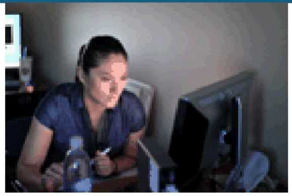
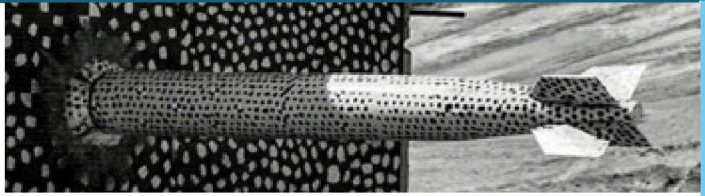
SAND2019-9127C

An Introduction to Sandia National Laboratories Cost Products to Advance Collaboration





CECOP
Cost Estimating Community of Practice

PRESENTED BY

Jonell N. Samberson, PhD

Cost Estimating Community of Practice Symposium

Lawrence Livermore National Laboratory

August 6-7, 2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SJN11

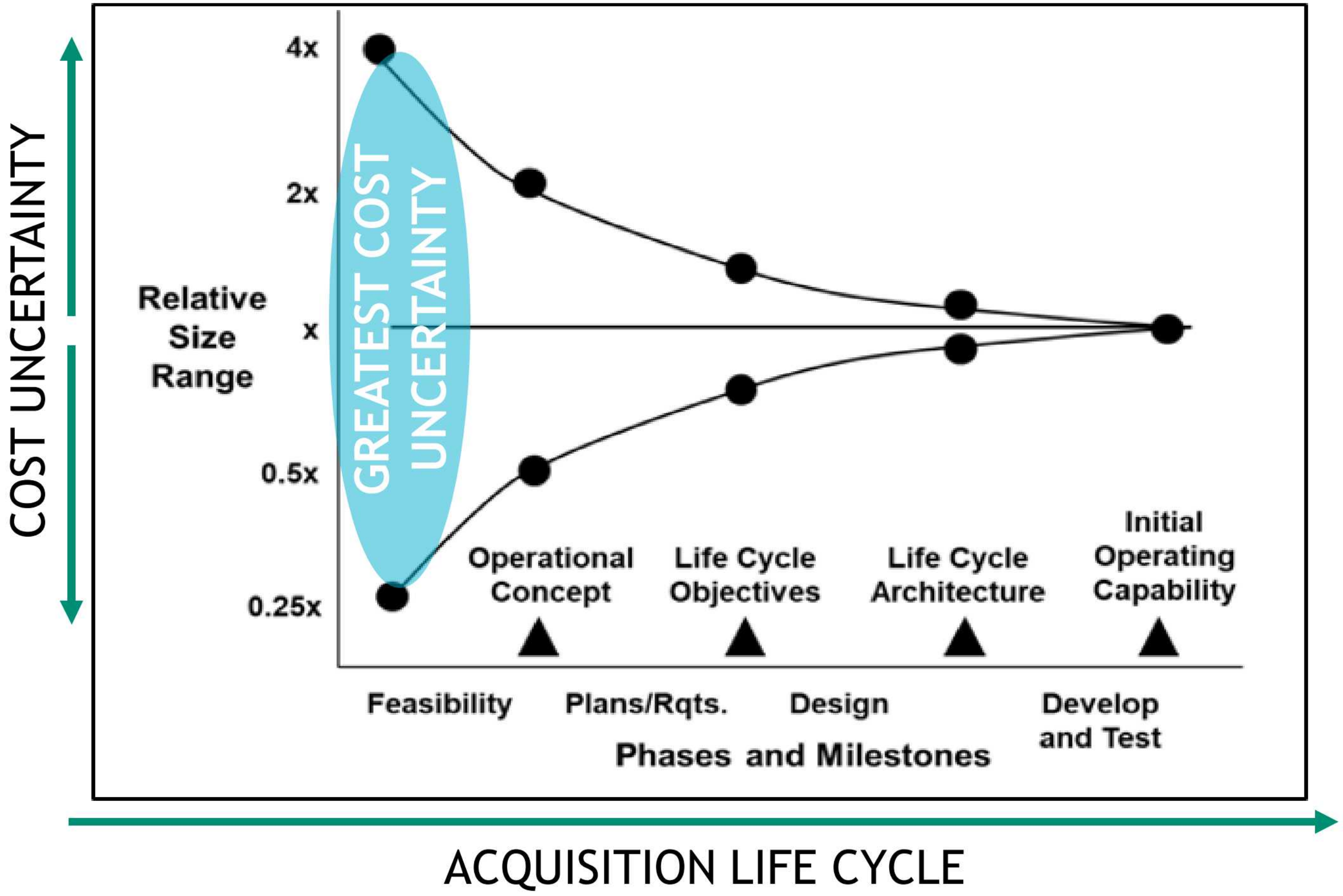
SAND2019-6388-C

Slide 1

SJN11 UPDATE: SAND Number

Samberson, Jonell Nicole, 7/31/2019

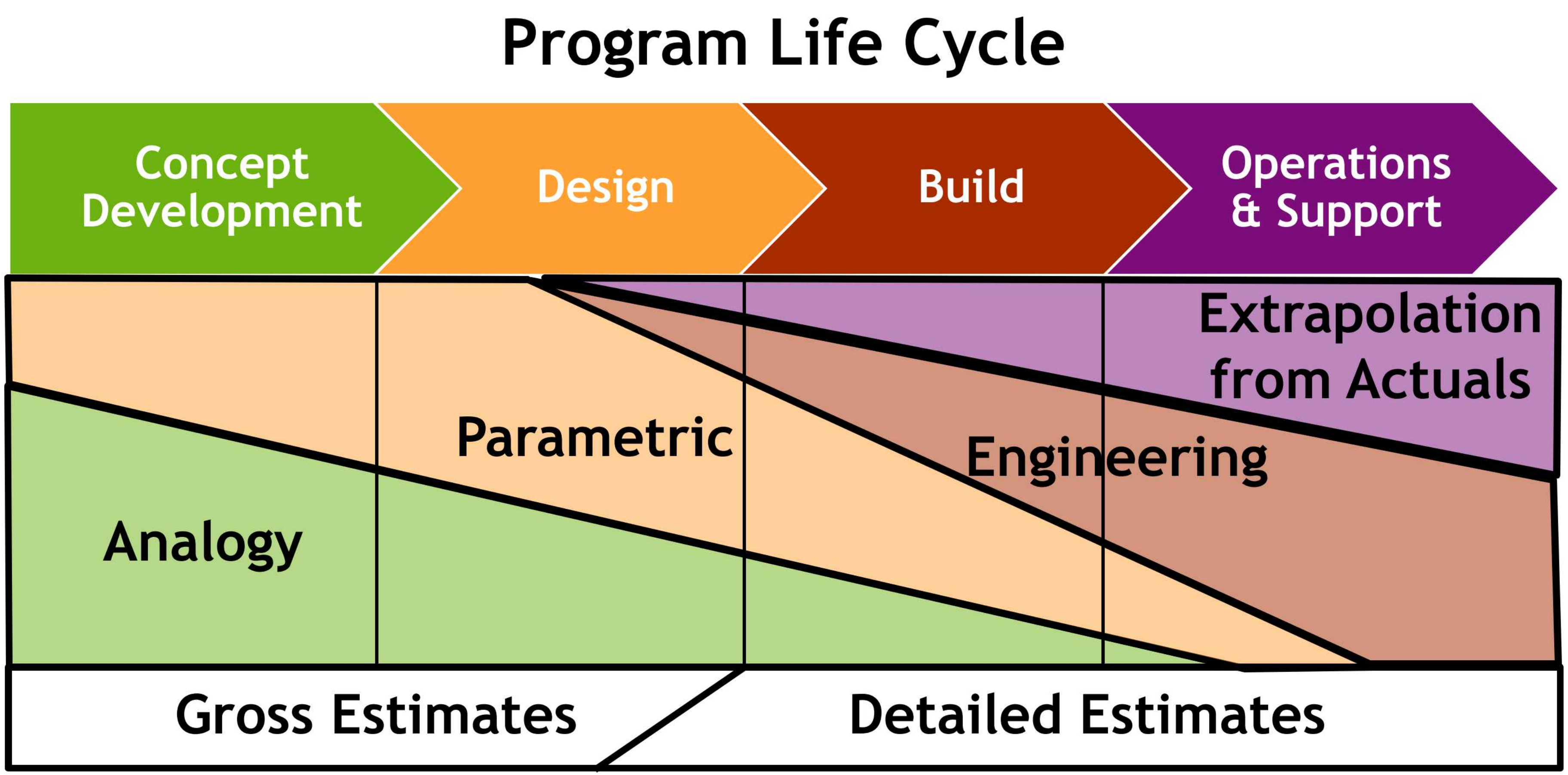
Cost Uncertainty Decreases as Program Maturity Increases



