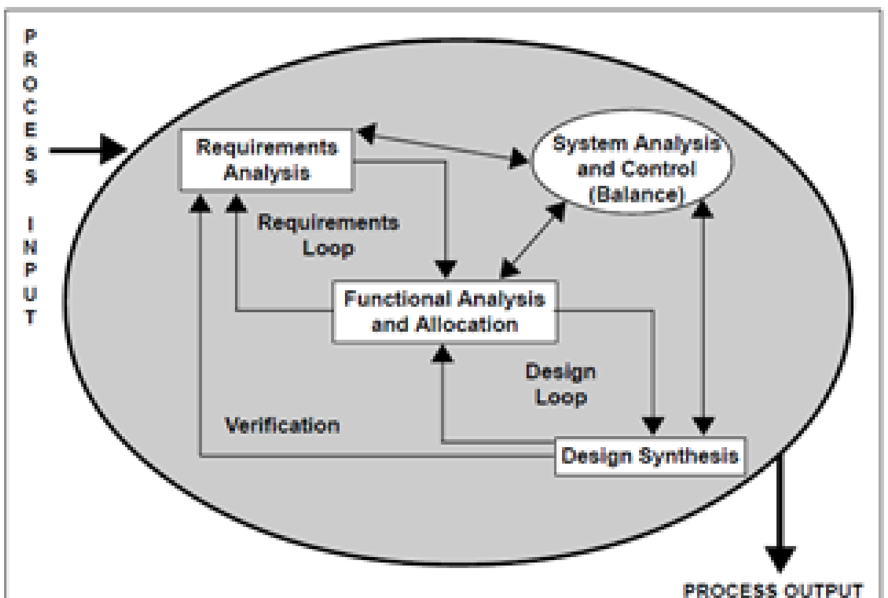
Abstract

This paper describes initial research results of a statistical analysis between Model Based System Engineering (MBSE) activities and their impact on complex project cost and schedule. These activities include Mission /Purpose Definition (MD), Requirements Engineering (RE), System Architecting (SA), System Integration (SI), Verification and Validation (VV), Technical Analysis (TA), Scope Management (SM), and Technical Leadership/Management (TM) which combine to an overall Model Based System Engineering Effort (MBSEE).

The objective of the research is to establish a quantitative relationship between cost, schedule and complexity within system engineering projects that employ MBSE activities. This research builds upon previous investigations on this topic using traditional SE approaches. Those results uncovered an inverse correlation between cost and schedule overruns and the amount of SE effort applied to a project or development activity. The ultimate goal of this study is to develop an effective model to quantify the optimal MBSE effort required to reduce program cost overruns and maintain project schedule for complex programs. A novel approach was developed to test the model utilizing toy data to verify and validate the results of this study.

Introduction

Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. System engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operations. Systems engineering considers both business and technical needs of all customers with the goal of providing a quality product that meets the user needs [1].

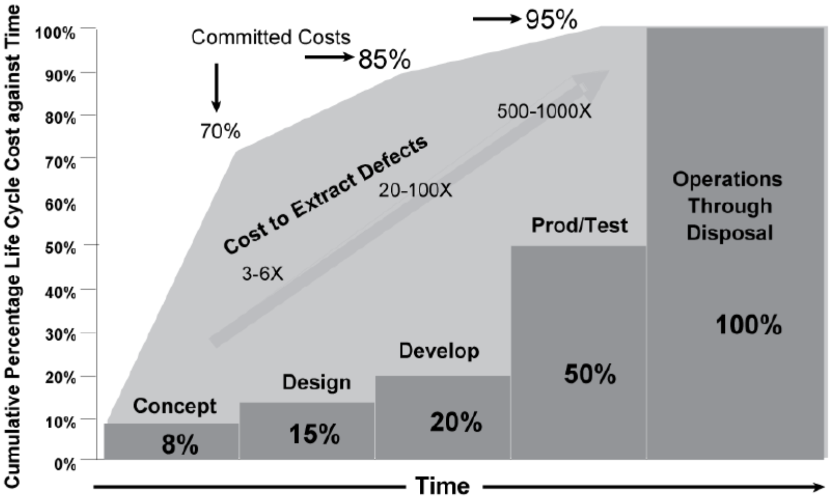


System Engineering Process

Source: The International Council of Systems Engineering (INCOSE)[1]

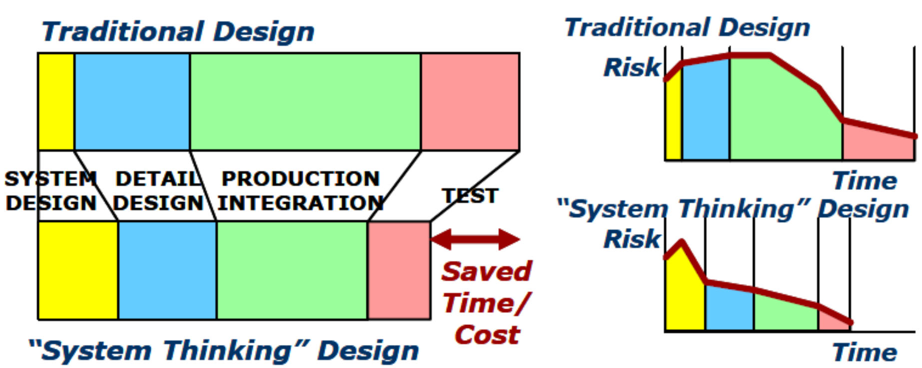
Benefits of System Engineering

- From a project management perceptive cost risk can be reduced if SE is applied early in the system development. As time progresses in a project this figure illustrates the life cycle cost (LCC) accrued over time. [1]



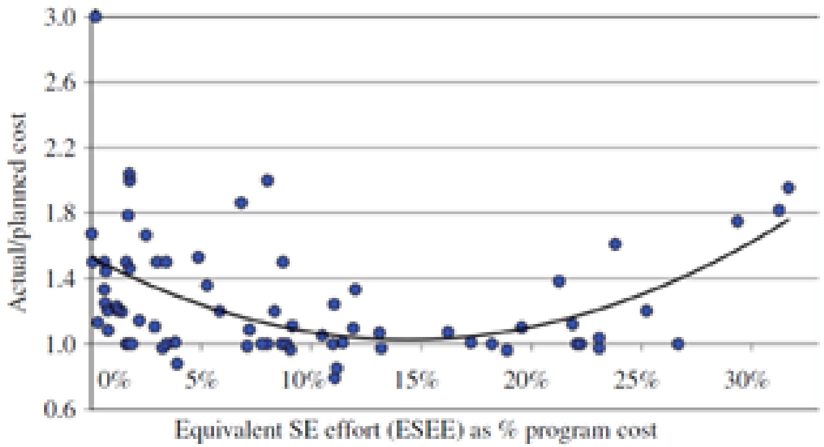
Committed life cycle cost against time. [1]

- In addition to saving defect cost SE can reduced lifecycle development schedules which in turn can result in additional savings. This figure shows the intuitive value of SE can reduce cost, save time and improve quality by reducing risk. [2]

