Methodology to assess cost and schedule impact using System and Technology Readiness Level (SRL/TRL)

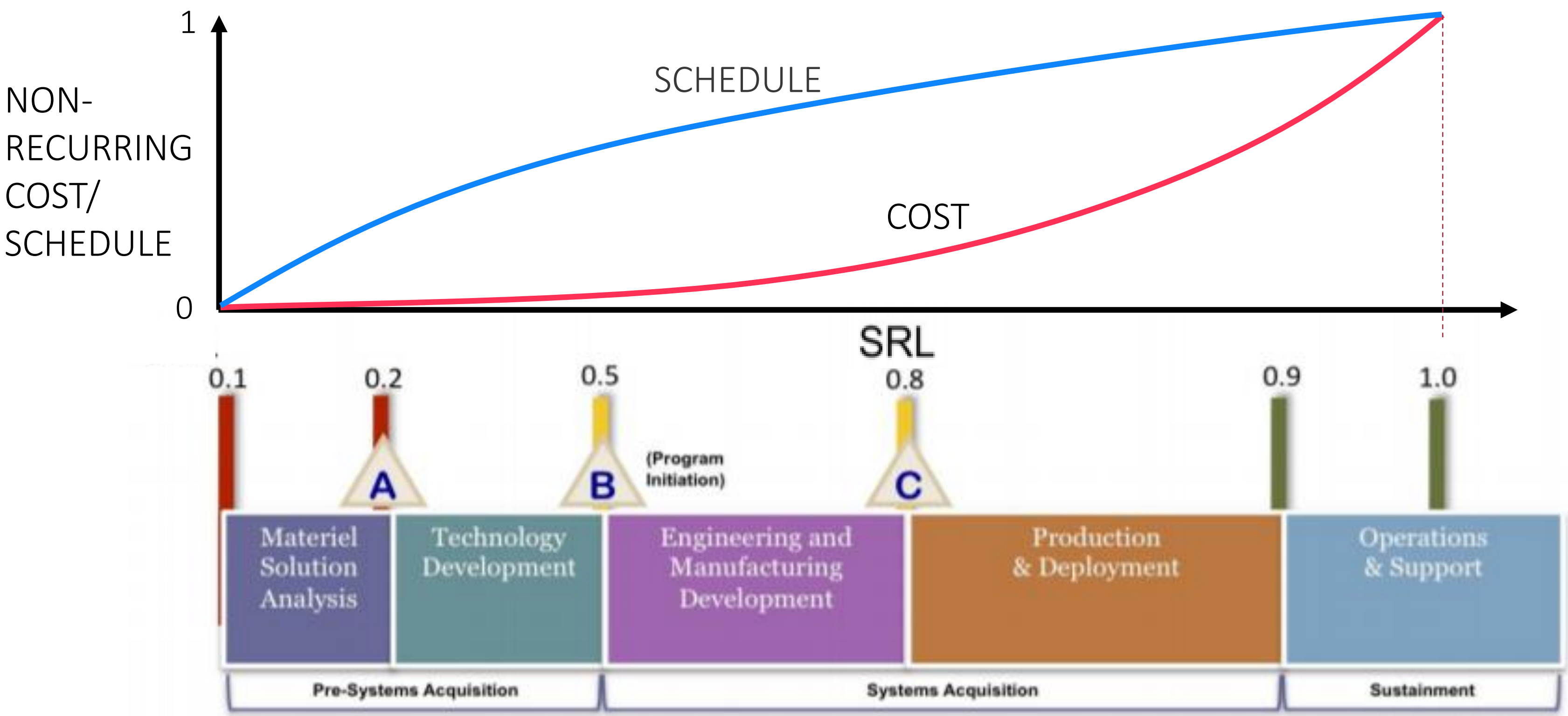
20 March 2019
Nate Sirirojvisuth, PhD

Agenda

- Background
- Analysis Framework
- Modeling Approach
- Implementation: Excel Prototype

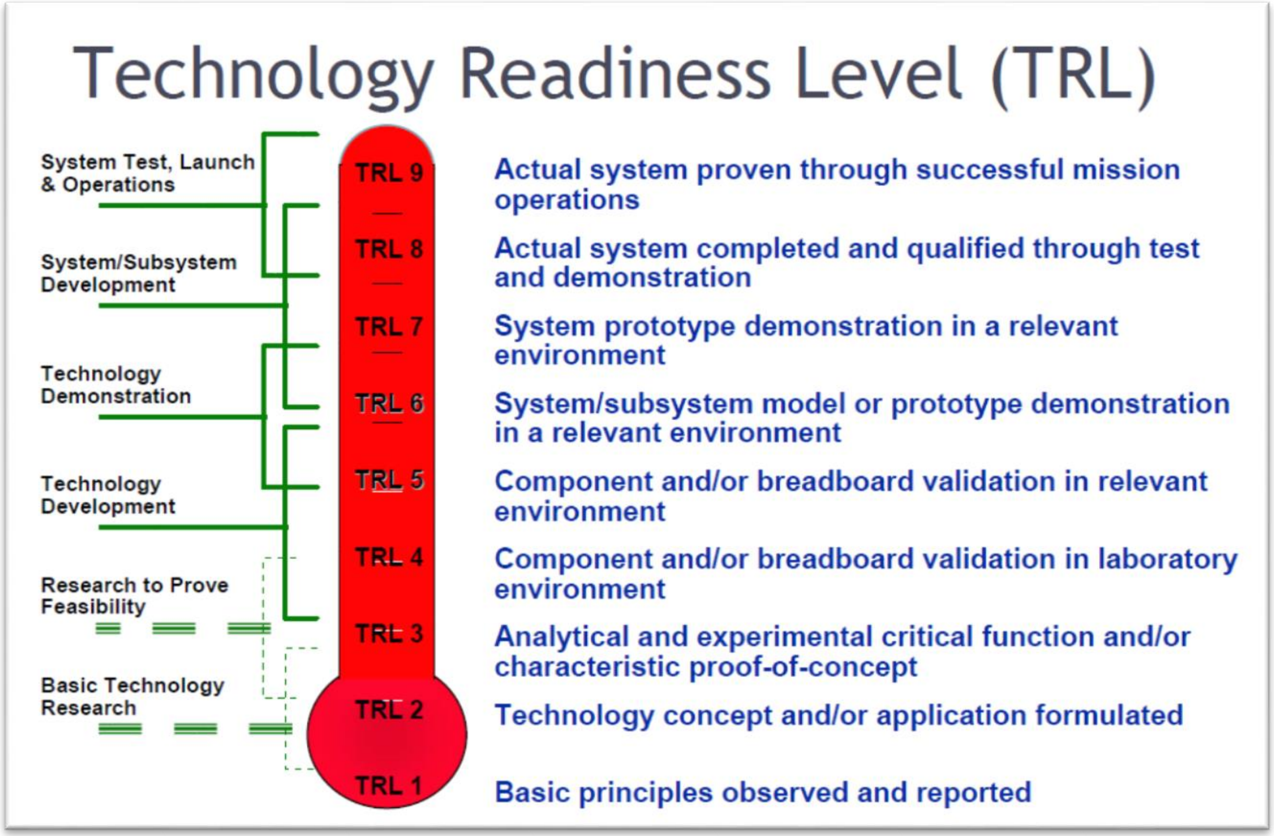
Background

To understand how program maturity influences non-recurring costs (NRDEV) and schedule



[Ref.1]

Definition



- Rate of maturity is unique to technology types
- Time is a factor and is dependent on investment

[Ref.2]

Cost Factor by TRL

Research by:

Dr. Roy Smoker, MCR LLC

Mr. Joe Hamaker, previous head of NASA Cost

Dr. Hamid Habib-Agahi, JPL NICM II Model

Ray Covert, MCR LLC

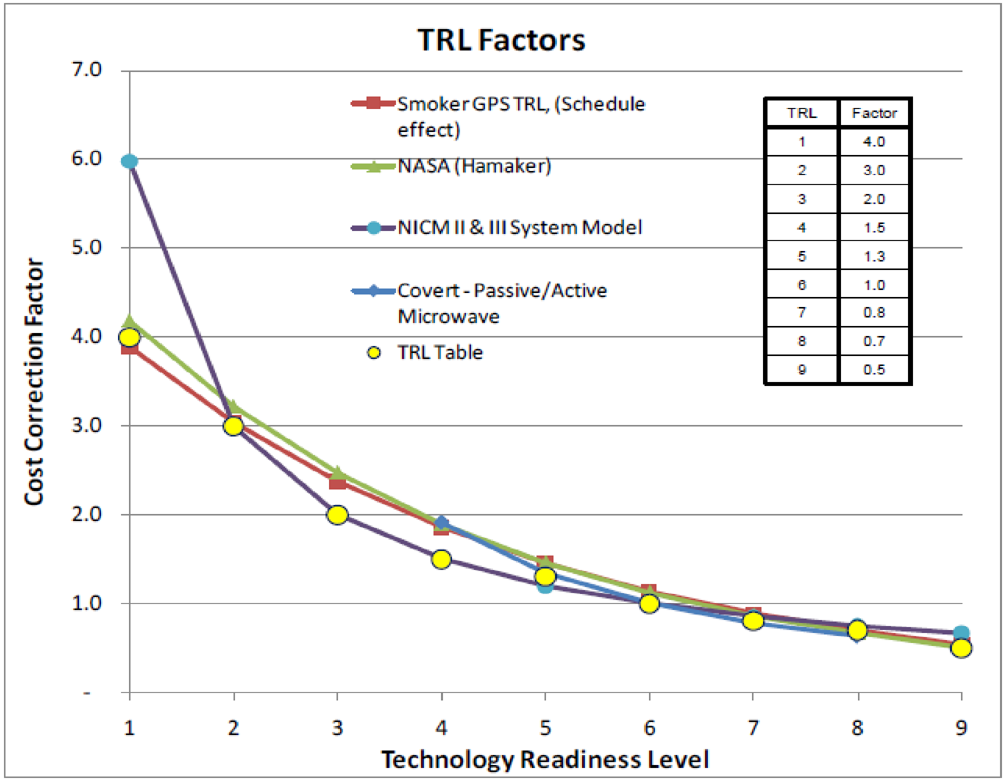


Figure 1. Cost correction factors based upon historical data.