Greatest cost uncertainty exists early on in the acquisition life cycle

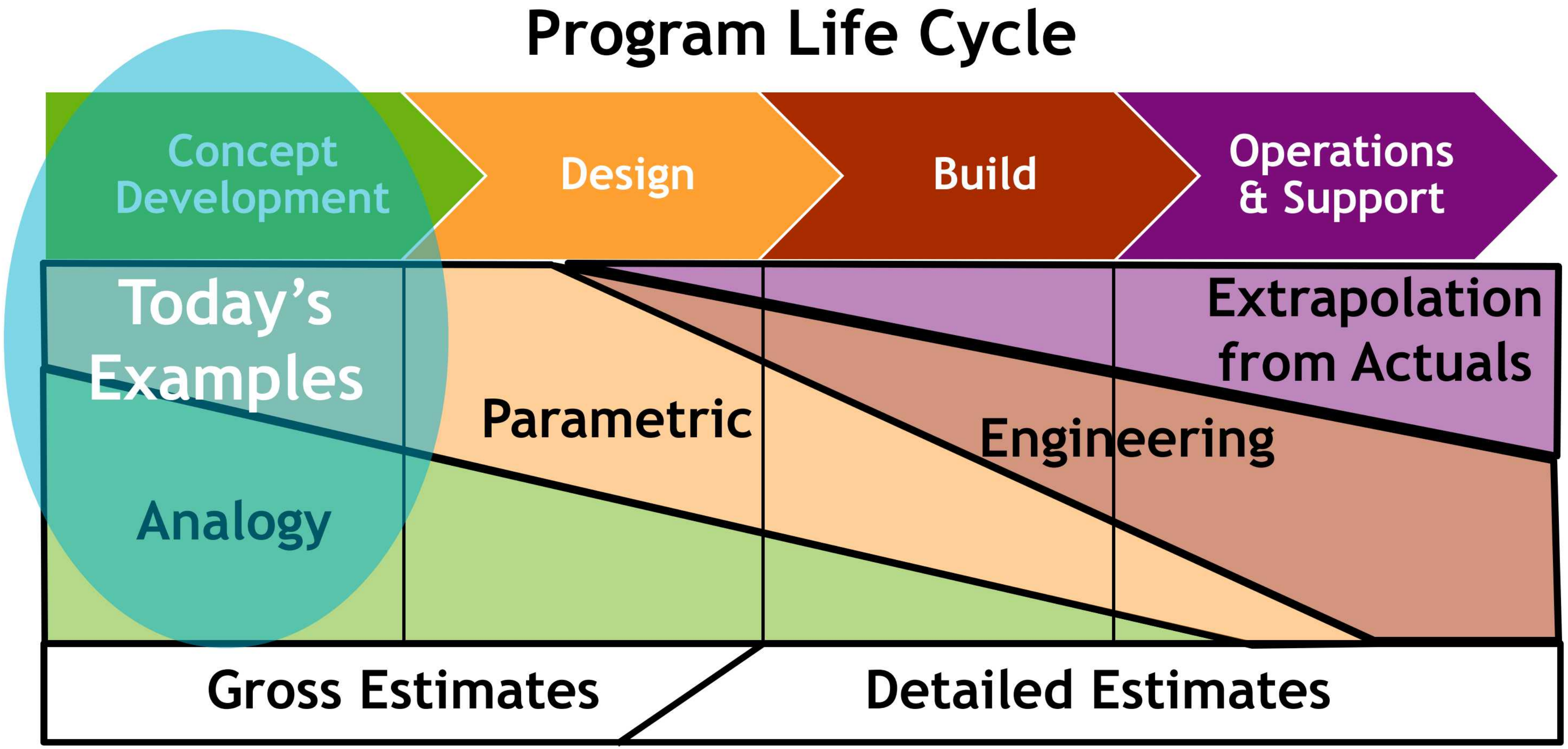
Boehm, B. W., Software Engineering Economics, Prentice Hall, 1981

Multiple Estimating Techniques can be Applied Throughout the Life Cycle



Modified: Defense Acquisition University, "Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework chart (v5.2)," 2008, as reproduced in the International Cost Estimating and Analysis Association's "Cost Estimating Body of Knowledge Module 2."

Today's Examples will Focus on the Concept Development Phase



Modified: Defense Acquisition University, "Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework chart (v5.2)," 2008, as reproduced in the International Cost Estimating and Analysis Association's "Cost Estimating Body of Knowledge Module 2."

Nuclear Security Enterprise and SNL Cost Analysis Examples

Nuclear Security Enterprise Support:

- Stockpile Stewardship and Management Plan Releases (Six releases; August 2014 to Present)

Sandia National Labs Specific Support:

- W78/88-1 analysis (2014)
- Long Range Standoff (LRSO) options analysis (2014, 2015)
- W80-4 Federal Program Manager options analysis (May 2016)
- W80-4 complexity analysis (Nov 2015)
- Bus-based LDRD Grand Challenge (May 2017)
- W78 systems options (Aug 2017, Sept 2018)
- B61 Preflight Controller (Sept 2017)
- W80-4 Independent Cost Estimate (April 2018)
- W76-2 electronics component (June 2018, July 2019)
- Navy Missile Update (September 2018, est. September of each subsequent year)
- W87-1 Federal Program Manager options analysis (May 2019)

Nuclear Security Enterprise and SNL Cost Analysis Examples

Nuclear Security Enterprise Support:

1 → ◦ Stockpile Stewardship and Management Plan Releases (Six releases; August 2014 to Present)

Sandia National Labs Specific Support:

- W78/88-1 analysis (2014)
- Long Range Standoff (LRSO) options analysis (2014, 2015)
- W80-4 Federal Program Manager options analysis (May 2016)
- W80-4 complexity analysis (Nov 2015)
- Bus-based LDRD Grand Challenge (May 2017)
- 2 → W78 systems options (Aug 2017, Sept 2018)
- B61 Preflight Controller (Sept 2017)
- W80-4 Independent Cost Estimate (April 2018)
- W76-2 electronics component (June 2018, July 2019)
- 3 → Navy Missile Update (September 2018, est. September of each subsequent year)
- W87-1 Federal Program Manager options analysis (May 2019)

Nuclear Security Enterprise and SNL Cost Analysis Examples

Nuclear Security Enterprise Support:

1 → ◦ Stockpile Stewardship and Management Plan Releases (Six releases; August 2014 to Present)

Sandia National Labs Specific Support:

- W78/88-1 analysis (2014)
- Long Range Standoff (LRSO) options analysis (2014, 2015)
- W80-4 Federal Program Manager options analysis (May 2016)
- W80-4 complexity analysis (Nov 2015)
- Bus-based LDRD Grand Challenge (May 2017)
- 2 → W78 systems options (Aug 2017, Sept 2018)
- B61 Preflight Controller (Sept 2017)
- W80-4 Independent Cost Estimate (April 2018)
- W76-2 electronics component (June 2018, July 2019)
- 3 → Navy Missile Update (September 2018, est. September of each subsequent year)
- W87-1 Federal Program Manager options analysis (May 2019)

Background

National **N**uclear **S**ecurity **A**dministration (NNSA) has the unique challenge of developing and comparing strategic plans for weapon system development & production that span 25 plus years

A NNSA sponsored collaborative, multi-site analysis group, the **E**nterprise **M**odeling & **A**nalysis **C**onsortium (EMAC), developed and refined the process, tools, and approach NNSA needed

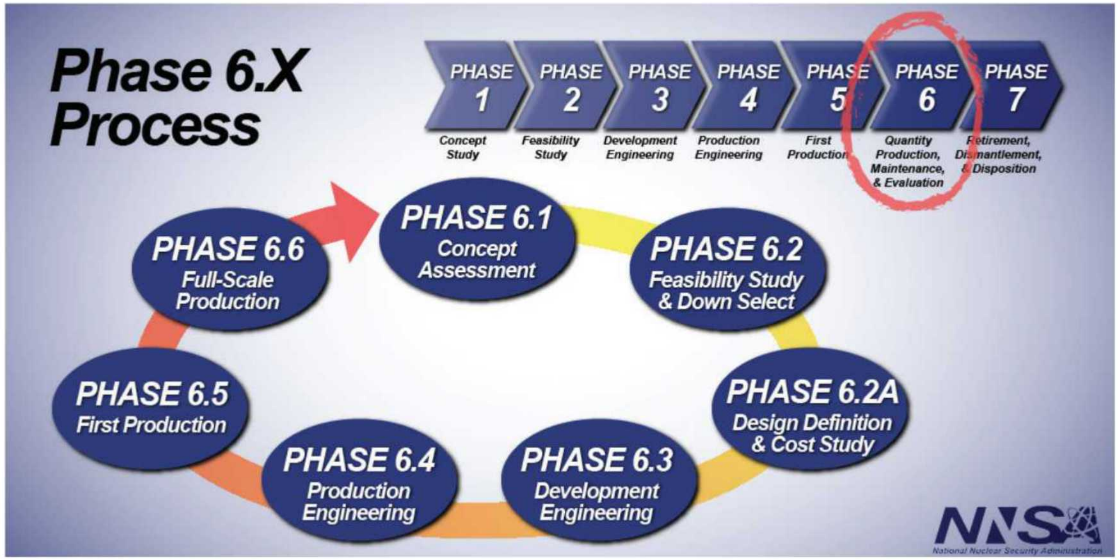
Scope, **C**omplexity, **O**ptions, **R**isks, **E**xcursions (**SCORE**) model and analysis process formed to support NNSA's early planning cost estimates

Lewis, F. D., et al (2016). Planning the Future: Methodologies for Estimating U.S. Nuclear Stockpile Cost. *Cost Engineering,58(5) pp. 6-12.*

SCORE Process Motivation

Improve the fidelity and repeatability of enterprise-level complexity analysis, including:

- Developing a common language to use across programs
- Ability to perform trade studies in order to understand the importance of work scope parameters
- Tool and process which include input from subject matter experts (SMEs)
- A systematic approach to capture work scope, complexity, and uncertainty
- Enable capture of full program scope with differentiation at the appropriate level of detail
- Standard output reports and charts that can be used by decision makers
- All phases and activities for warheads are considered



https://www.energy.gov/sites/prod/files/2018/06/f53/6x%20process.pdf

Traceable work scope definition & assumptions supported by a technical community of experts

Complexity Analysis Process Flow

Define System & Create Analysis Artifacts

Define the complex system(s)

Identify elements of the systems

Gather available historical work scope and cost data at the appropriate level

Review and group the elements according to the discovered data

Define System & Create Analysis Artifacts

Common analysis and reference terms across all documents and communications

Analysis Artifacts

1. ***WBS Code & Element Mapping***
2. ***Reference Cost Data***
3. ***Model Input Files***
4. ***Design Definitions***
5. ***Complexity Estimates***
6. ***Assumptions***

WBS Code	Element Name	Reference System	Phase	Design Choices					
				New Design			Reuse Design		
				Low	Mode	High	Low	Mode	High
1.X.5.1	Widget 1	System Alpha	SE&I	110	120	180	90	100	110
			T&Q	110	120	140	90	100	110
			PD	100	110	120	60	70	80
			Prod	100	110	120	60	70	80

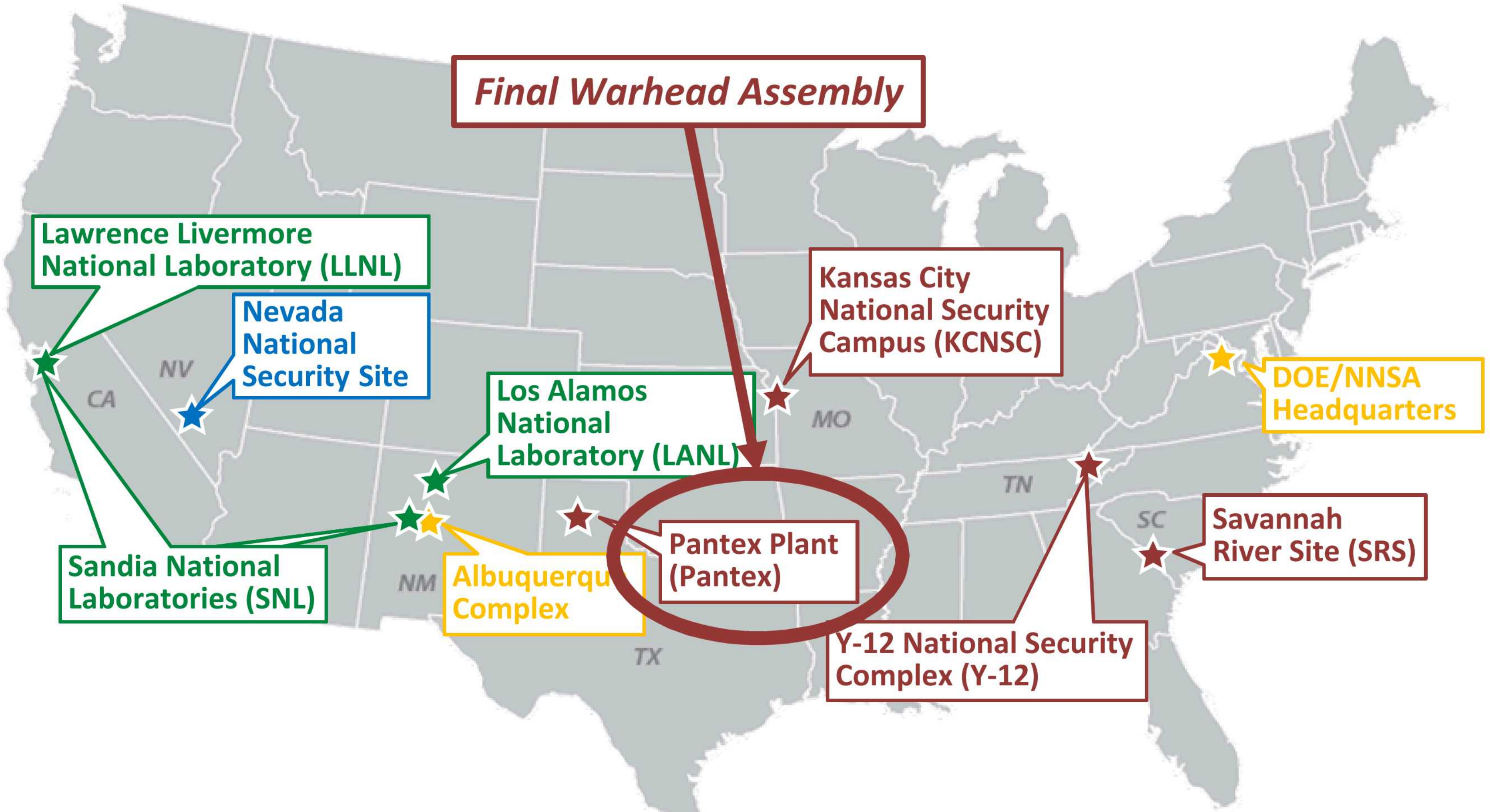
SE&I: Systems Engineering and Integration | T&Q Test and Qualification | PD: Process Development | Prod: Production