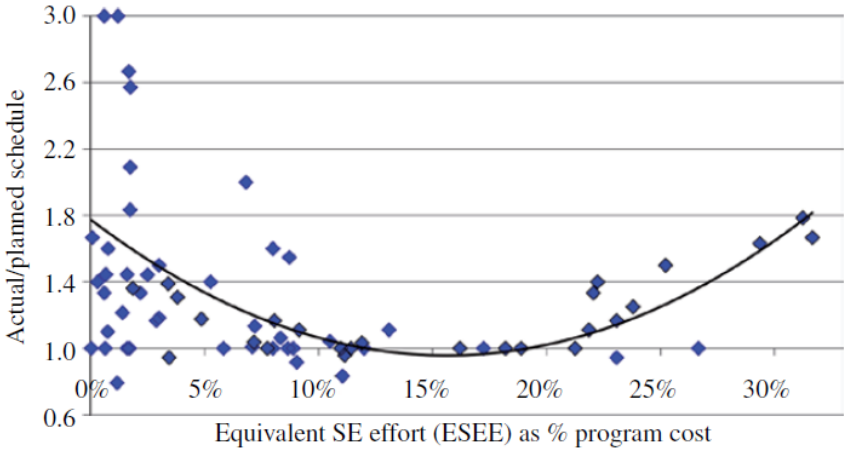


Intuitive value of SE [2]

Return on Investment for System Engineering Research



Cost overruns correlated with SE effort [1]



Schedule overruns correlated with SE effort [1]

- Dr. Honour research results shown cost overruns correlated with SE effort [1]
- Also schedule overruns correlated with SE effort [1]
- Both graphs showed a significant and quantifiable effort on program success with a correlation factor as high as 80% [1].

Dr. Eric Honour's research results revealed the optimum level of SE effort is 14% of the total program cost [1].

System Engineering Challenges

1. Mission complexity is growing faster than our ability to manage it which introduces risk.

2. System design emerges for pieces, rather than architecture resulting in expensive, complex systems which are difficult to test and operate.

3. Knowledge and investment are lost at project life cycle phase boundaries increasing development cost and risk late defect detections

4. Knowledge and investment are lost between projects which increase cost and risk

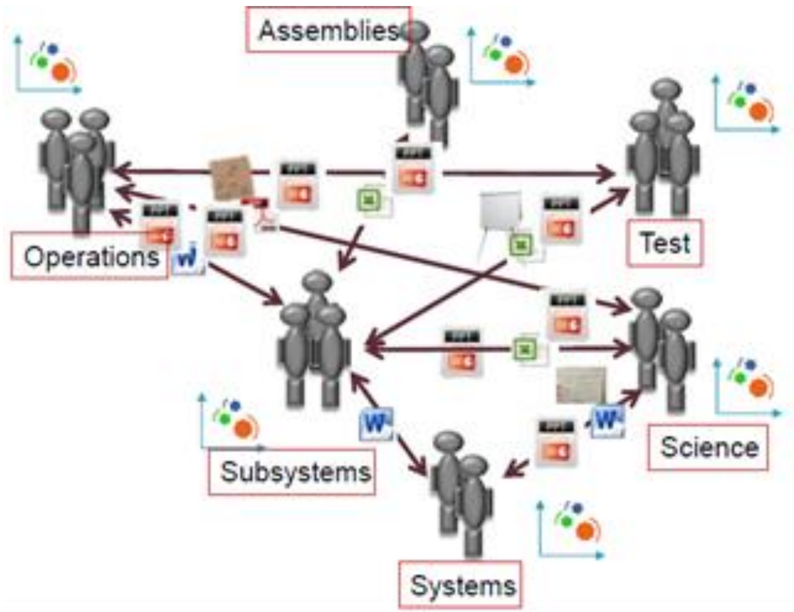
5. Technical and programmatic sides of a project are poorly coupled which hamper effective project decision making.

6. Need for an independent technical authority**.**

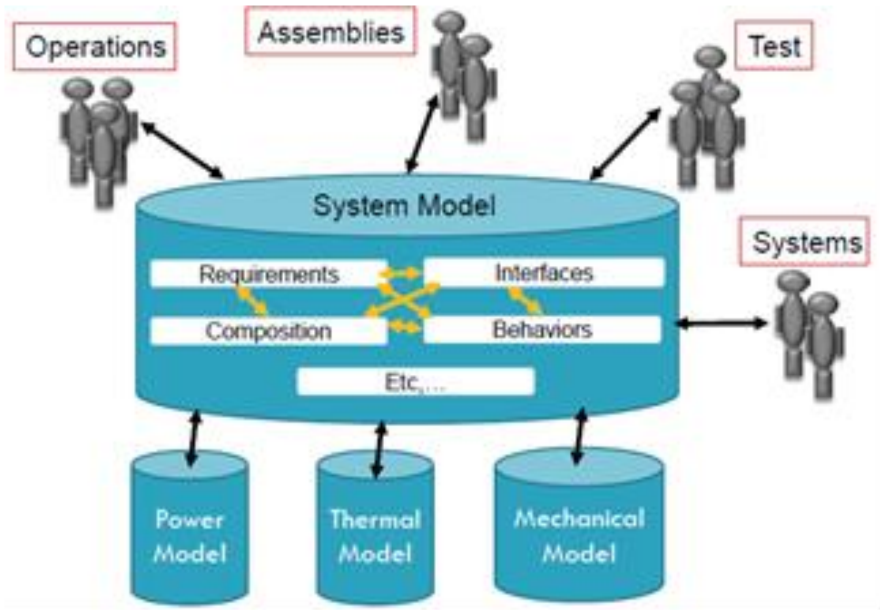
Source: INCOSE SE Vision 2025 [3]

Model Based System Engineering

Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases. [4]



Typical system engineering approach [5]



Model Based Systems Engineering approach [5]

MBSE Benefits [4]

- **Improved communications** among the development stakeholders (e.g. the customer, program management, systems engineers, hardware and software developers, testers, and specialty engineering disciplines).

- **Increased ability to manage** system complexity by enabling a system model to be viewed from multiple perspectives, and to analyze the impact of changes.