[Ref.3]

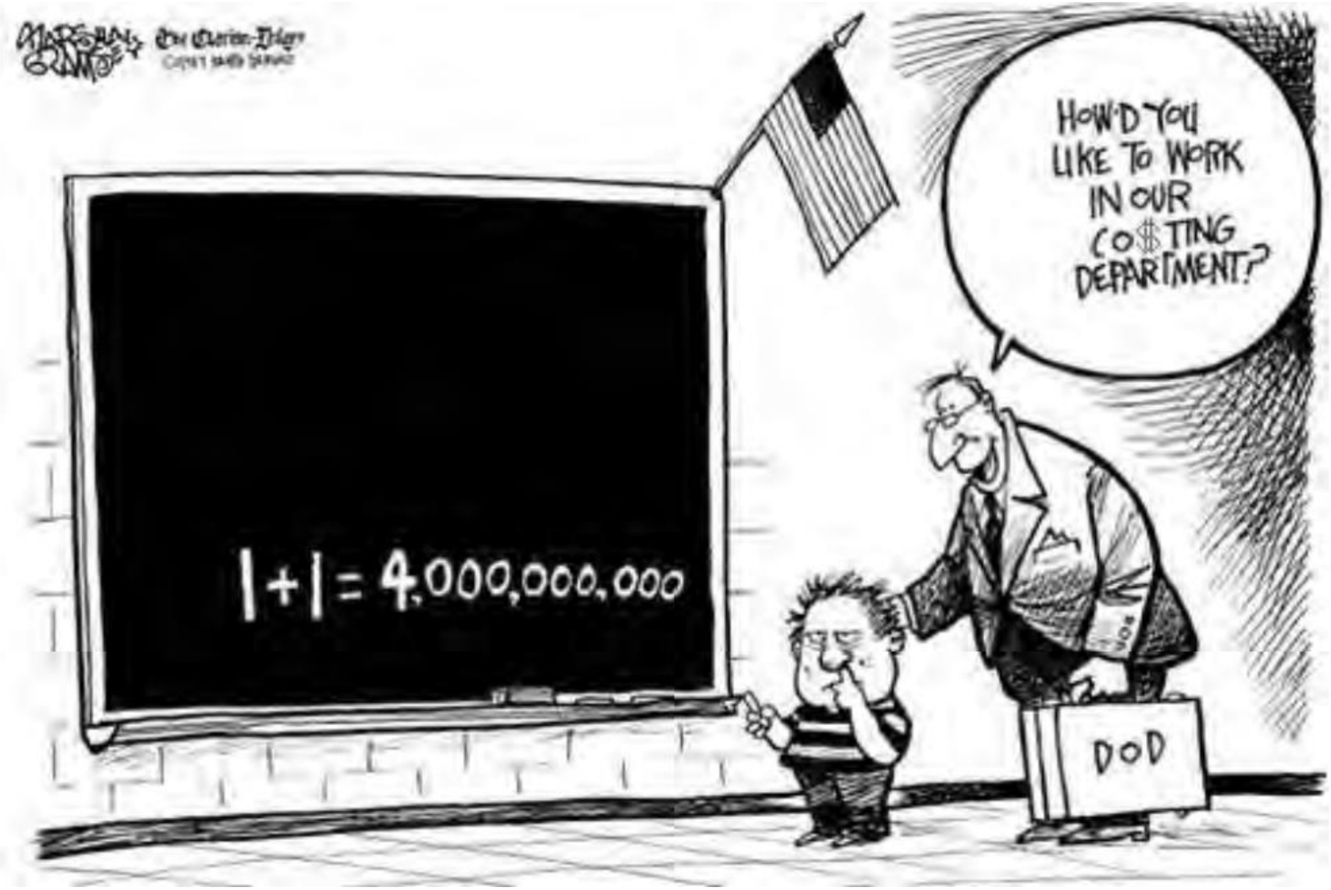
Analysis Framework

TRL Shortcomings

- Application of TRL to systems of technologies is not sufficient to give a holistic picture of complex system of systems readiness
  - TRL is only a measure of an individual technology
- Assessments of several technologies rapidly becomes very complex without a systematic method of comparison
- Multiple TRLs do not provide insight into integrations between technologies nor the maturity of the resulting system
  - Yet most complex systems fail at the integration points

[Ref.4]

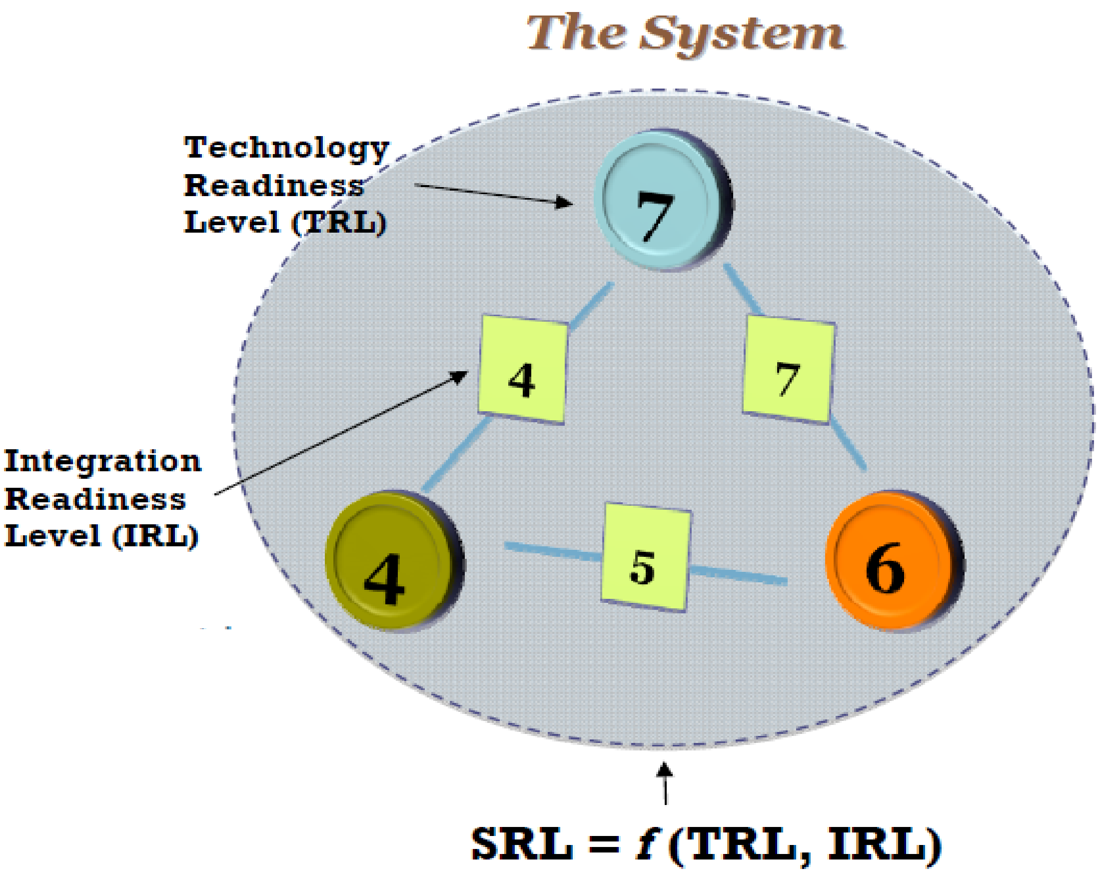
Technologies ≠ System



Integration Readiness Level (IRL)

	IRL	Definition
Pragmatic	9	Integration is **Mission Proven** through successful mission operations.
	8	Actual integration completed and **Mission Qualified** through test and demonstration, in the system environment.
Syntactic	7	The integration of technologies has been **Verified and Validated** with sufficient detail to be actionable.
	6	The integrating technologies can **Accept, Translate, and Structure Information** for its intended application.
	5	There is sufficient **Control** between technologies necessary to establish, manage, and terminate the integration.
	4	There is sufficient detail in the **Quality and Assurance** of the integration between technologies.
Semantic	3	There is **Compatibility** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
	2	There is some level of specificity to characterize the **Interaction** (i.e. ability to influence) between technologies through their interface.
	1	An **Interface** between technologies has been identified with sufficient detail to allow characterization of the relationship.

SRL Calculation



SRL Calculation

- The SRL is not user defined, but is instead based on the outcomes of the documented TRL and IRL evaluations
- Through mathematically combining these two separate readiness levels, a better picture of overall complex system readiness is obtained by examining all technologies in concert with all of their required integrations

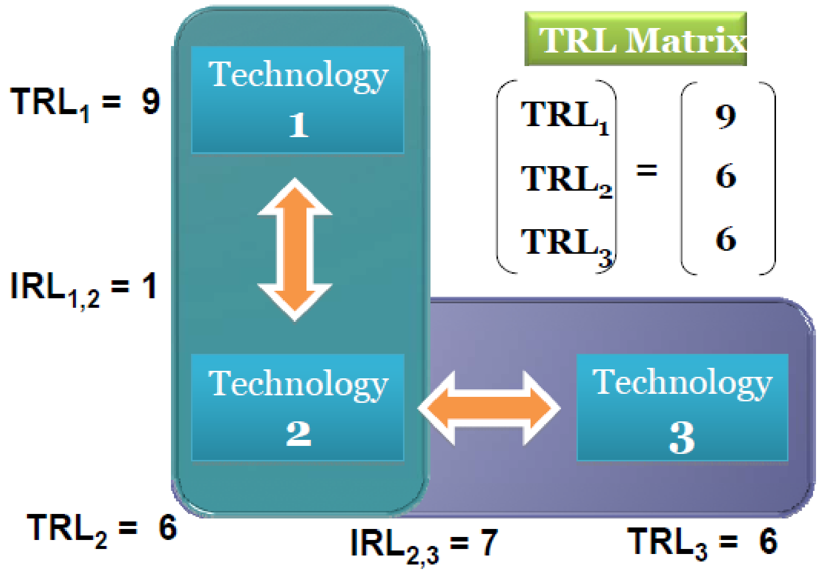
SRL = IRL x TRL

$$\begin{bmatrix} SRL_1 & SRL_2 & SRL_3 \end{bmatrix} = \begin{bmatrix} IRL_{11} & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_{22} & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_{33} \end{bmatrix} \times \begin{bmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{bmatrix}$$

$$\text{Composite SRL} = 1/n\left(SRL_1/n + SRL_2/n + SRL_3/n\right)$$

$$= 1/n^2\left(SRL_1 + SRL_2 + SRL_3\right)$$

SRL Example



TRL Matrix

$$\begin{pmatrix} TRL_1 \\ TRL_2 \\ TRL_3 \end{pmatrix} = \begin{pmatrix} 9 \\ 6 \\ 6 \end{pmatrix}$$