WBS Code	Element Name
1.X.1	Systems Engineering and Integration
1.X.2	Systems Test and Qualification
1.X.3	Systems Production
1.X.4	Nuclear Components
1.X.4.1	Component A
1.X.4.2	Component B
1.X.5	Non-Nuclear Components
1.X.5.1	Widget 1

Element Name	Work Scope	Phase	New Design		
			Low	Mode	High
Widget 1	Design requires one additional type A electrical connection	SE&I	Minimal challenges	Some challenges	Major challenges

Complexity Analysis Process Flow

Technical Evaluation of Analysis Artifacts with Subject Matter Experts



★ Headquarters

★ National Security Laboratories

★ National Security Site

★ Nuclear Weapons Production Facilities

~50 people over one week for the NNSA analysis session

https://www.energy.gov/sites/prod/files/2018/10/f57/FY2019%20SSMP.pdf

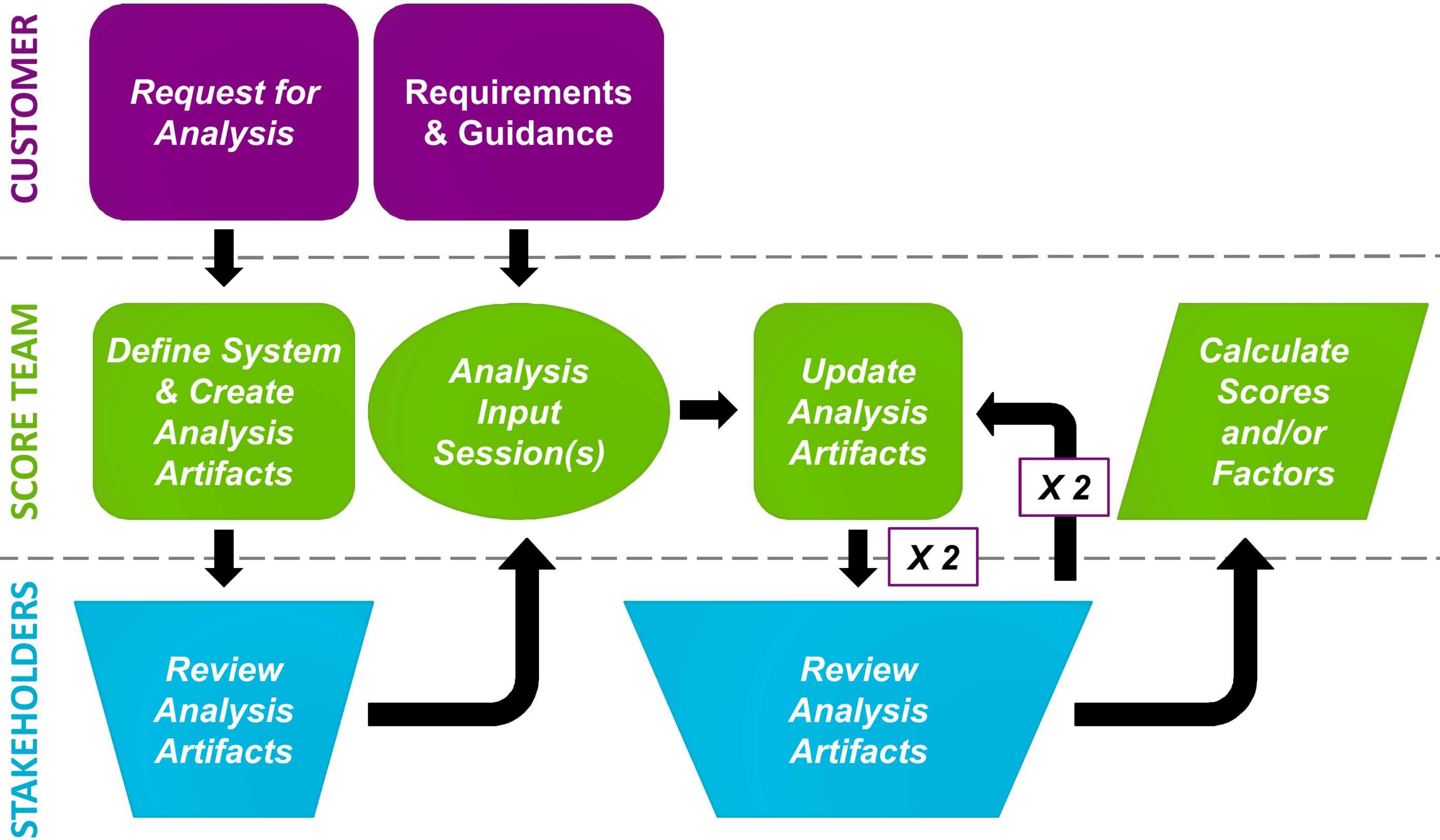
Common Analysis & Reference Terms

Relative Level of Scope	Design Agency Term	Design Agency Description	Production Agency Term	Production Agency Description
High	**New**	To create a **different** design • Implies ***major*** design requirements and/or specification changes and qualification efforts	**Manufacture** & Accept	To produce a component from a **New** design • Implies *major* material and/or process changes and qualification efforts
	Modify **Redesign** **Refurbish** **Refresh**	To **Reuse** design with some changes • Implies ***moderate*** design requirements and/or specification changes and qualification efforts	**Manufacture** & Reaccept **Remanufacture** & Reaccept	To produce a component from a **Modified** design • Implies *moderate* material and/or process changes and qualification efforts
Low	**Reuse**	To make use of an **existing** design • Implies ***minor*** design requirements and/or specification changes and qualification efforts	**Remanufacture** & Reaccept	To produce a component from a **Reused** design • Implies *minor* material and/or process changes and qualification efforts

Note: These definitions should be reviewed and updated as needed.