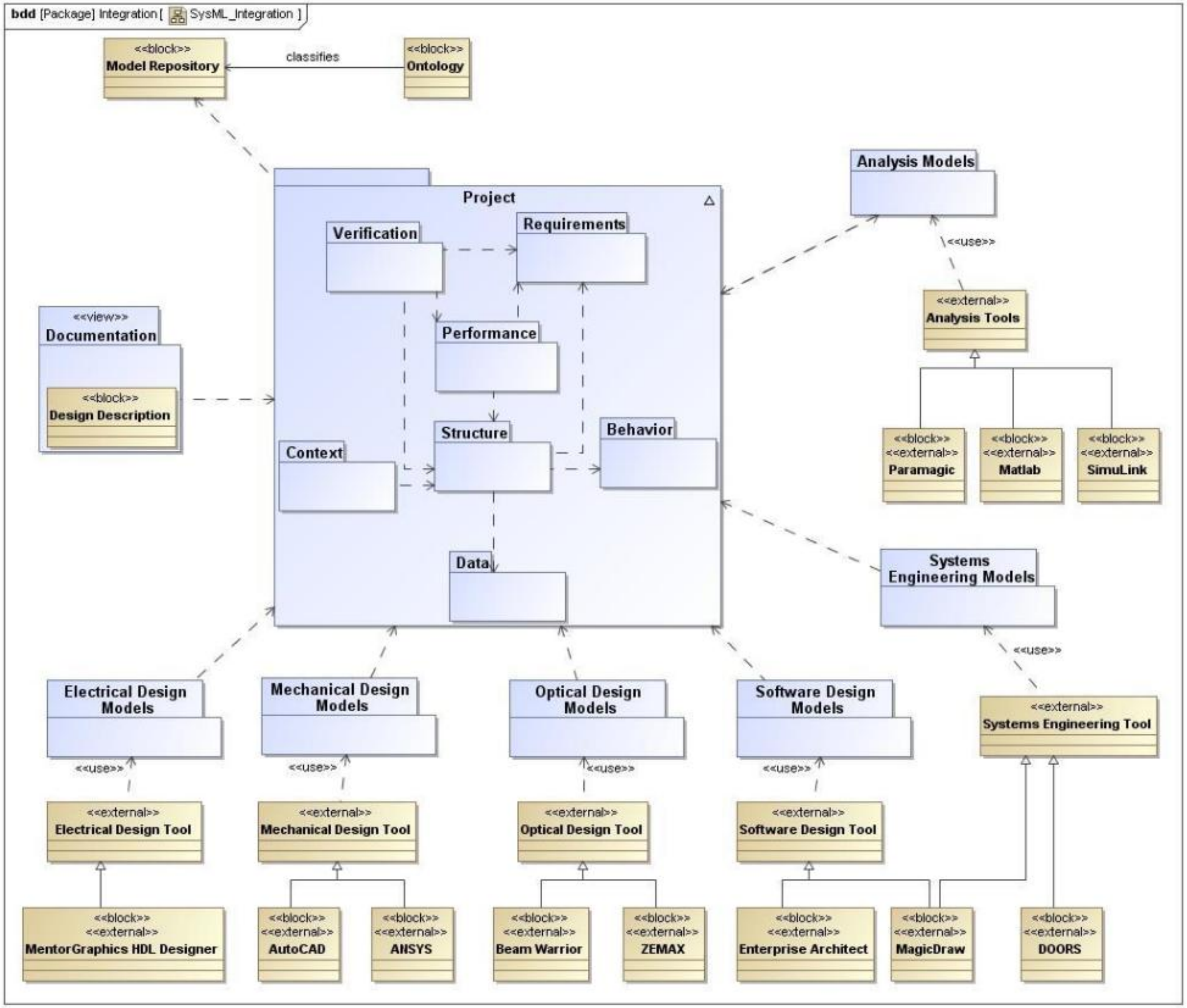
- **Improved product quality** by providing an unambiguous and precise model of the system that can be evaluated for consistency, correctness, and completeness.

- **Enhanced knowledge capture and reuse** of the information by capturing information in more standardized ways and leveraging built in abstraction mechanisms inherent in model driven approaches. This in turn can result in reduced cycle time and lower maintenance costs to modify the design.

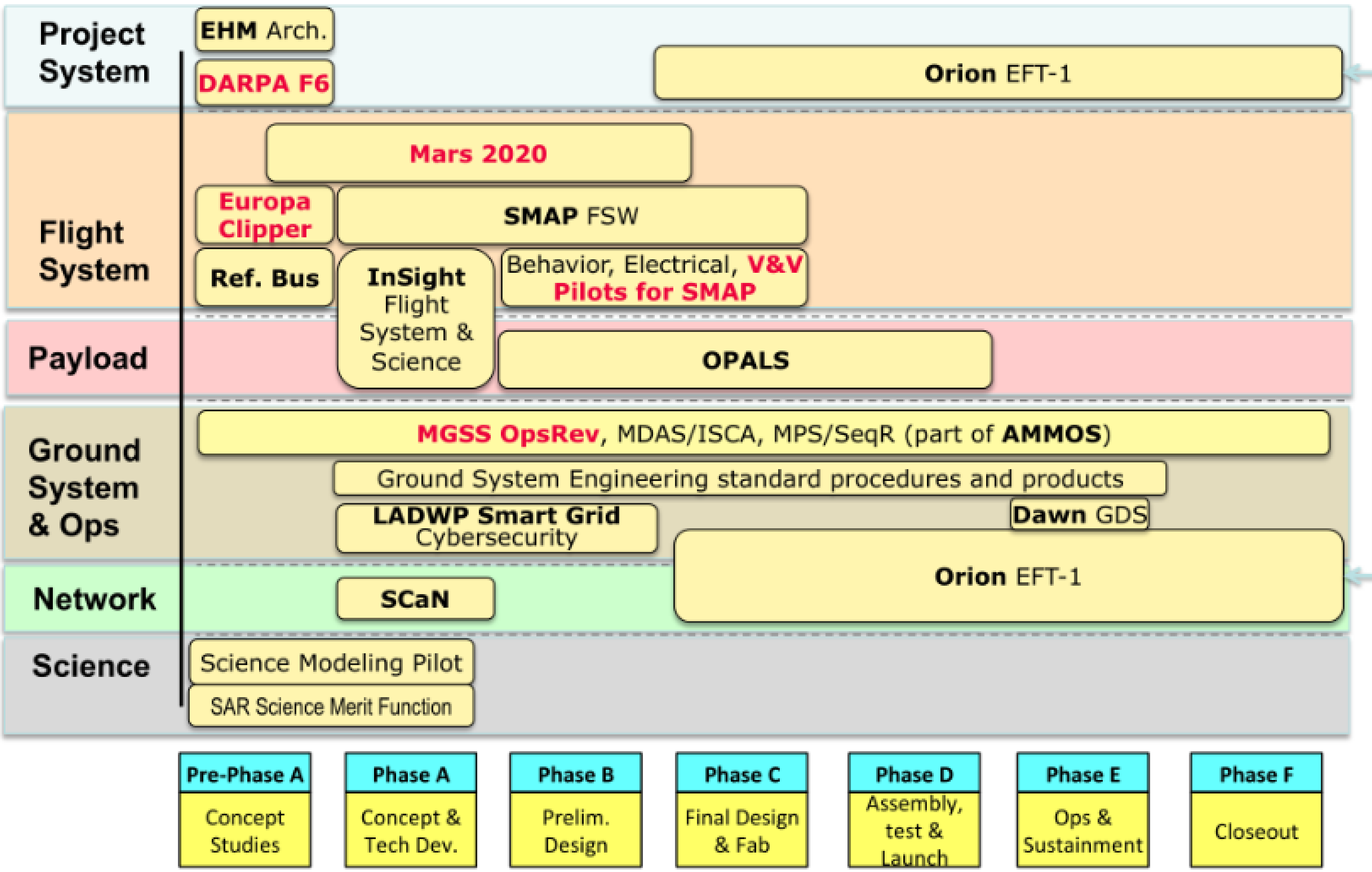
- **Improved ability to teach and learn** systems engineering fundamentals by providing a clear and unambiguous representation of the concepts.