IRL Matrix

$$\begin{pmatrix} IRL_1 & IRL_{12} & IRL_{13} \\ IRL_{12} & IRL_2 & IRL_{23} \\ IRL_{13} & IRL_{23} & IRL_3 \end{pmatrix} = \begin{pmatrix} 9 & 1 & 0 \\ 1 & 9 & 7 \\ 0 & 7 & 9 \end{pmatrix}$$

SRL = IRL x TRL
(Normalized)

$$\text{Component SRL} = \begin{bmatrix} SRL_1 & SRL_2 & SRL_3 \end{bmatrix} = \begin{pmatrix} 0.54 & 0.43 & 0.59 \end{pmatrix}$$

Component SRL_x represents Technology “X” and its IRLs considered

$$\text{Composite SRL} = 1/3\ (0.54 + 0.43 + 0.59) = 0.52$$

The Composite SRL provides an overall assessment of the system readiness

Modeling Approach

Source: http://acqnotes.com/acqnote/acquisitions/major-defense-acquisition-program

SAR - Milestone Dates

Selected Acquisition Report (SAR)

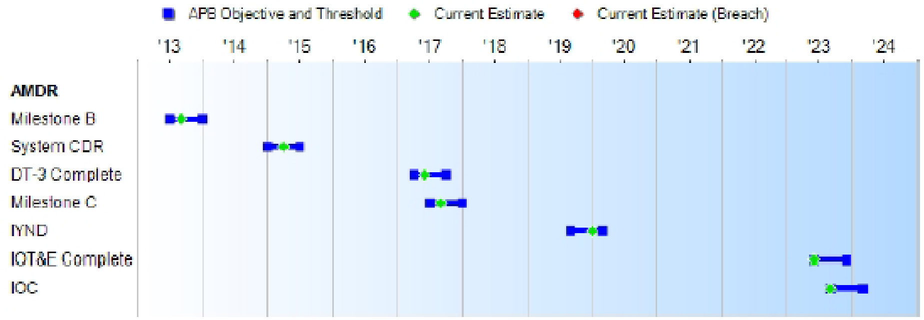
RCS: DD-A&T(Q&A)823-384

Air and Missile Defense Radar (AMDR)

As of FY 2015 President's Budget

Defense Acquisition Management
Information Retrieval
(DAMIR)

Schedule



Milestones	SAR Baseline Dev Est	Current APB Development Objective/Threshold		Current Estimate
Milestone B	JUL 2013	JUL 2013	JAN 2014	SEP 2013
System CDR	JAN 2015	JAN 2015	JUL 2015	APR 2015
DT-3 Complete	APR 2017	APR 2017	OCT 2017	JUN 2017
Milestone C	JUL 2017	JUL 2017	JAN 2018	SEP 2017
IYND	SEP 2019	SEP 2019	MAR 2020	JAN 2020
IOT&E Complete	JUN 2023	JUN 2023	DEC 2023	JUN 2023
IOC	SEP 2023	SEP 2023	MAR 2024	SEP 2023

SAR - Total Cost and Quantity

Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-384

Air and Missile Defense Radar (AMDR)

As of FY 2015 President's Budget

Defense Acquisition Management Information Retrieval (DAMIR)

Cost and Funding

Cost Summary

Total Acquisition Cost and Quantity

	BY2013 $M			BY2013 $M	TY $M		
Appropriation	SAR Baseline Dev Est	Current APB Development Objective/Threshold		Current Estimate	SAR Baseline Dev Est	Current APB Development Objective	Current Estimate
RDT&E	1860.0	1860.0	2046.0	1711.2	1911.1	1911.1	1761.4
Procurement	3846.9	3846.9	4231.6	3290.8	4724.0	4724.0	4043.8
Flyaway	--	--	--	2672.0	--	--	3286.2
Recurring	--	--	--	2654.0	--	--	3266.2
Non Recurring	--	--	--	18.0	--	--	20.0
Support	--	--	--	618.8	--	--	757.6
Other Support	--	--	--	521.9	--	--	638.3
Initial Spares	--	--	--	96.9	--	--	119.3
MILCON	28.8	28.8	31.7	28.6	27.5	27.5	27.5
Acq O&M	0.0	0.0	--	0.0	0.0	0.0	0.0
Total	5735.7	5735.7	N/A	5030.6	6662.6	6662.6	5832.7

Confidence Level for Current APB Cost 50% -

Based on the AMDR Independent Cost Estimate (ICE) prepared for the Milestone B Defense Acquisition Board (DAB) review (memo dated May 29, 2013), it is about equally likely that the estimate will prove too low or too high.

Quantity	SAR Baseline Dev Est	Current APB Development	Current Estimate
RDT&E	0	0	0
Procurement	22	22	22
Total	22	22	22

SAR - Annual Funding

Selected Acquisition Report (SAR)

RCS: DD-A&T(Q&A)823-384

Air and Missile Defense Radar (AMDR)

As of FY 2015 President's Budget

Defense Acquisition Management Information Retrieval (DAMIR)

Cost and Funding

Annual Funding By Appropriation

Annual Funding TY$

1319 | RDT&E | Research, Development, Test, and Evaluation, Navy

Fiscal Year	Quantity	End Item Recurring Flyaway TY $M	Non End Item Recurring Flyaway TY $M	Non Recurring Flyaway TY $M	Total Flyaway TY $M	Total Support TY $M	Total Program TY $M
2006	--	--	--	--	--	--	10.9
2007	--	--	--	--	--	--	35.3
2008	--	--	--	--	--	--	92.9
2009	--	--	--	--	--	--	92.5
2010	--	--	--	--	--	--	164.9
2011	--	--	--	--	--	--	204.2
2012	--	--	--	--	--	--	138.8
2013	--	--	--	--	--	--	193.9
2014	--	--	--	--	--	--	125.1
2015	--	--	--	--	--	--	144.7
2016	--	--	--	--	--	--	247.3
2017	--	--	--	--	--	--	100.4
2018	--	--	--	--	--	--	43.1
2019	--	--	--	--	--	--	41.3
2020	--	--	--	--	--	--	32.3
2021	--	--	--	--	--	--	30.5
2022	--	--	--	--	--	--	32.9
2023	--	--	--	--	--	--	30.4
Subtotal	--	--	--	--	--	--	**1761.4**

Data Extraction Process

Process: SARs Extraction and Conversion to txt → Python Code for Data Extraction → CSV Dump → On Going Processing

SARs Extraction and Conversion to txt
- 504 SAR Reports for DoD MDAP ACAT-1 programs
- >50% are duplicates since SARs are updated yearly for active programs

Python Code for Data Extraction
- createObject.py
- inflation.py
- main.py
- rdteSpendingProfile.py

CSV Dump
- Program name
- RDTE and Proc $$
- Base Year
- RDTE units
- Procurement Units
- Unit Flyaway
- MS-B, MS-C, IOC dates
- RDTE yearly spending

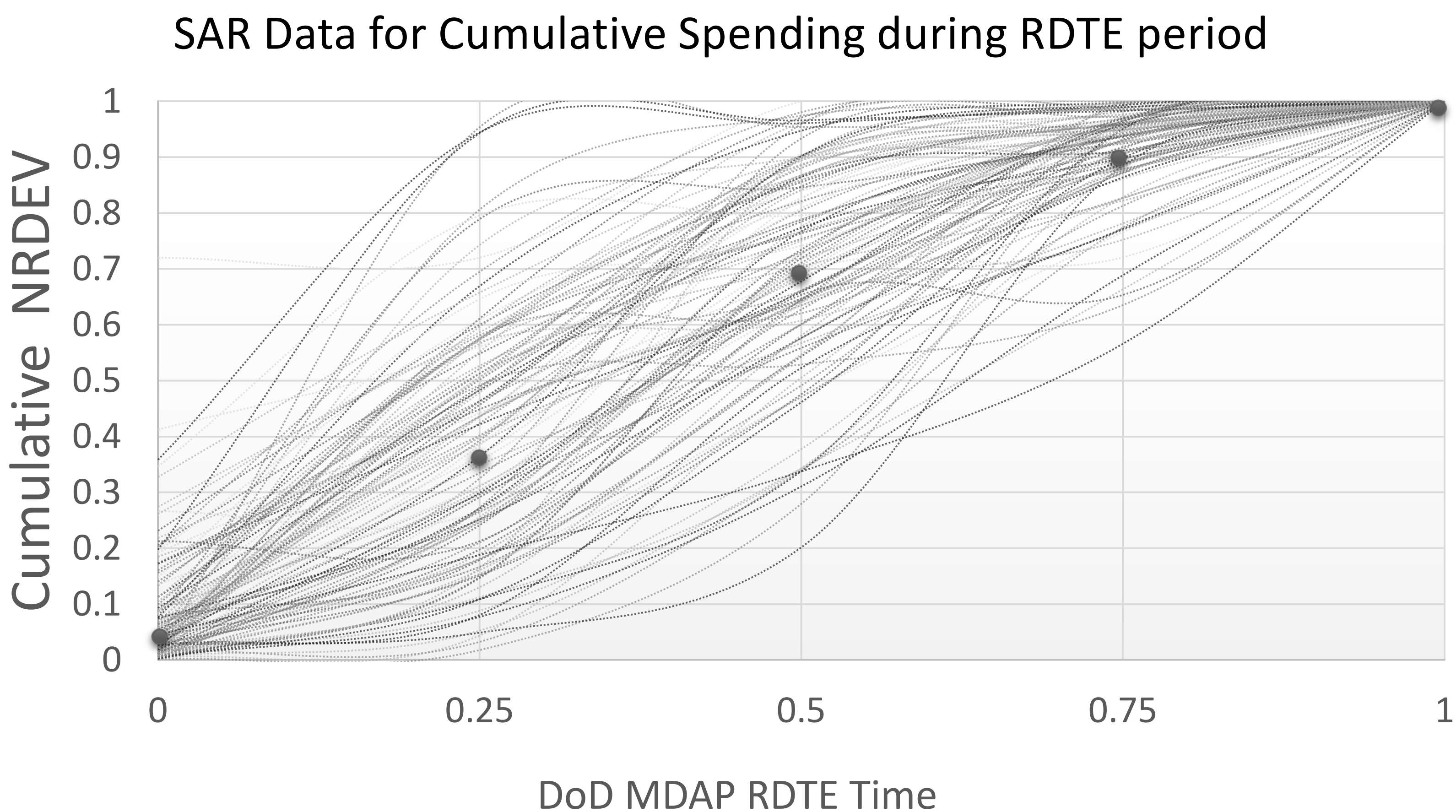
+

On Going Processing
- Milestone Duration (mos)
- Milestone Spending (FY2016)