Table developed to promote consistent terminology usage when defining the scope of work

Complexity Analysis Process Flow



Calculate Complexity Scores and/or Factors

Tool performs sampling and calculates a complexity score at various levels of detail

$$S^{\cdot}_{i,p,m,\epsilon} = W_{i,p} \cdot \frac{F^{\cdot}_{i,p,D_{i,m}}}{100} \cdot \left(\beta_p \cdot \frac{\epsilon \cdot Z_{i,m} + (1-\epsilon) \cdot t_i}{\sum_r \gamma_{i,r} \cdot {N^{Build}}_i} + (1-\beta_p) \right)$$

Complexity Score

Relative Complexity Estimate

Relative Complexity Associated with Production

Reference Cost Weight

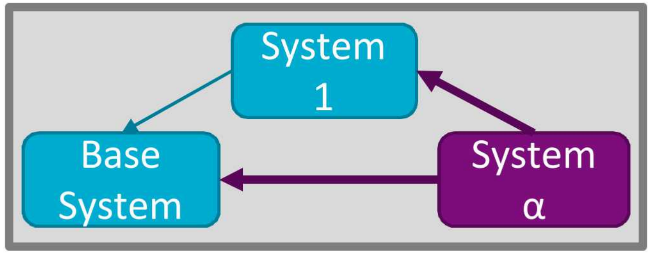
For complexity through full production, use full production quantity

For complexity through first production unit (FPU), divide quantity needed for single system

No production adjustment for non-production phases

Calculate Complexity Scores and/or Factors

Score * **Reference Conversion Factor** = **Factor**



WBS Code	Element Name	System α Reference System
1.X.1	Systems Engineering	Base System
1.X.2	Widget A	Base System
1.X.2	Widget B	System 1
1.X.3	Widget 1	N/A
1.X.3	Widget 2	Base System
1.X.4.1	Component A	System 1
1.X.4.1	Component B	System 1
1.X.4.2	Component 1	New Scope

WBS Code	Element Name	Phase	Base System Reference Cost	System α Complexity Estimate Mode	System 1 Complexity Estimate Mode
1.X.2	Widget A	SE&I	32	120	-
		T&Q	10	140	-
		PD	9	50	-
1.X.2	Widget B	SE&I	28	150	180
		T&Q	17	140	200
		PD	14	50	100
1.X.2 Total			110		

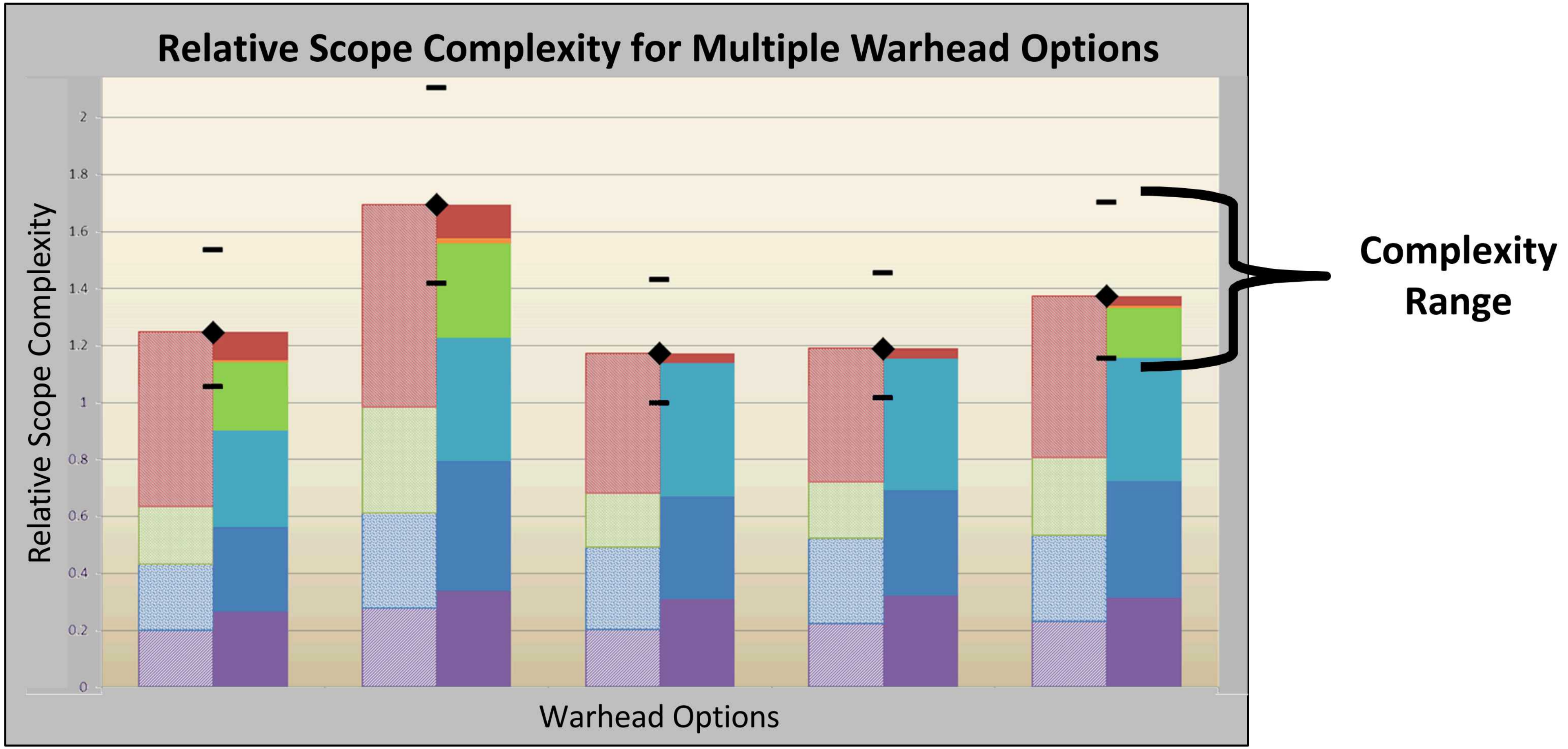
$$\{1.X.2\ \text{Factor}\} = \underbrace{1.2 * \frac{32}{110} + 1.4 * \frac{10}{110} + 0.5 * \frac{9}{110}}_{\text{Widget A}}$$

$$+ \underbrace{1.5 * 1.8 * \frac{28}{110} + 1.4 * 2.0 * \frac{17}{110} + 0.5 * 1.0 * \frac{14}{110}}_{\text{Widget B}} = 1.7$$

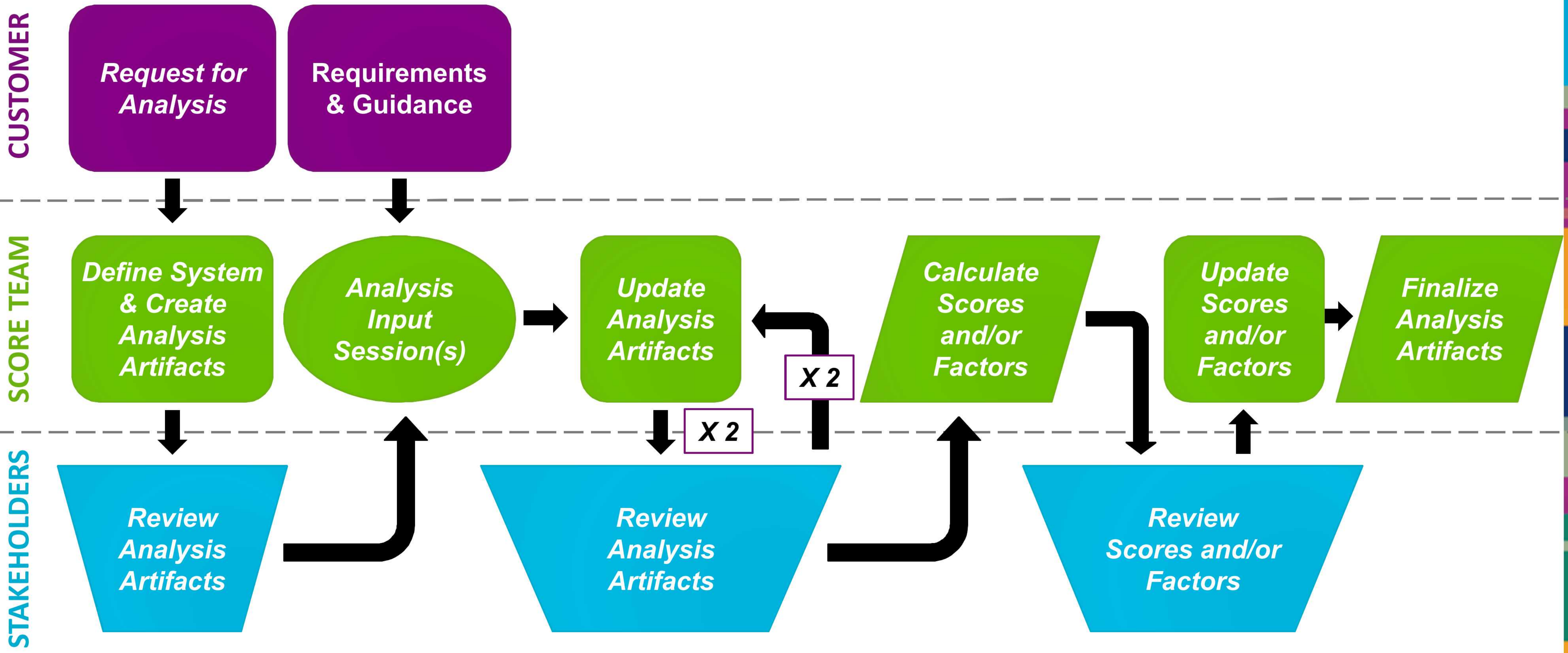
*System α is **70** percent more complex than the Base System for WBS 1.X.2.*