Return on Investment for Model Based Systems Engineering (MBSE)

MBSE Integrating Multiple Aspects of the System [6]



Real-Life Space Projects using MBSE



Landscape of MBSE Application at JPL

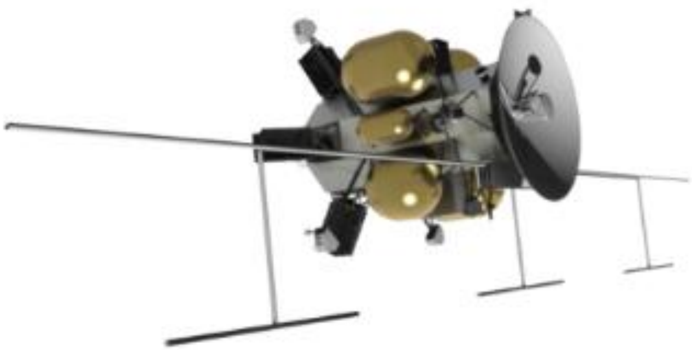
Source: http://blog.nomagic.com/mbse-real-life-space-exploration-projects/[6]

Motivations for using MBSE [6]:

- Strengthen the quality of formulation products by allowing exploration of more comprehensive options for space and more rapid analysis of alternatives.
- Perform early validation of system designs.
- Give systems engineers time to do more engineering analysis and less paper management.
- Significantly improve the quality of communications and understanding among system and subsystem engineers.
- Achieve greater design reuse.
- Align with the expectations and work habits of the next generation of engineering talent. This is the way new engineers are being trained and the way many of our early career engineers want to work.

Return on Investment for Model Based Systems Engineering (MBSE)

The Europa Clipper Project [6]



Mission

- To conduct detailed reconnaissance of Jupiter's moon Europa and JPL MBSE practitioners investigate whether the icy moon could harbor conditions suitable for life.
- The nominal Europa Clipper mission would perform 45 flybys of Europa at altitudes varying from 1700 miles to 16 miles (2700 kilometers to 25 kilometers).

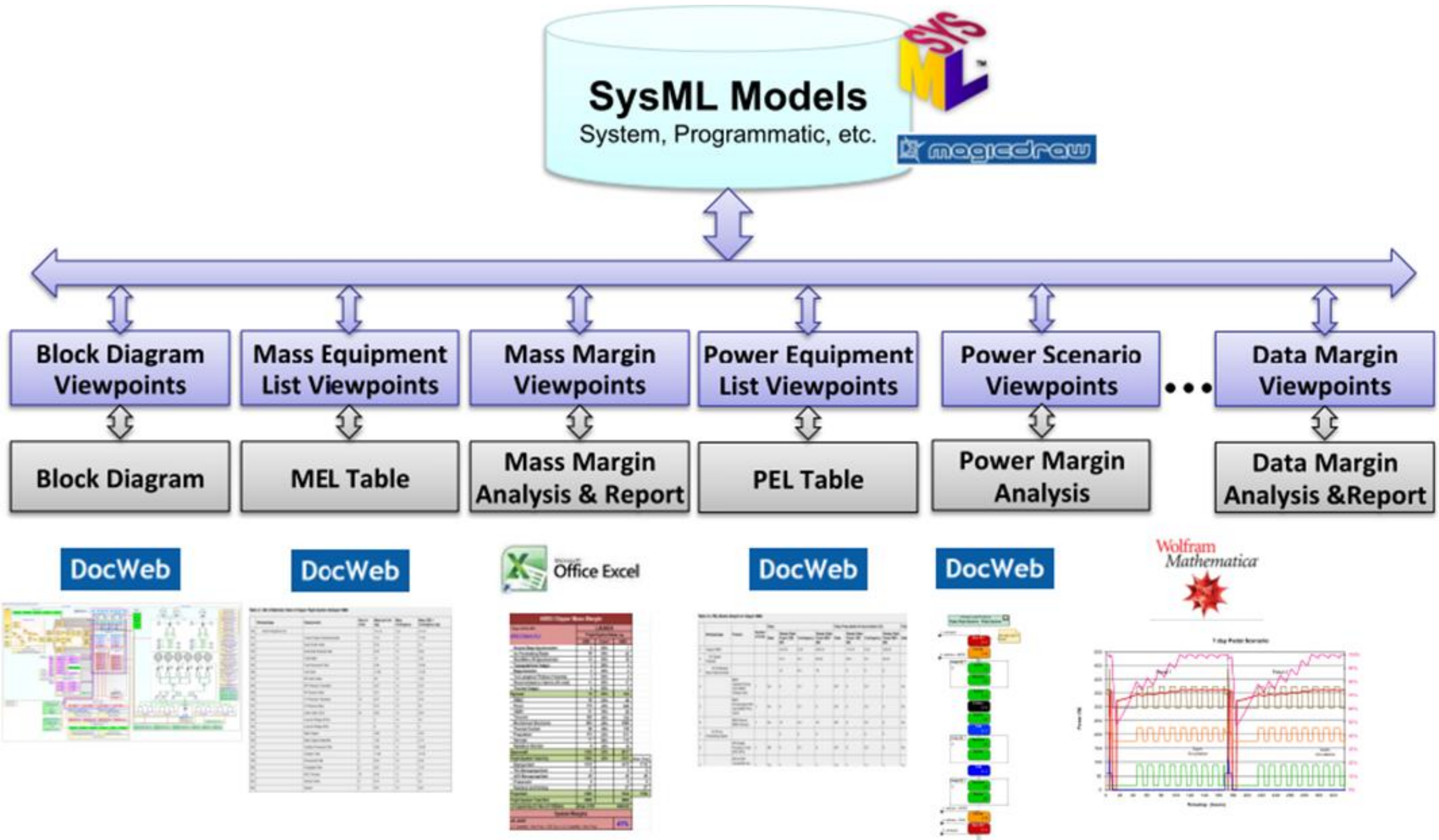
System Engineering Challenges

- Managing multiple architectural alternatives
- Reliably determining whether design concepts "close" on key technical resources
- Ensuring correctness and consistency of multiple, disconnected engineering reports
- Managing design changes before a full design exists

MBSE Implemented

- Configuration-management
- Web-based reporting
- Integrated data throughput analysis
- Integrated power and energy analysis
- Automated mass counting

Europa System Model Framework [6]