↓

- allPrograms_
- goodProgra
- spendingPro

SAR Data Extraction and Normalization

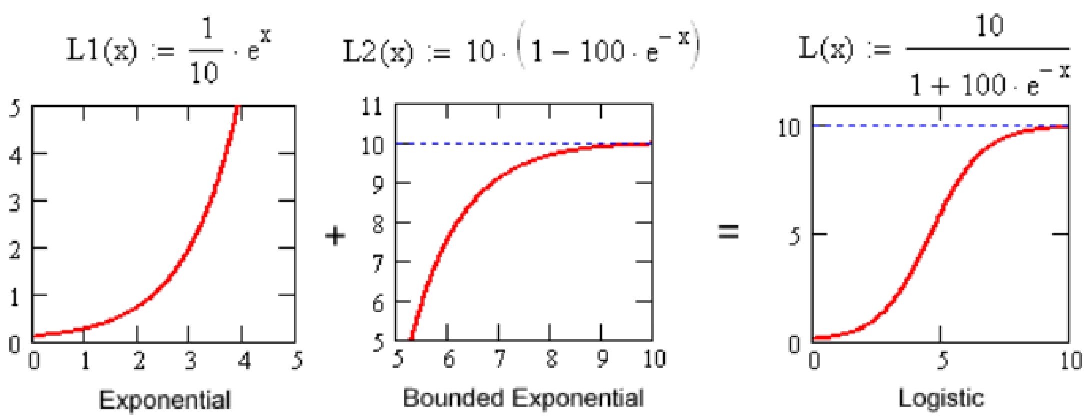


Logistic Function

$$f(x) = \frac{L}{1 + e^{-k(x-x_0)}}$$

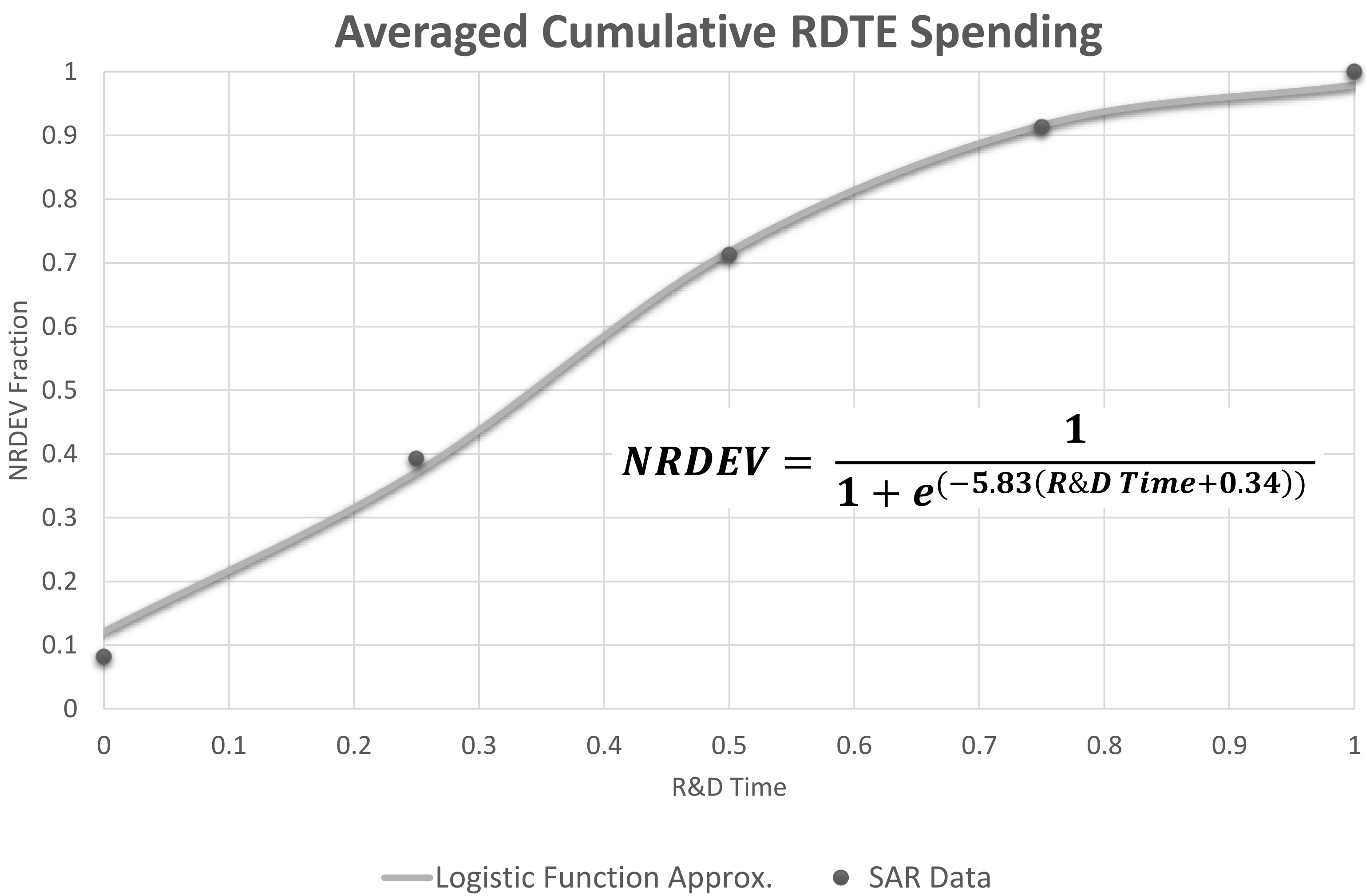
where

- e = the natural logarithm base (also known as Euler's number),
- x_0 = the x-value of the sigmoid's midpoint,
- L = the curve's maximum value, and
- k = the steepness of the curve.[1]

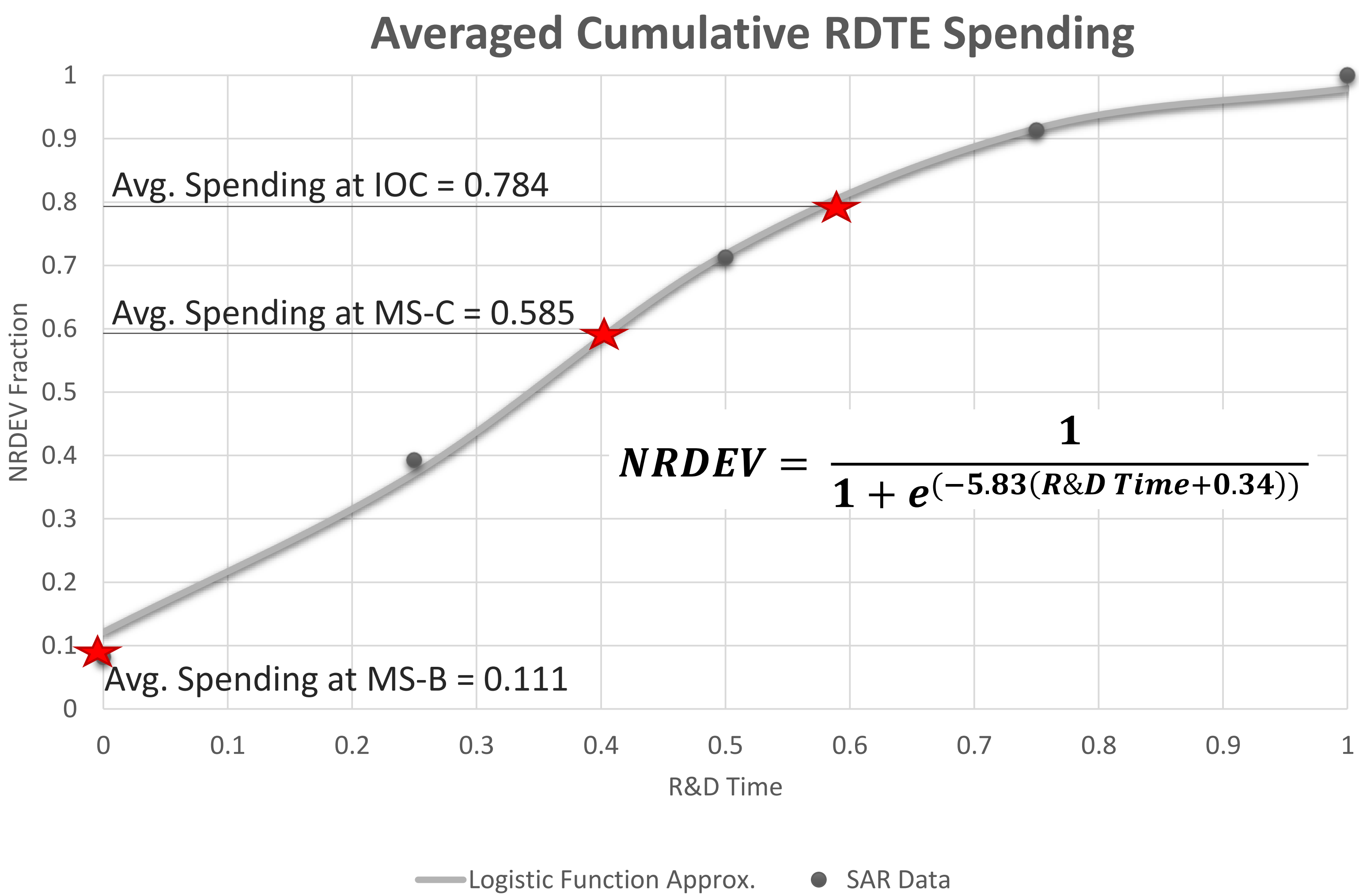


[Ref.5,6]