Calculate Complexity Scores and/or Factors

Tool performs sampling and calculates a complexity score at various levels of detail



Complexity Analysis Process Flow



Finalize Analysis Artifacts

<u>Analysis Artifacts</u>

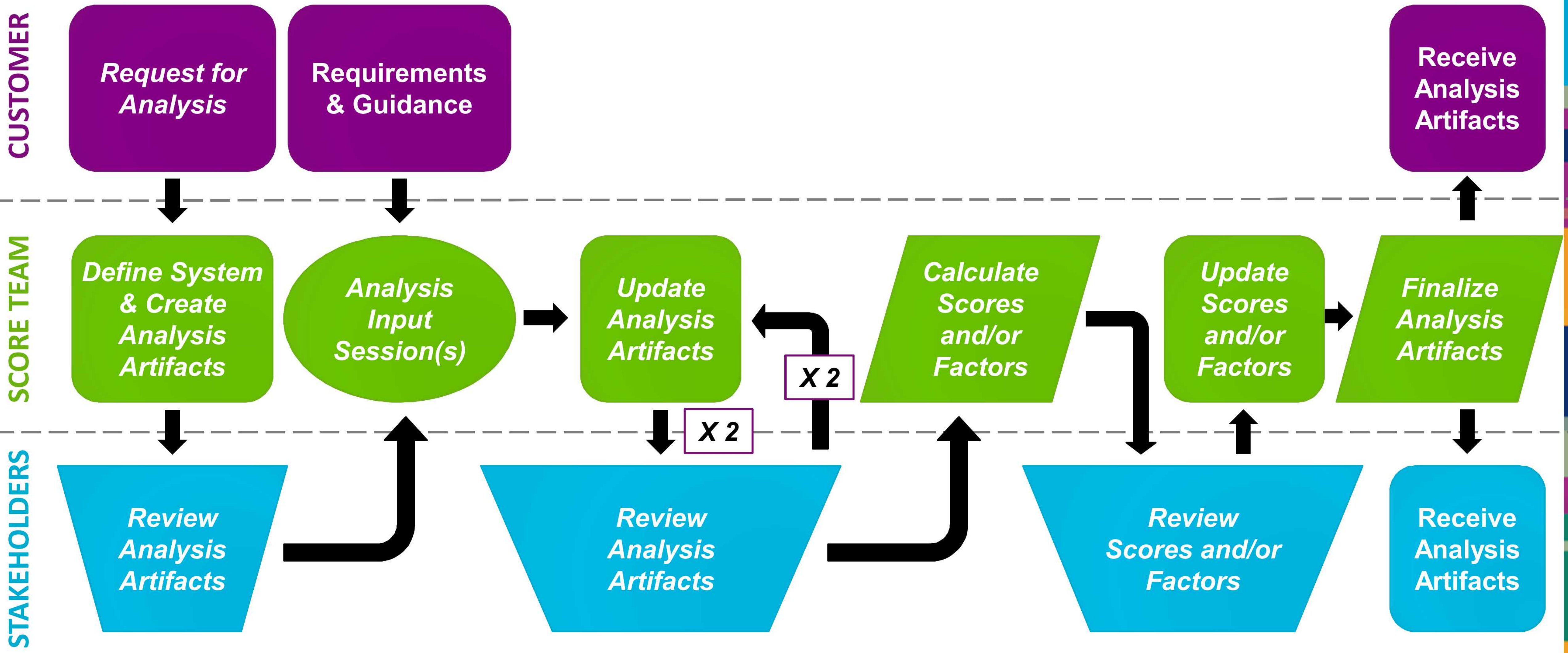
1. ***WBS Code & Element Mapping***
2. ***Reference Cost Data***
3. ***Model Input Files***
4. ***Design Definitions***
5. ***Complexity Estimates***
6. ***Assumptions***

Products generated throughout the process provide traceability and justification to support analysis and the resulting cost estimates

Data produced from this process can be easily regenerated and compared to future complexity analysis estimates

Data use from this process can be easily leveraged for other projects

Complexity Analysis Process Flow



Challenges

Decomposing a complicated product(s) into a common language across programs

Availability of historical cost data and work scope

Coordinating ~50 stakeholders to be present for the full one week session

Capturing information in real-time and but also a widely distributable format

Identifying the correct stakeholder for each piece of information

Assuring all stakeholder voices are heard but they do not cause unintentional bias

Unintentional bias by using complexity estimates from a previous analysis as a starting point for the current analysis

Capturing the correct information a SME will find valuable during the review process

Getting full participation during the review process

Summary and Conclusions

Tools and processes have provided a systematic approach that has greatly improved the fidelity, traceability, and repeatability of early planning cost estimates

Tool and processes have been successfully applied to multiple areas:

- Warhead options down select
- Component and warhead level early planning cost estimates
- Warhead platform interface early planning cost estimates

Tools and processes can be applied to many complex problems

SCORE's analogous approach hinges on expert knowledge and valid reference systems

Nuclear Security Enterprise and SNL Cost Analysis Examples

Nuclear Security Enterprise Support:

1 → ◦ Stockpile Stewardship and Management Plan Releases (Six releases; August 2014 to Present)

Sandia National Labs Specific Support:

- W78/88-1 analysis (2014)
- Long Range Standoff (LRSO) options analysis (2014, 2015)
- W80-4 Federal Program Manager options analysis (May 2016)
- W80-4 complexity analysis (Nov 2015)
- Bus-based LDRD Grand Challenge (May 2017)
- 2 → W78 systems options (Aug 2017, Sept 2018)
- B61 Preflight Controller (Sept 2017)
- W80-4 Independent Cost Estimate (April 2018)
- W76-2 electronics component (June 2018, July 2019)
- 3 → Navy Missile Update (September 2018, est. September of each subsequent year)
- W87-1 Federal Program Manager options analysis (May 2019)

W78 Systems Options Cost Estimate Overview (August 2017)

SNL cost analysis team supported the W78 weapon systems technical and SNL business teams to develop early planning cost estimates for quick turn tasker from NNSA/USAF