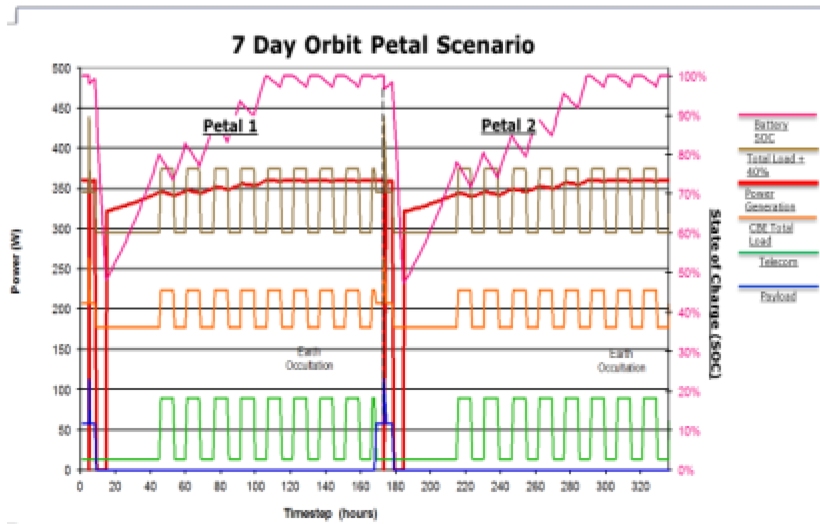
Europa System : Integrated Power/Energy Analysis [6]

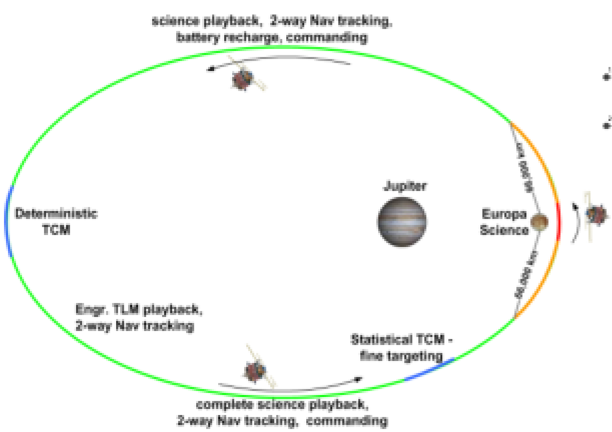
System Model:
- Equipment List
- Demand vs Mode
- Scenario Definitions

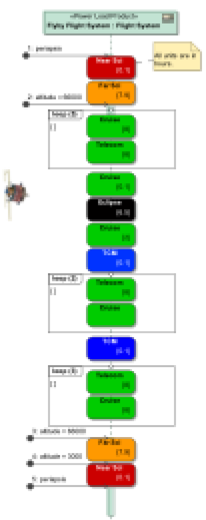
Subsystem Power Models
- Power Source Models
- Battery Models
- Load Profile Simulation

Integrated Power/Energy Analysis

Power Profile Analysis







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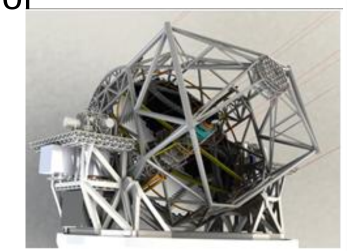
Return on Investment for Model Based Systems Engineering (MBSE)

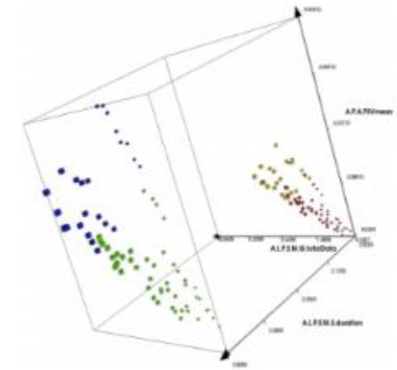
European Southern Observatory (ESO)

ESO adopts MBSE in large scale. MBSE is used for wide spectrum of applications (for example documentation, requirements, analysis, trade studies) and purposes addressing a particular development need, or accompanying a project throughout many – if not all – its lifecycle phases, fostering reuse and minimizing ambiguity



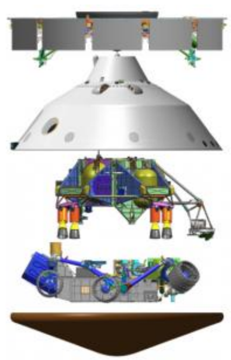
Tradespace Exploration for Fractionated Satellite Architectures

Understand and define the business case for fractionated spacecraft. MBSE is used for architecture variants and analysis via simulation



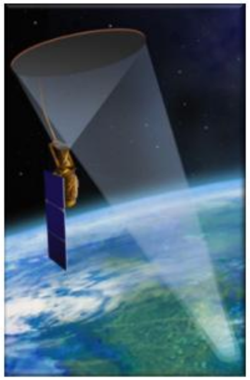
Mars2020 – the Follow-on to Curiosity

Engineer an inherently complex mission and system with lower cost and changes to science and rover payload. All we have to do is repeat the miracle. MBSE is used for requirements, logical and physical decomposition, and interfaces and blocks specification



The Soil Moisture Active Passive (SMAP) Mission

Explore a greater statespace in less time. MBSE is used for test plan and procedures, hardware and software configuration for testing, requirements, and design verification via executable state charts



Source: http://blog.nomagic.com/mbse-real-life-space-exploration-projects/[6]

Literature Review

Balram, Sara S. (2012). "Perceptions of Model-Based Systems Engineering as the Foundation for Cost Estimation and its Implications to Earned Value Management." Order No. 1532176, The University of Arizona.

- This thesis attempts to quantify the benefits of MBSE. Its also supports using Earned Value Management as a data mechanism.

Maheshwari, A. (2015). Industrial adoption of model-based systems engineering: Challenges and strategies (Order No. 10061186). Available from ProQuest Dissertations & Theses Global.

- This thesis examines a case study to incorporate MBSE tools into projects. The Agent Based Modeling tools in this paper supports the requirements data elements key to this research.

Ryan, J. (2013). Leveraging variability modeling techniques for architecture trade studies and analysis (Order No. 3558224). Available from Dissertations & Theses @ George Washington University

- This paper proposes a framework for efficient architecture definition using MBSE and simulation methods to evaluate alternatives. It supports the architecture data element for this research.

Bassam, S. S. (2015). Applications of model-based systems engineering in performance-based vulnerability assessment (Order No. 1600967).

- This paper discusses the role of MBSE (SySML) within requirement analysis and supports the requirements data elements key to this research.

Research Methodology

Define Research Area
- Novel
- Relevance
- ROI MBSE Approved

Analyze Approach
- Problem
- Goals
- Scope
- Constraints

Evaluation Criteria
- Data Sources
- Metrics
- Risk

Data Collection
- Existing Survey Database

You Are Here

Statistical Analysis
- Null Hypothesis Testing
- ANOVA

Research Results
- Reject /Fail to Reject the Null
- Confidence Levels
- Recommendations

MBSE Hypotheses

The objective of this research is to establish the correlation between MBSE efforts (MBSEE) and project cost and schedule. The ROI for these efforts needs to answer the research questions discussed earlier in the form of a hypothesis.

- H1o: There is no quantitative relationship between cost overruns and the amount of Model Based System Engineering efforts applied to a complex project.

- H1a: There is a quantitative relationship between cost overruns and the amount of Model Based System Engineering efforts applied to a complex project.

- H2o: There is no quantitative relationship between schedule lags and the amount of Model Based System Engineering efforts applied to a complex project.