Logistic Function Approximation



Average RDTE Spending Over Time

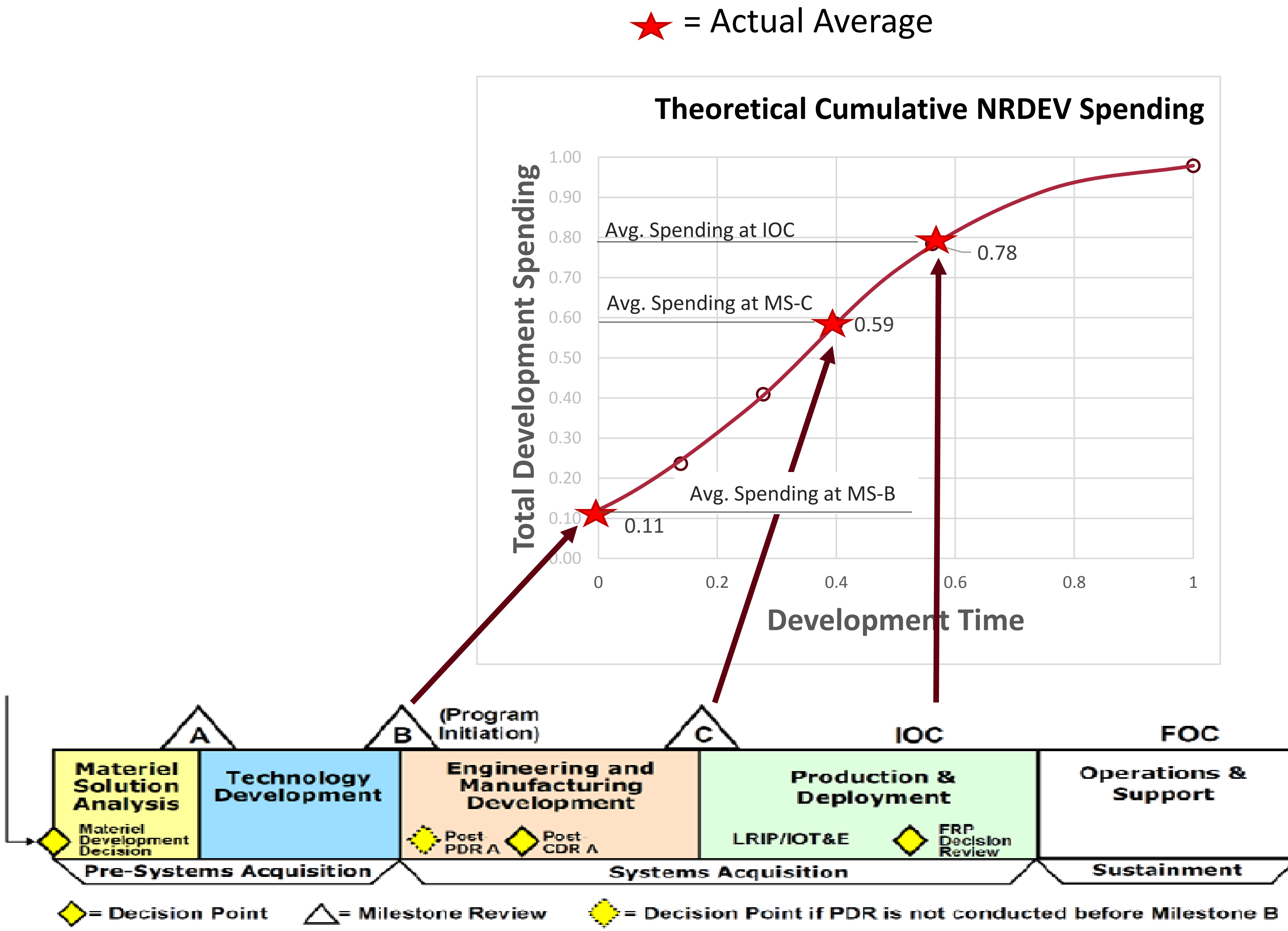


Mapping of TRL and SRL to DoD Event

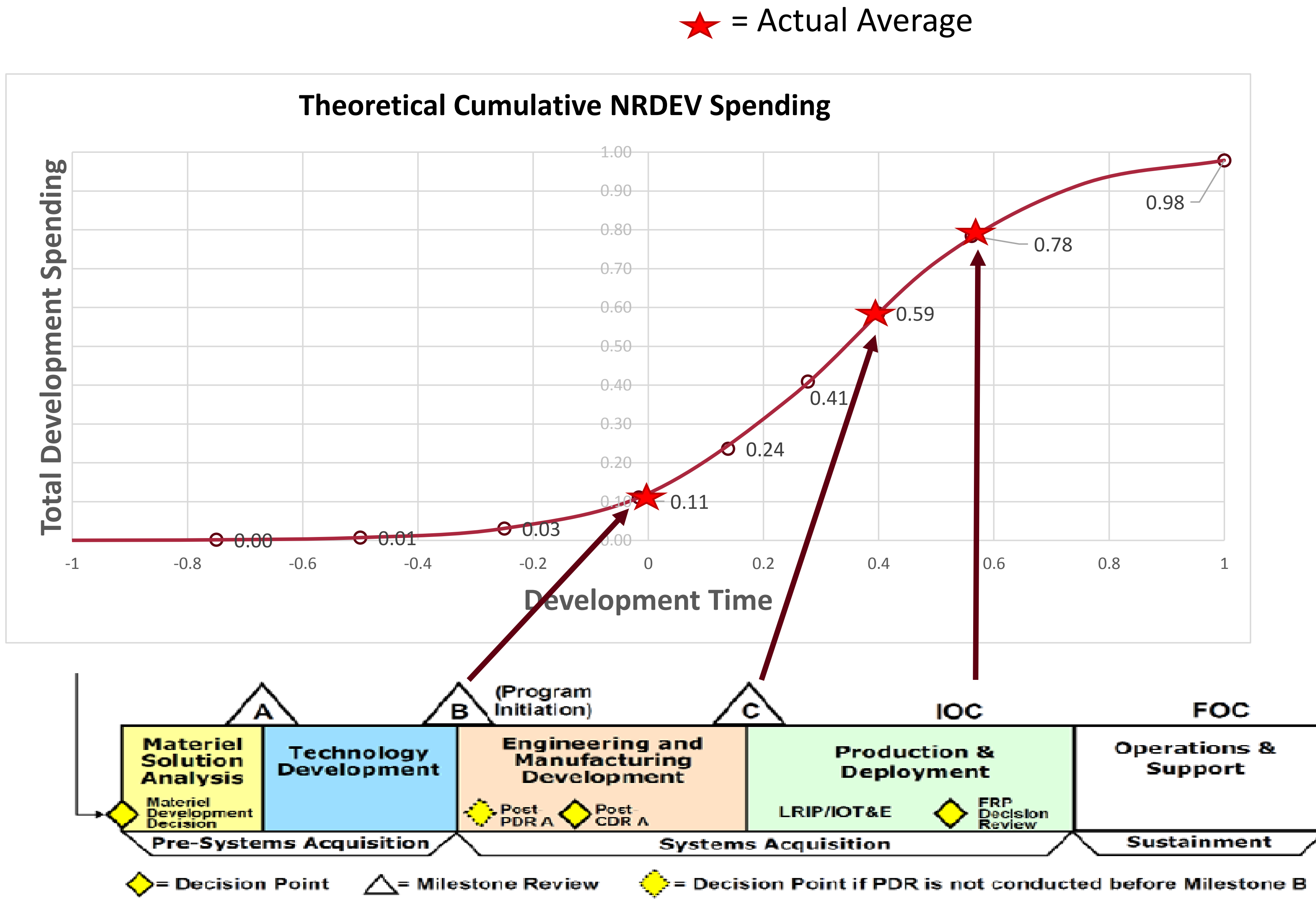
SRL	TRL	DoD Event
0.5	4	MS-B (Milestone B, Contract Award)
0.6	5	PDR (Preliminary Design Review)
0.7	6	CDR (Critical Design Review)
0.8	7	LRIP (Low Rate Initial Production) or MS-C
0.9	8	IOC (Initial Operational Capability)
1	9	FOC (Full Operational Capability)

[Ref.7]