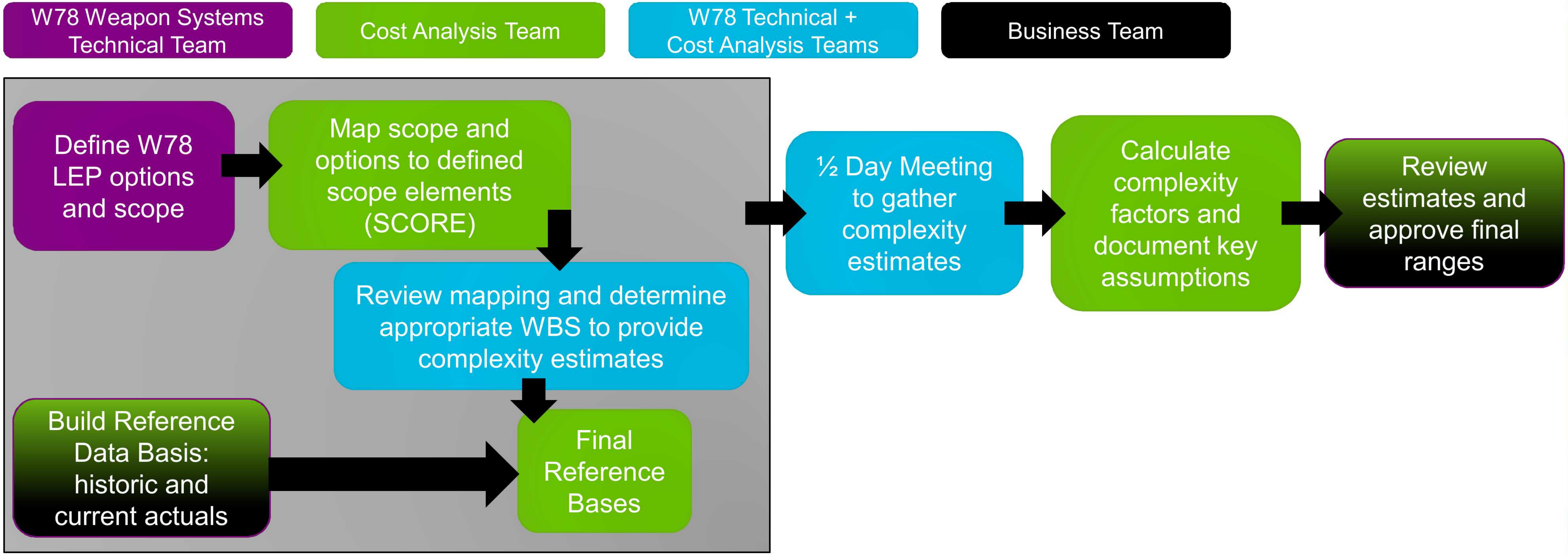
W78 weapon systems technical team defined the set of three options upon which the cost estimates were based

SNL business team was responsible for the final cost estimates

Cost analysis team provided:

- Templates for capturing technical scope and assumptions
- Develop a work break down (WBS) structure specific to the technical team's scope of work
- Historic and current actual costs was the basis for analogous estimate methodology (business team collected data)
- Facilitation of complexity estimation and analysis
- Documentation of approach to defend the estimate
- Range of complexity factors based upon the analogous approach to be used to estimate cost

Cost Estimate Approach Required Teaming Across SNL Departments



Summation of the elements informed the final cost estimate for all options

Nuclear Security Enterprise and SNL Cost Analysis Examples

Nuclear Security Enterprise Support:

1 → ◦ Stockpile Stewardship and Management Plan Releases (Six releases; August 2014 to Present)

Sandia National Labs Specific Support:

- W78/88-1 analysis (2014)
- Long Range Standoff (LRSO) options analysis (2014, 2015)
- W80-4 Federal Program Manager options analysis (May 2016)
- W80-4 complexity analysis (Nov 2015)
- Bus-based LDRD Grand Challenge (May 2017)
- 2 → W78 systems options (Aug 2017, Sept 2018)
- B61 Preflight Controller (Sept 2017)
- W80-4 Independent Cost Estimate (April 2018)
- W76-2 electronics component (June 2018, July 2019)
- 3 → Navy Missile Update (September 2018, est. September of each subsequent year)
- W87-1 Federal Program Manager options analysis (May 2019)

Navy Missile Update Cost Estimate Overview (September 2018)

Cost Analysis supported Navy Stockpile Systems Team in developing:

1. **"Planning Factors"** were developed to inform cost estimating process (October 2018)
   - Defined and utilized an approach that ties projected missile changes to proposed Sandia work scope
   - Technical scope and assumptions were captured using and internal WBS structure developed for this work
   - Current assumptions are highly dependent upon Lockheed Martin status and assumptions
   - Includes significant uncertainty and will be updated as the program progresses
   - Documented in GE4A8208-000 Issue A

2. A defendable, traceable, **budgetary wedge cost estimate** (December 7, 2018) [orig. end February 2019]
   - Limited knowledge of requirements and significant scope uncertainty
   - Bottom-up labor estimate approach supplemented with actuals and analogous program comparisons
   - Estimates developed for three timeframes using different approaches:

	High-level Description	Timeframe	Cost Estimate Approach
1	Review and Analysis of Documentation and Requirements	20 year span	Expert Judgement & Analogous
2	Continued Systems Engineering Activities plus Ground Testing		Expert Judgement & Analogous
3	Flight Bodies and Systems Engineering Support		Expert Judgement, Analogous, & Historic Actuals

Process Flow for Navy Missile Update Cost Estimate

Develop Planning Factors
- October 2018
- Formal documentation

Identify Suite of Workload Options
- Assess the most likely scenario given the current expected scope of work

Estimate Scope of Work for Each Element
- Mixture of SME Judgement, Analogous, and actuals

Gather Data for the Cost Estimate
- Historic program data
- Current and projected labor rates
- Use literature to inform the estimate
- SME Judgement

Map Cost Data to Elements
- Calculate a cost for each piece that was estimated

Produce Cost Estimate
- Combine the data and bound the estimate appropriately for an Early Planning Cost Estimate

Review Estimate Internally

Deliver Estimate to the Navy
- Estimate delivered via memo (December 7, 2018)

Concluding Lessons Learned

Clarify the expectations of your customer and management chain early on

- What type of estimate are they expecting?

Define as much technical scope as possible before you start the cost estimate

- Bounding the scope of work to determine level of uncertainty and manage types of risk (e.g., unknown-unknowns)

Identify the type of data you need early on and store it for future use

- Data discovery, availability, mining capabilities, and understanding can be challenging

Cost estimating teams need both program management and technical perspectives

- Communicating across this type of team can be challenging

Standardize approaches, tools, language, etc.