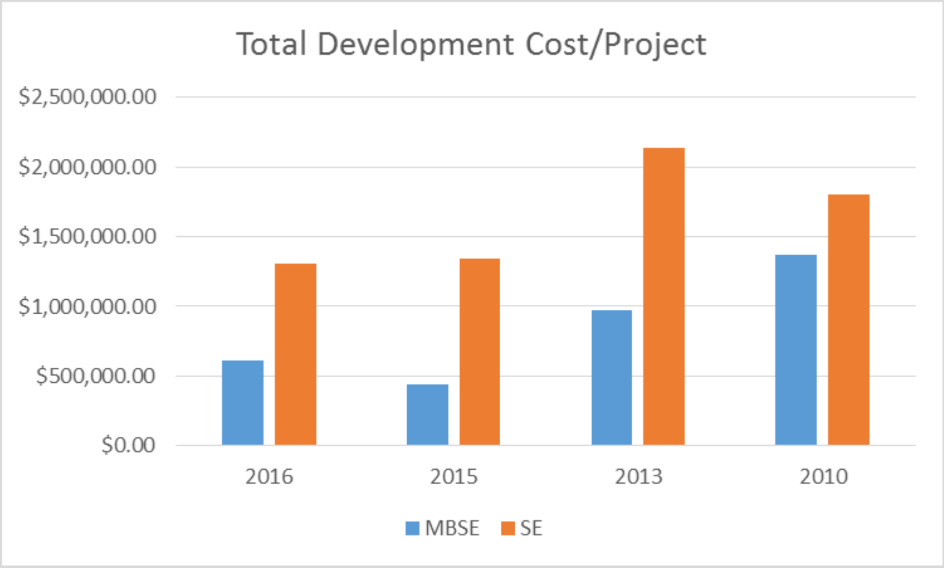
- H2a: There is a quantitative relationship between schedule lags and the amount of Model Based System Engineering efforts applied to a complex project.

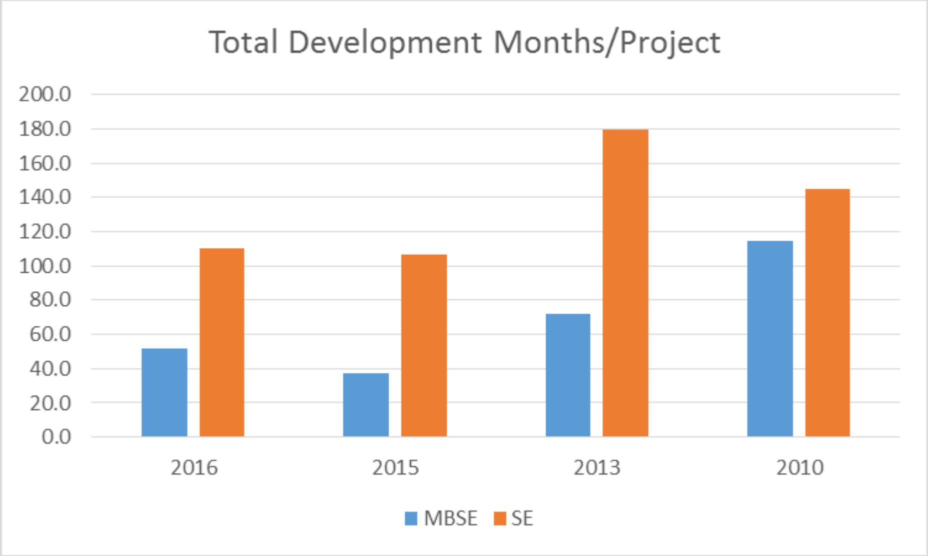
Return on Investment for Model Based Systems Engineering (MBSE)

Initial MBSE Dataset [7]

	2016		2015		2013		2010	
	Systems Engineering with MBSE	Systems Engineering non-MBSE	Systems Engineering with MBSE	Systems Engineering non-MBSE	Systems Engineering with MBSE	Systems Engineering non-MBSE	Systems Engineering with MBSE	Systems Eng Systems Engineering
Devel time Months	12.1	12.7	13.2	12.7	8.5	13.4	12.9	11.7
% behind schedule	29.0%	34.5%	31.5%	38.6%	38.7%	38.8%	45.6%	56.5%
Months behind	4.7	3.7	5.2	4.9	5.9	4.9	4.2	3.9
% cancelled	12.0%	11.8%	8.9%	16.3%	11.1%	12.7%	11.4%	14.3%
Months lost to cancellation	3.2	4.3	4.1	4.3	6.0	5.4	5.4	4.3
SW Developers/proj	4.3	8.7	2.8	8.4	8.5	13.4	8.9	12.4
Average Developer months/project	52.0	110.5	37.0	106.7	72.3	179.6	114.8	145.1
Developer months lost to schedule	5.9	11.1	4.6	15.9	19.4	25.5	17.0	27.3
Developer months lost to cancellation	1.7	4.4	1.0	5.9	5.7	9.2	5.5	7.6
Total developer months/ project	59.5	126.0	42.6	128.5	97.3	214.2	137.3	180.0
At $10,000/developer month								
Average developer cost/project	$520,300	$1,104,900	$369,600	$1,066,800	$722,500	$1,795,600	$1,148,100	$1,450,800
Average cost to delay	$75,121	$155,199	$56,081	$217,753	$194,081	$254,761	$170,453	$273,234
Average cost to cancellation+	$16,512	$44,144	$10,217	$58,876	$56,610	$91,897	$54,788	$76,248
Total developer cost/project	$611,933	$1,304,243	$435,898	$1,343,429	$973,191	$2,142,258	$1,373,341	$1,800,282

MBSE Cost and Schedule Analysis





Return on Investment for Model Based Systems Engineering (MBSE)

Initial MBSE Dataset

Row	SE/MBSE/Year	Development Time (months)	Schedule delay %	Delay (months)	% Cancelled	Months Lost to Cancellation
1	MBSE	12.1	29.0%	4.7	12.0%	3.2
2	SE	12.7	34.5%	3.7	11.8%	3.2
3	MBSE	13.2	31.5%	5.2	8.9%	3.2
4	SE	12.7	38.6%	4.9	16.3%	3.2
5	MBSE	8.5	38.7%	5.9	11.1%	3.2
6	SE	13.4	38.8%	4.9	12.7%	3.2
7	MBSE	12.9	45.6%	4.2	11.4%	3.2
8	SE	11.7	56.5%	3.9	14.3%	3.2

Row	SW Developer per project	Avg. Developer months/proj.	Developer mon. lost to schedule	Developer mon. lost to cancel.	Total developer months per proj	Avg Developer cost/proj
1	4.3	52.0	5.9	1.7	59.5	$520,300.00
2	8.7	110.5	11.1	4.4	126.0	$1,104,900.00
3	2.8	37.0	4.6	1.0	42.6	$369,600.00
4	8.4	106.7	15.9	5.9	128.5	$1,066,800.00
5	8.5	72.3	19.4	5.7	97.3	$722,500.00
6	13.4	179.6	25.5	9.2	214.2	$1,795,600.00
7	8.9	114.8	17.0	5.5	97.3	$1,148,100.00
8	12.4	145.1	27.3	7.6	214.2	$1,450,800.00

Row	Avg cost to delay	Avg cost to cancel.	Total develop cost/project
1	$75,212.00	$16,512.00	$611,933.00
2	$115,199.00	$44,144.00	$1,304,243.00
3	$56,081.00	$10,217.00	$435,898.00
4	$217,753.00	$58,876.00	$1,343,429.00
5	$194,081.00	$56,610.00	$973,191.00
6	$254,761.00	$91,897.00	$2,142,258.00
7	$170,453.00	$54,788.00	$1,373,341.00
8	$273,234.00	$76,248.00	$1,800,282.00

Sample SE vs MBSE Dataset

Correlation: Development , Schedule del, Delay (month, % Cancelled, Months Lost , ...