Theoretical Correlation

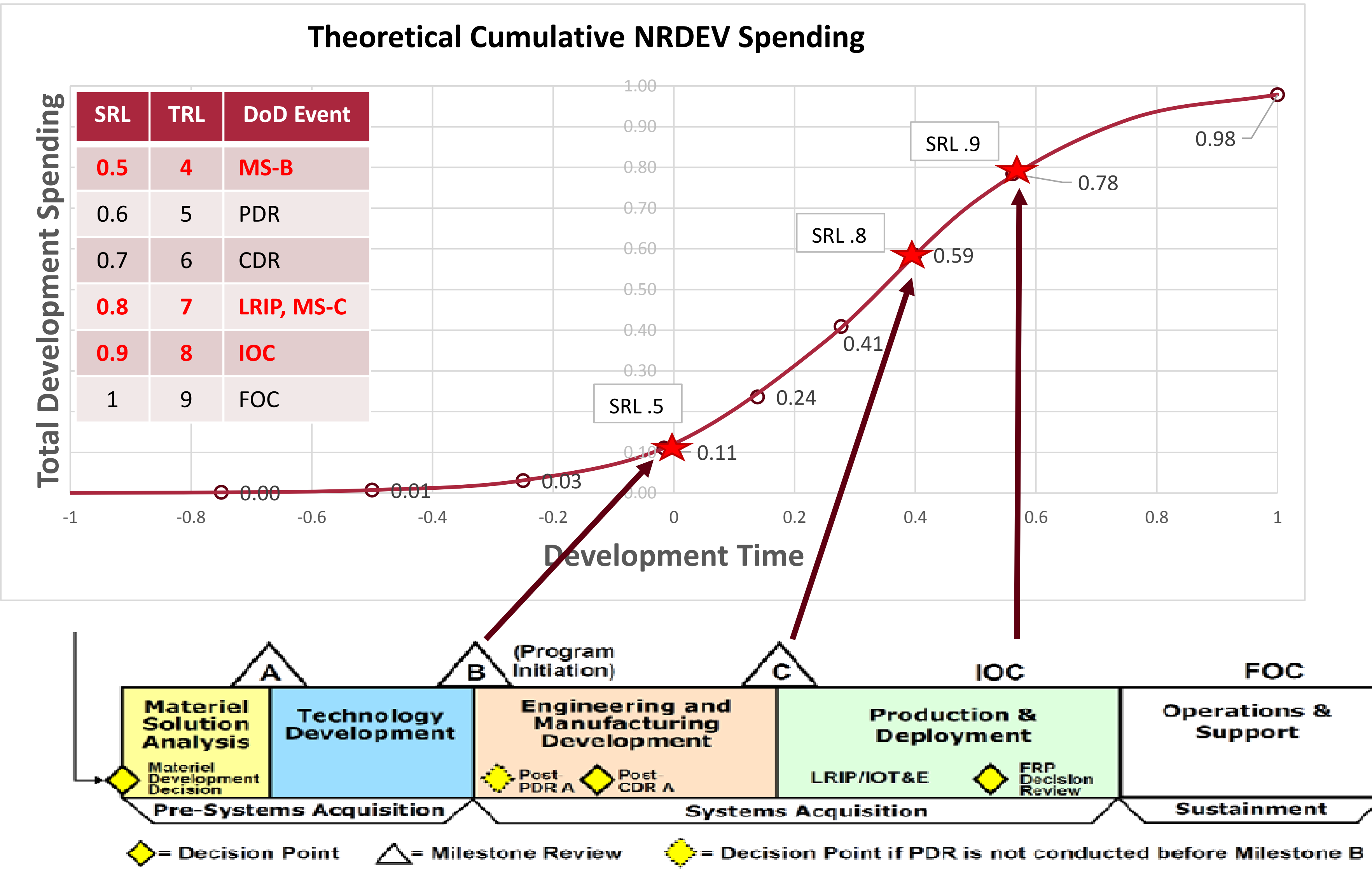


Theoretical Correlation



Theoretical Correlation

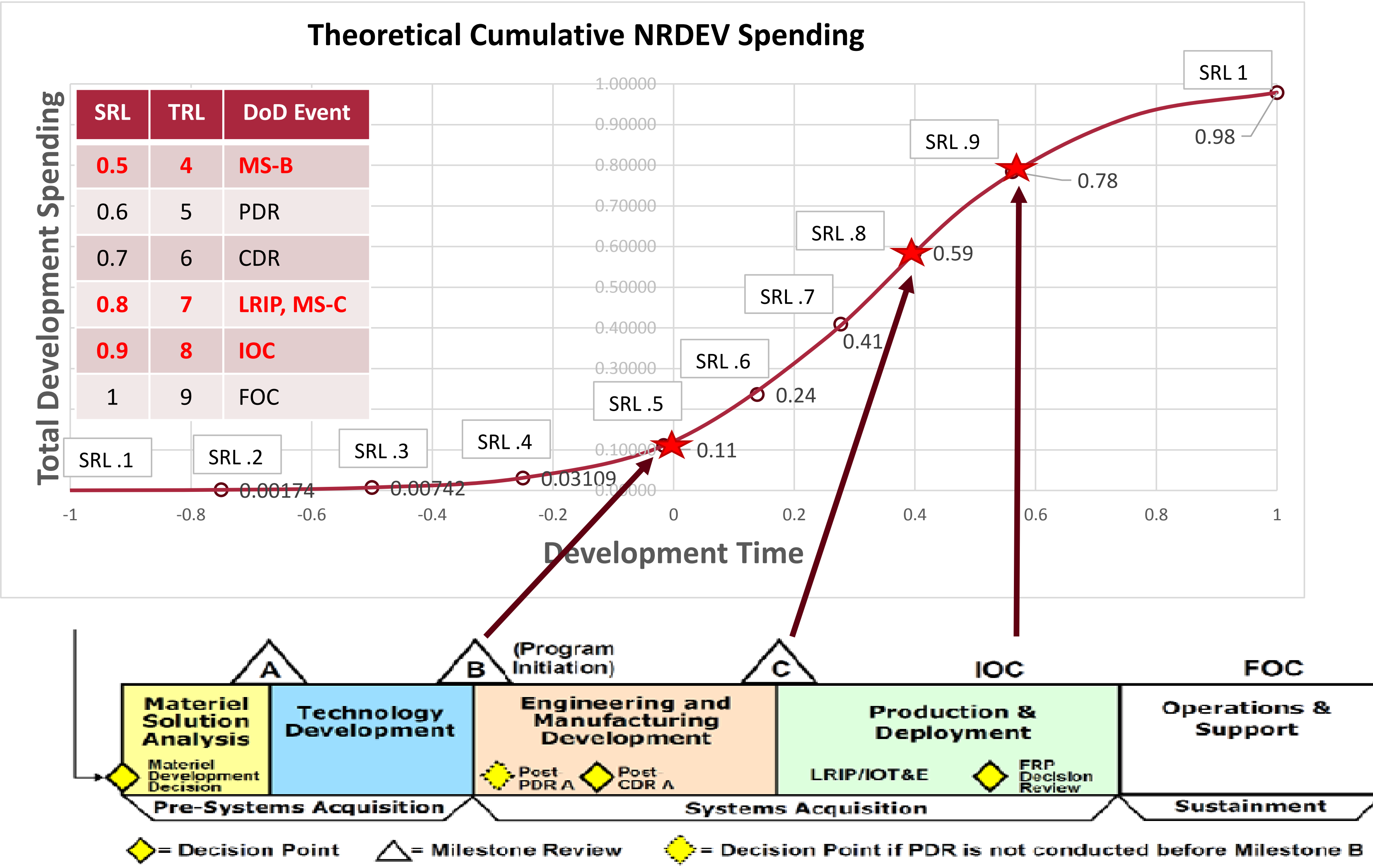
★ = Actual Average



SRL	TRL	DoD Event
0.5	**4**	**MS-B**
0.6	5	PDR
0.7	6	CDR
0.8	**7**	**LRIP, MS-C**
0.9	**8**	**IOC**
1	9	FOC

Theoretical Correlation

★ = Actual Average



SRL	TRL	DoD Event
0.5	**4**	**MS-B**
0.6	5	PDR
0.7	6	CDR
0.8	**7**	**LRIP, MS-C**
0.9	**8**	**IOC**
1	9	FOC

Preliminary Result

Cost and schedule factors to move one increment based on the previous increment

TRL	SRL	Schedule Factor	Cost Factor
0-1	0.1-0.2	1.25	4.29
1-2	0.2-0.3	1.20	4.27
2-3	0.3-0.4	1.17	4.19
3-4	0.4-0.5	1.13	3.58
4-5	0.5-0.6	1.08	2.12
5-6	0.6-0.7	1.06	1.73
6-7	0.7-0.8	1.05	1.43
7-8	0.8-0.9	1.07	1.34
8-9	0.9-1.0	1.17	1.25

Example: If the program cost $1M to go from SRL 0.5 to 0.6,

it will cost another $1.73M to achieve SRL 0.7

it will cost another $4.14M to achieve FOC

Implementation: Excel Prototype

Excel Prototype

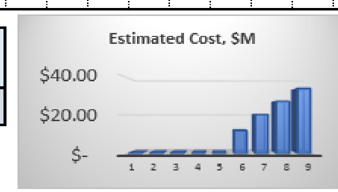
- The tool lets user assess the impact of critical technologies on SRL
- It allows up to 20 critical technology elements to be assessed
  - With an NxN matrix defining their interaction
- The top level SRL or Equivalent TRL (eTRL) is then used to calculate the cost and schedule breakdown for each TRL progression
- Two outputs are generated for TP:
  - Engineering Complexity for HW object
  - System Complexity for Assembly object

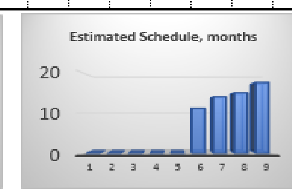
Excel Prototype

Critical Technology Assessment

	Description	Weight (lb)	MCplx	TRL	IRL																			
1.0	Assembly/HW				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1.1	Tech/Component 1	1	1	9	9	1	0																	
1.2	Tech/Component 2	1	1	6		9	7																	
1.3	Tech/Component 3	1	1	6			9																	
1.4	Tech/Component 4																							
1.5	Tech/Component 5																							
1.6	Tech/Component 6																							
1.7	Tech/Component 7																							
1.8	Tech/Component 8																							
1.9	Tech/Component 9																							
1.10	Tech/Component 10																							
1.11	Tech/Component 11																							
1.12	Tech/Component 12																							
1.13	Tech/Component 13																							
1.14	Tech/Component 14																							
1.15	Tech/Component 15																							
1.16	Tech/Component 16																							
1.17	Tech/Component 17																							
1.18	Tech/Component 18																							
1.19	Tech/Component 19																							
1.20	Tech/Component 20																							