- Standardization supports repeatability

Always document your work throughout the process and at the end of the study

- Cost estimates are generally leveraged for the next phase in the life cycle and require traceability

Interactions between the customer and cost estimating team impact results

- Customers, policies, deadlines, technical scope, etc. can change while the cost estimate is being developed

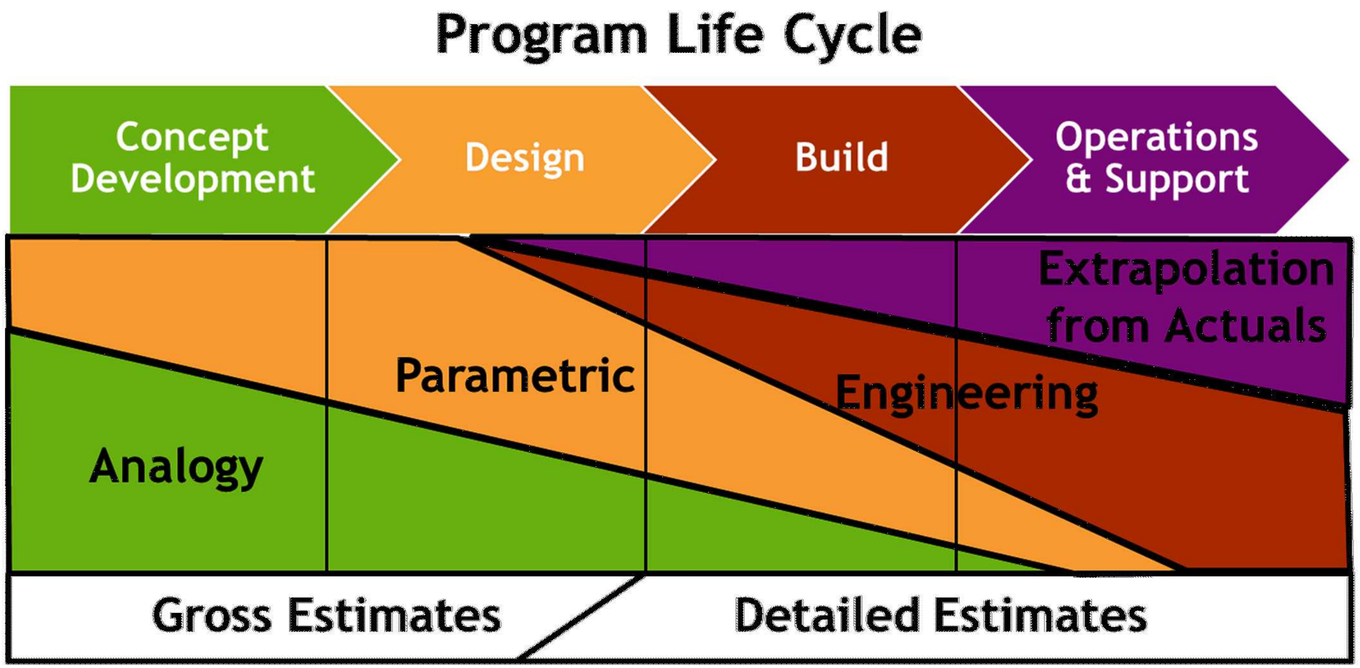
Discussion

How do you approach cost estimating?

Are we preparing the right data, etc. for the next step in the life cycle?

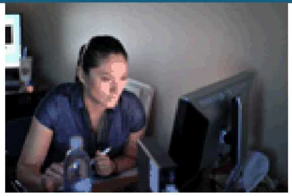
How can we improve cost estimating, especially for early cost estimates?

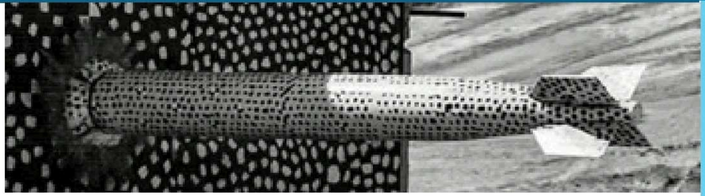
How can we increase collaboration, especially across the Nuclear Security Enterprise?



Modified: Defense Acquisition University, "Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework chart (v5.2)," 2008, as reproduced in the International Cost Estimating and Analysis Association's "Cost Estimating Body of Knowledge Module 2."

An Introduction to Sandia National Laboratories Cost Products to Advance Collaboration





CECOP
Cost Estimating Community of Practice

PRESENTED BY

Jonell N. Samberson, PhD

Cost Estimating Community of Practice Symposium

Lawrence Livermore National Laboratory

August 6-7, 2019

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

ADDITIONAL SLIDES

Acronyms

ADD ACRONYMS

ALPHABATIZE

NSE	Nuclear Security Enterprise		
SNL	Sandia National Laboratories		

Multiple estimating techniques can be applied throughout the life cycle

CATEGORIES	Conceptual Exploration	Component Advanced Development	Systems Integration/ Preliminary Design	Systems Demonstration, Test, & Evaluation	Production	Operations, Support & Disposal
Parametric Cost Estimation	●	●	◒	○	○	◒
Analogy	●	◒	◒	◒	○	◒
Detailed Engineering Build Up	◒	◒	●	●	●	◒

● Primary Technique ◒ Some Applicability ○ Little or No Utility

Modified: Farr, John V. (2012) Life Cycle Cost Considerations for Complex Systems, Systems Engineering - Practice and Theory, InTechOpen. Accessed https://www.intechopen.com/books/systems-engineering-practice-and-theory/life-cycle-cost-considerations-for-complex-systems

Cost Estimation Techniques

Method	Description	Advantages	Disadvantages
Actual Costs	Use costs experienced during prototyping, hardware engineering development models and early production items to project future costs for the same system	• Could provide detailed estimate • Reliance on actual development data	• Development data may not reflect cost correctly • Higher uncertainty • Often mistakenly use contract prices to substitute for actual cost • Various levels of detail involvement • Require existing actual production data
Analogy/Comparative Method	Extrapolate available data from similar completed projects and adjust estimates for the proposed project	• Reliance on historical data • Less Complex than other methods • Save time	• Subjective/bias may be involved • Limited to mature technologies • Reliance on single data point • Hard to identify appropriate analog • Software and hardware often do not scale linearly
Cost Accounting	Formulate based on the expenditures of reliability, maintainability, and decomposed component cost characteristics	• Reliance on detailed data collection	• Accounting Ethics (i.e. Cook the Book) • Post-production phase strongly preferred • Requires of large and complex data collections • Labor Intensive

Young, Leone (2014) "Cost Overruns and Cost Growth: A Three Decade Old Cost Performance Issue within DoD's Acquisition Environment". In proceedings of 2014 International Cost Estimating and Analysis Association annual conference. Denver, CO. USA

Cost Estimation Techniques (cont'd)

Method	Description	Advantages	Disadvantages
Detailed Engineering Builds/Bottom-Up	Estimate directly at the decomposed component level leading to a total combined estimate	• Most detailed at the component level through work breakdown structures • Systemic oriented • Highly accurate • High Visibility of Cost Drivers	• Resource-intensive (time and labor) • May overlook system integration costs • Reliance on stable systems architectures and technical knowledge
Expert Judgment	Produce by human expert(s)' knowledge and experience could be accomplished via iterative processes and feedbacks	• Available when there are insufficient data, parametric cost relationships, or unstable system architectures	• Subjective/Bias • Detail cost influence/driver may not be identified • Programs complexities can make estimates less reliable • Human experience and knowledge required

Young, Leone (2014) "Cost Overruns and Cost Growth: A Three Decade Old Cost Performance Issue within DoD's Acquisition Environment". In proceedings of 2014 International Cost Estimating and Analysis Association annual conference. Denver, CO. USA

Cost Estimation Techniques (cont'd)

Method	Description	Advantages	Disadvantages
Parametric/Statistical Algorithm	Use mathematical expressions and historical data to create cost relationships models via regression analysis	• Statistical predictors provide information on expected value and confidence of prediction • Less reliance on systems architectures • Less subjective	• Heavy reliance on historical data • Attributes within data may be too complex to understand • Resource intensive (time and labor) • Difficult to collect data and generate correct cost relationships • Limited by data and independent variables
Top-Down	Based on the overall project characteristics and derive by decomposing into lower level components and life cycle phases. into the lower level components and life	• Fast and easy deployment • Minimal project detail required • Systemic oriented	• Less accurate than others • Tend to overlook lower level component details or major cost drivers • Limited detail for justification

Young, Leone (2014) "Cost Overruns and Cost Growth: A Three Decade Old Cost Performance Issue within DoD's Acquisition Environment". In proceedings of 2014 International Cost Estimating and Analysis Association annual conference. Denver, CO. USA