	Development Time	Schedule delay %	Delay (months)	% Cancelled
Schedule delay %	-0.127 0.764			
Delay (months)	-0.510 0.197	-0.388 0.343		
% Cancelled	0.069 0.872	0.435 0.281	-0.260 0.535	
Months Lost to C	* *	* *	* *	* *
SW Developer per	-0.027 0.950	0.709 0.049	-0.300 0.470	0.533 0.174
Avg. Developer m	0.262 0.530	0.618 0.102	-0.421 0.299	0.533 0.174
Developer mon. l	-0.208 0.622	0.811 0.015	-0.105 0.805	0.505 0.201
Developer mon. l	-0.065 0.879	0.676 0.066	-0.132 0.755	0.564 0.145
Total developer	0.101 0.812	0.681 0.063	-0.356 0.387	0.593 0.122
Avg Developer co	0.262 0.530	0.618 0.102	-0.421 0.298	0.533 0.173
Avg cost to dela	-0.165 0.696	0.778 0.023	-0.073 0.864	0.675 0.066

Cell Contents: Pearson correlation
P-Value

Correlation Analysis

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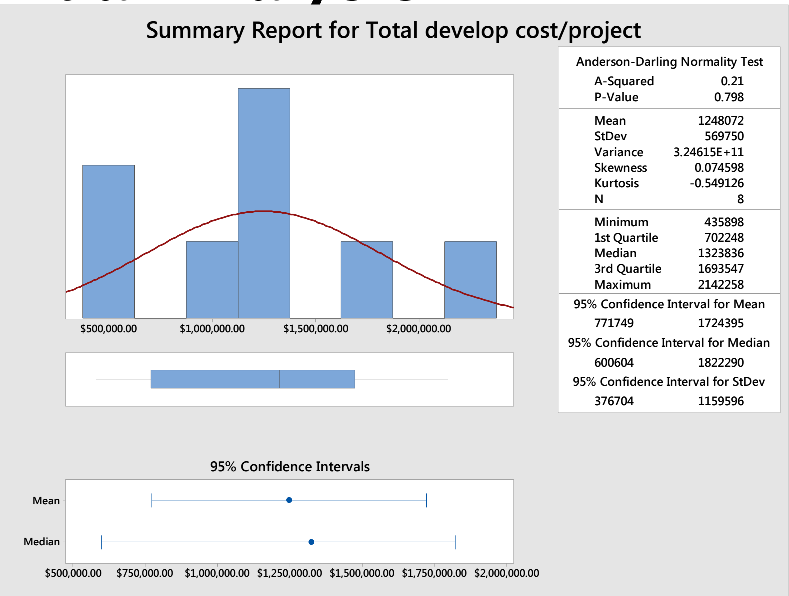
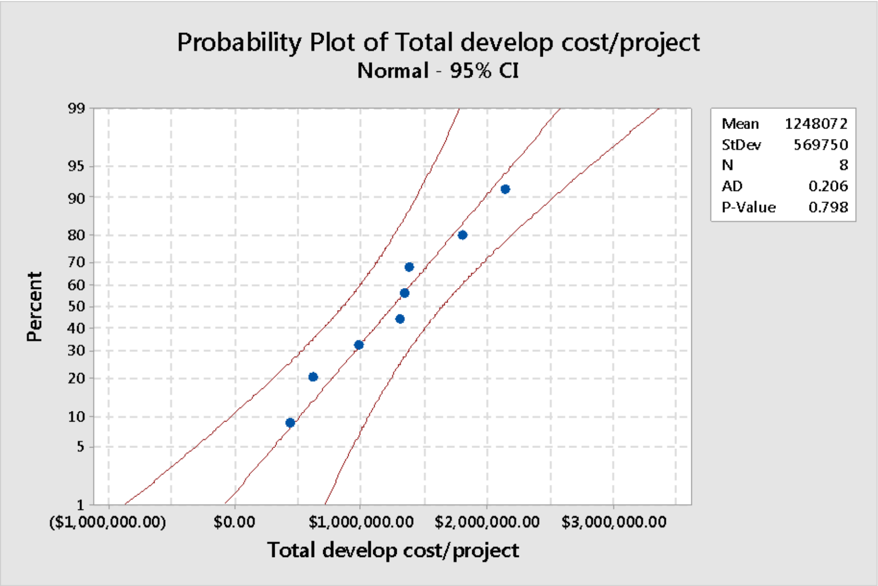
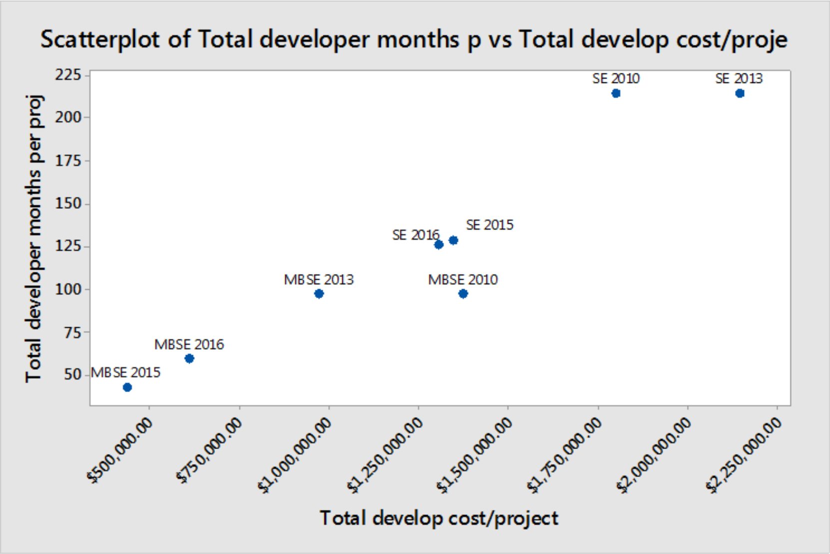
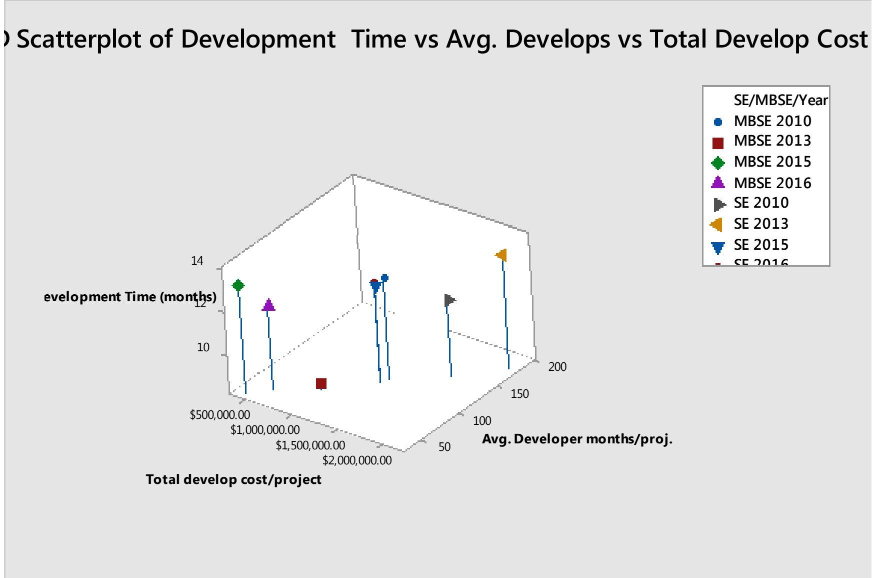
Return on Investment for Model Based Systems Engineering (MBSE)