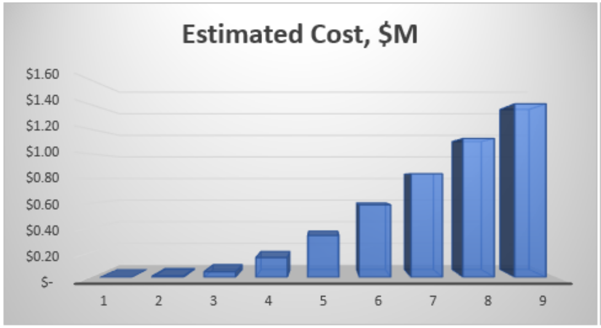
Engineering Cplx For HW Obj	System Cplx For Assembly Obj	SRL	Equiv. TRL (eTRL)	Est. Cost $M	Est. Schedule (mo)
0.85	21.19	0.52	5.16	$ 93.10	58

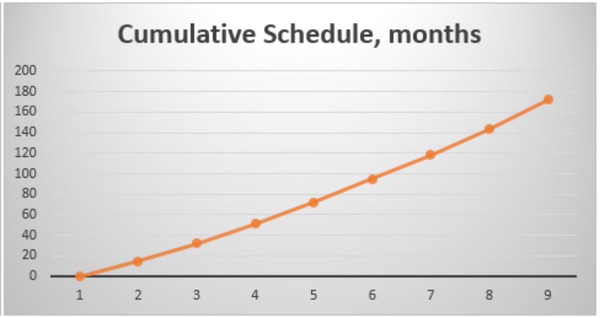




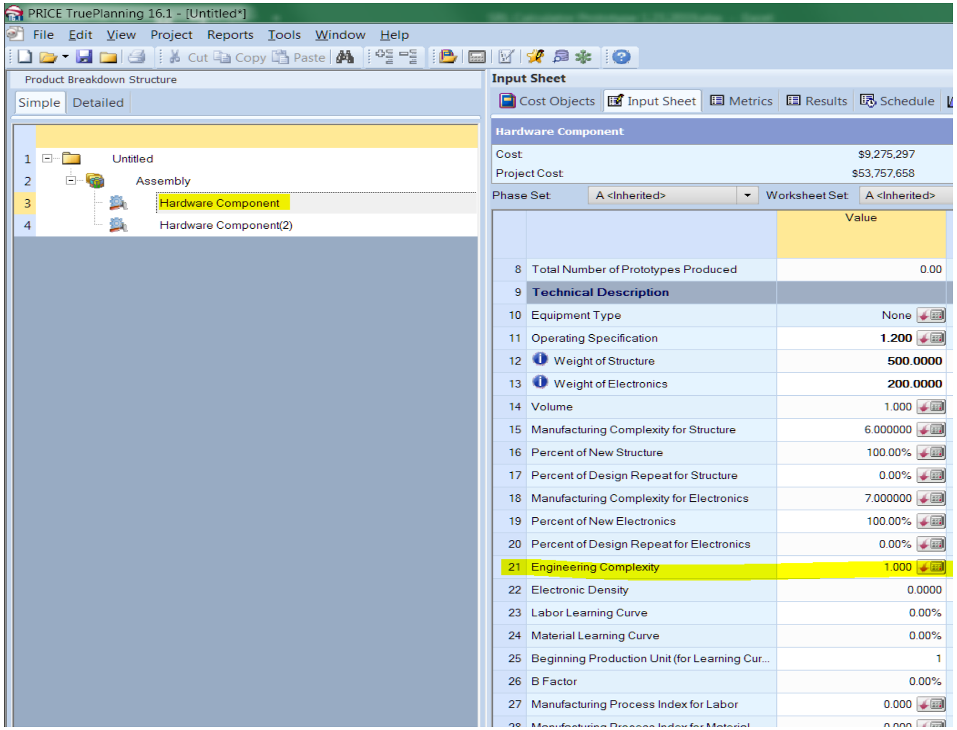
Excel Prototype

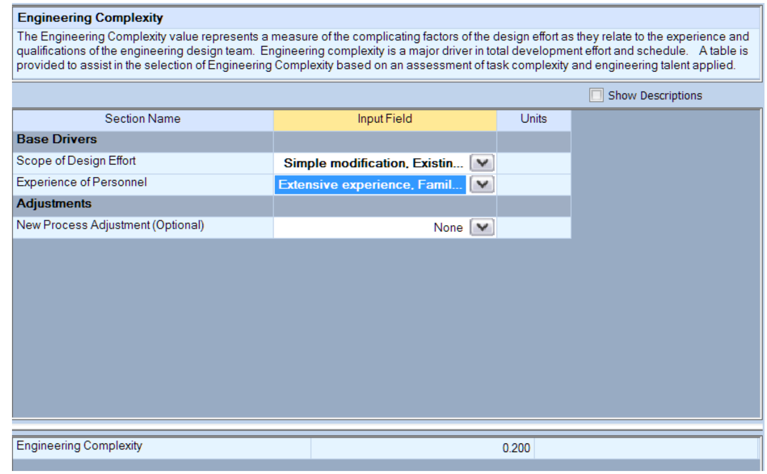
	Starting TRL/eTRL	Ending TRL/eTRL	Estimated Cost ($M)	Estimated Schedule (mo)
BASELINE ESTIMATE (USER REQUIRED INPUT)	**5**	**9**	**$ 1.00**	**100**
SCENARIO-BASED ESTIMATE	1.00	9.00	$ 4.51	172
ESTIMATE BREAKDOWN	0	1	$ -	0
	1	2	$ 0.01	15
	2	3	$ 0.04	17
	3	4	$ 0.16	19
	4	5	$ 0.34	21
	5	6	$ 0.59	22
	6	7	$ 0.84	23
	7	8	$ 1.12	25
	8	9	$ 1.41	29
CUMULATIVE	1	1	$ -	0
	1	2	$ 0.01	15
	1	3	$ 0.06	32
	1	4	$ 0.22	51
	1	5	$ 0.55	72
	1	6	$ 1.14	95
	1	7	$ 1.98	118
	1	8	$ 3.10	143
	1	9	$ 4.51	172

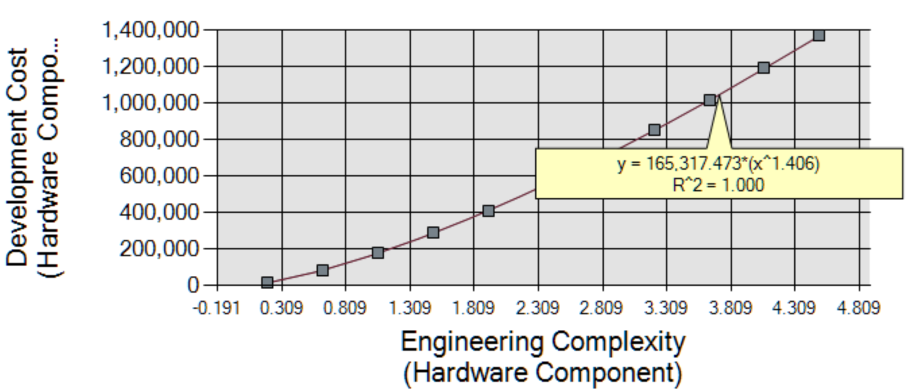


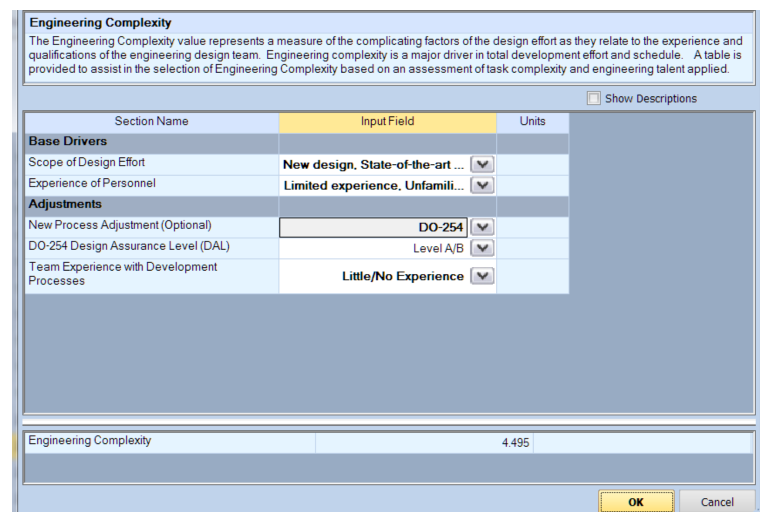


Engineering Complexity Input for HW Obj

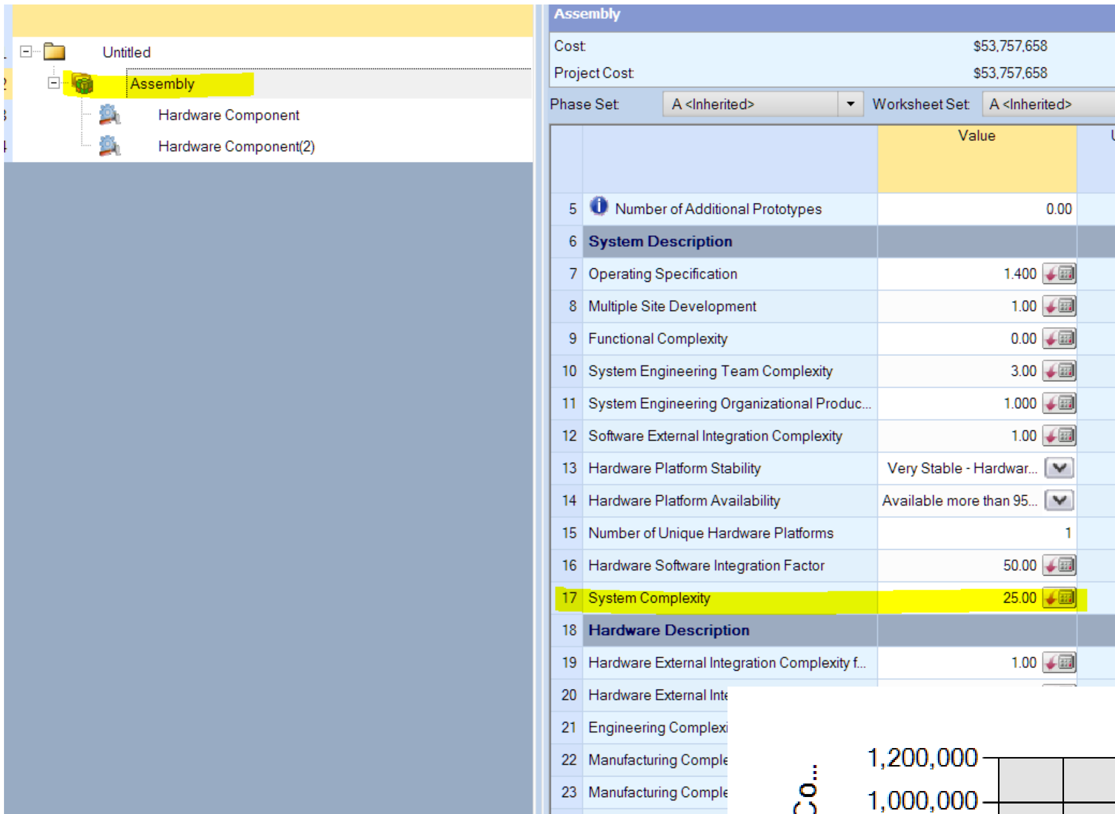


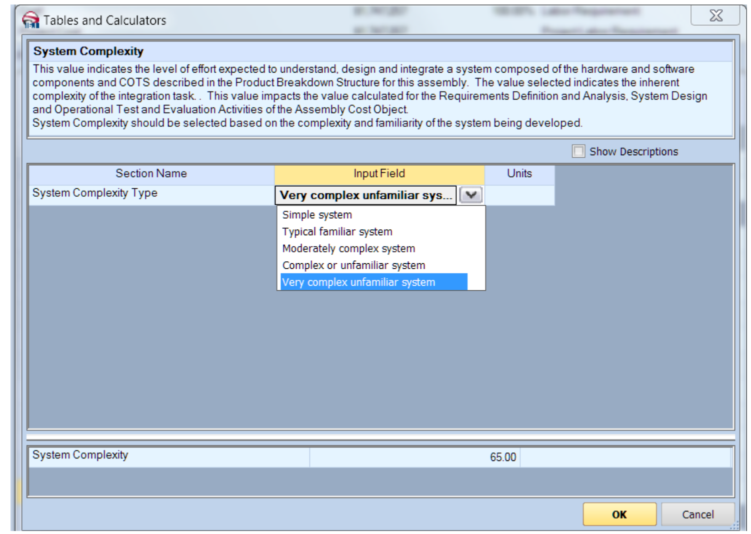


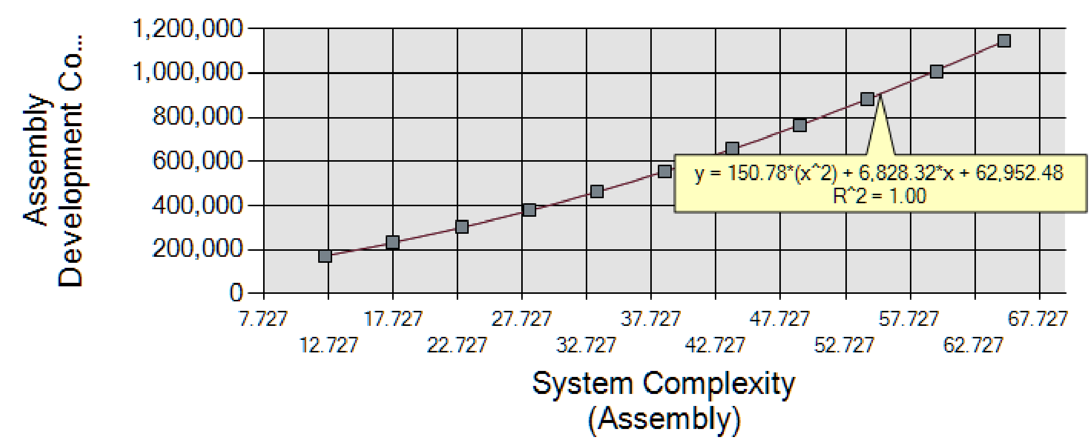




System Complexity Input for Assembly Obj



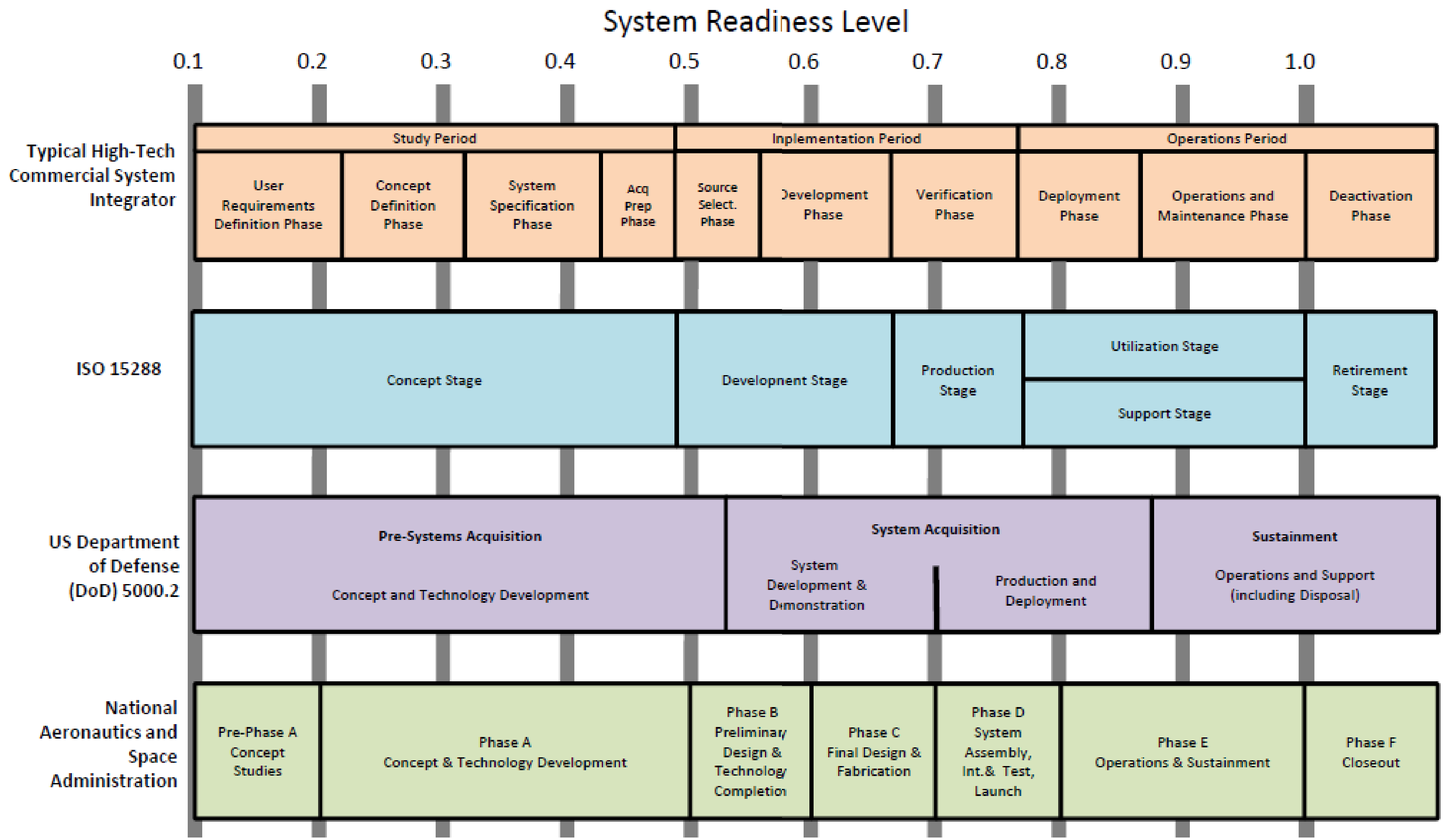




References

1. Sauser, B., Ramirez-Marquez, J., Nowicki, D., Deshmukh, A., and Sarfaraz, M., “Development of systems engineering maturity models and management tools”, Final Technical Report 2011-TR-014, 2011.
2. Dr. R. Smoker, Dr. D. Armon, “An integrated approach to managing technology maturation costs”, NDIA 13th Annual Systems Engineering Conference, October 28, 2010.
3. NDIA 13th Annual Systems Engineering Conference Technology Maturity Session October 28, 2010.
4. The Concept of Systems Readiness Levels, Conference on Systems Engineering Research, Los Angeles, CA, April 2006.
5. https://en.wikipedia.org/wiki/Logistic_function
6. http://wmueller.com/precalculus/families/1_80.html
7. Adapted from Sauser, B., Ramirez-Marquez, J., “Development of Systems Engineering Maturity Models and Management Tools, Final Technical Report 2011-TR-014

Mapping of SRL to Development Processes



Proposed by Brian J. Sauser, Ph.D., Stevens Institute of Technology, School of Systems and Enterprise

Summary of Work

- SRL calculation framework to complement existing TRA*
- Mapping of SRL to DoD Milestones*
- SAR data are extracted for cost and schedule data
- Math model representing normalized, non-linear behavior of SRL/TRL progression (cost and time) is proposed

*Methodology proposed by Brian J. Sauser, Ph.D., Stevens Institute of Technology, School of Systems and Enterprise

Dr. Nate Sirirojvisuth

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Dr. Nate is a cost research analyst at PRICE Systems. His work focuses on applied mathematics and data collection techniques to develop data-driven, product-centric costing solutions. He also has expertise in concurrent engineering and advanced system design methods in aerospace industry. He received his PhD in Aerospace Engineering from Georgia Tech. His passion is to search for ways to address various affordability issues in the design and development of complex system through data analytic and modeling techniques.

Contact: nate.sirirojvisuth@pricesystems.com | (404) 455-2717