Initial Analysis









Next Phase of Research

- Initial data results support rejection of the null hypotheses, but the level of significance cannot be evaluated with the limited data set.

- For the next phase of this study approximately 50-75 additional MBSE projects will be evaluated for the following engineering activities: Mission/Purpose Definition (MD), Requirements Engineering (RE), System Architecting (SA), System Integration (SI), Verification and Validation (VV), Technical Analysis (TA), Scope Management (SM), and Technical Leadership/Management (TM) which combine to an overall Model Based System Engineering Effort (MBSEE).

- Cost and schedule metrics will be used to statistically reject or fail to reject the null hypotheses and optimize the MBSE data model.

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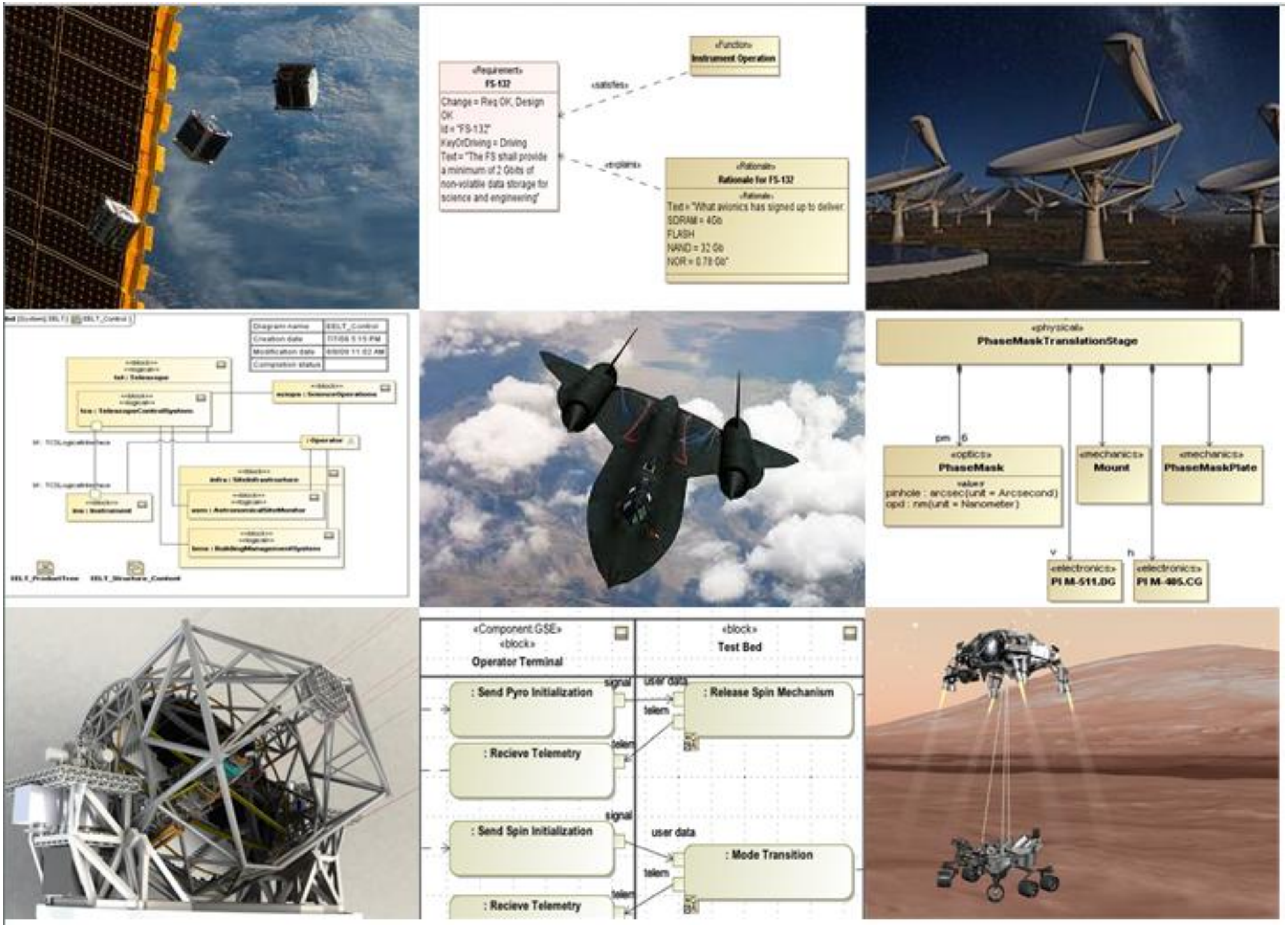
Questions?



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Acknowledgments

Dr. Steven M.F. Stuban, Dissertation Advisor,
George Washington University

- Steven Stuban, Ph.D., P.E., is Deputy Director of the National Geospatial-Intelligence Agency's Facility Program Office. He is a Professional Engineer and is Defense Acquisition Workforce Improvement Act Level III certified in the Program Management, Program Systems Engineer and Facilities Engineering career fields.

- He has a bachelor's degree in Engineering from the U.S. Military Academy, a master's degree in Engineering Management from the University of Missouri-Rolla, and both a master's degree and a doctorate in Systems Engineering from George Washington University.

- Dr. Stuban is Adjunct Professor with GW and serves on a standing doctoral committee.

Acknowledgments

Dr. Jason Dever, Dissertation Advisor,
George Washington University

- Jason Dever, Ph.D., works as a Systems Engineer supporting the National Reconnaissance Office, responsible for developing an open IT framework such that software components can be shared across the government. In previous posts, Jason supported numerous positions across the systems engineering lifecycle, including requirements, design, development, deployment, and O&M.

- Jason received his bachelor's degree in Electrical Engineering from Virginia Tech, master's degree in Engineering Management from George Washington University, and Ph.D. in Systems Engineering from George Washington University. His teaching interests are project management, systems engineering, and quality control.