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Systems of Systems Cost Estimation Solutions

Josh Wilson

Content

- **Background**
  - Characteristics of a System of Systems (SoS)
  - System Engineering (SE) / System of Systems Engineering (SoSE)
- **Cost Estimating solution summary**
  - COSYSMO
  - COSOSIMO
  - SECOST
  - SEER-H with TSV
  - PES
  - TruePlanning Systems

Background

- **Maier's Criteria for defining a System of Systems**
  - Operational Independence of Elements
  - Managerial Independence of Elements
  - Evolutionary Development
  - Emergent Behavior
  - Geographical Distribution
- **Additional characteristics**
  - Inter-disciplinary
  - Heterogeneous
  - Ambiguous changing boundaries
  - Dynamically changing requirements

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Background

	Traditional SE	System of Systems Engineering
Purpose	Develop to specific performance and/or requirements	Develop to provide broad capability and enable interoperability
Architecture	Defined early and remains relatively stable	Dynamically reconfigured as needs change
Operability	Specific interface requirements to integrate components	Standards permit independent operation and SoS interoperability
Optimization	Optimized to meet performance standards	Optimized for both individual system and SoS performance
Emergent Behaviors	Minimized or eliminated	Leveraged to enhance performance, flexibility, and adaptability
Acquisition and Management	Centralized acquisition and management	Separate acquisitions managed independently

Background

- **The Wikipedia on System of Systems…**

“The need to solve System-of-Systems problems is urgent not only because of the growing complexity of today’s grand challenges, but also because System-of-Systems problems involve decisions that commit **large amounts of money and resources**, for which the ultimate outcome carries long-term consequences for a majority of the public population.”

http://en.wikipedia.org/wiki/System_of_systems

Overview

- **Currently available estimating solutions for Systems and SoS**
  - COSYSMO
  - COSOSIMO
  - Raytheon's SECOST
  - SEER-H with TSV
  - PRICE PES
  - PRICE TruePlanning Systems

Overview

- **Summary of estimating solutions currently available for Systems and SoS**
  - Type of model
  - History/Origin of CERs
  - Major Size/Cost drivers
  - Solution granularity
  - Solution tightness
  - Breadth of activity/resource coverage
  - Breadth of system lifecycle coverage
  - System of Systems capability

Overview

- **Where I obtained information used in this presentation**
  - COSYSMO
    - Ricardo Valerdi's dissertation, academicCOSYSMO User Manual
  - COSOSIMO
    - Lane, Jo Ann. (2006). "Constructive System of Systems Integration Cost Model (COSOSIMO) Tutorial". Proceedings from the 21st International Forum on Systems, Software, and COCOMO Cost Modeling. Herndon, VA.
  - Raytheon's SECOST
    - Ilseng, Jon K. (2006). "Systems Engineering Cost Estimation: System of Systems". Proceedings from the 21st International Forum on Systems, Software, and COCOMO Cost Modeling. Herndon, VA.
  - SEER-H with TSV
    - Hunt, Robert P. (2006). "Capturing Total System of Systems Costs Using SEER-H with TSV and SEER-SEM". Proceedings from the 21st International Forum on Systems, Software, and COCOMO Cost Modeling. Herndon, VA.
    - Stump, Evin. (n.d.) "Estimating System Level Costs." Retrieved January 4, 2007, from http://www.galorath.com/presentations/Estimating_System_Level_Costs.pdf.
  - PRICE PES and PRICE TruePlanning Systems
    - Minkiewicz, Arlene, & Shermon, Dale. (2006). "System of Systems Workshop". Proceedings from the 26th Annual PRICE Systems European Symposium. Prague, Belgium.

COSYSMO – History

- **Early 2001 – Raytheon affiliate builds first version of COSYSMO, called “MyCOSYSMO”**
- **August 2005 – Ricardo Valerdi Ph.D, Industrial & Systems Engineering, USC**
- **January 2006 – Academic COSYSMO spreadsheet available**
- **May 2006 – PRICE True COSYSMO available on disk for new TruePlanner installations**
  - Other commercial versions of COSYSMO are available too
- **July 2006 – Academic COSYSMO user manual available**
  - 28 page document covering model scope, usage, output, etc.

COSYSMO – General Information

- **Grew out of COCOMO family of USC cost models**
- **Stands for "Constructive Systems Engineering Cost Model"**
- **Primarily authored by Ricardo Valerdi**
- **Main usage in form of Excel spreadsheet**
  - Academic COSYSMO
- **Source of data is 34 projects from six companies in aerospace and defense sector**
  - Raytheon, BAE, General Dynamics, Aerospace Corp, Northrop Grumman, Lockheed Martin
  - Three of these companies were responsible for 27 of the 34 data sets

COSYSMO – General Information

- **Activities based on ANSI/EIA 632 *Processes for Engineering a System* standard**
  - Five fundamental Processes
  1. Acquisition and Supply
  2. Technical Management
  3. System Design
  4. Product Realization
  5. Technical Evaluation
  - These processes are broken into 13 process categories
    - Further broken into 33 low-level activities

COSYSMO – General Information

- **Life cycle phases based on ISO/IEC 15288 *System Lifecycle Processes***
  1. Conceptualize
  2. Develop
  3. Operational Test and Evaluation
  4. Transition to Operation
  5. Operate, Maintain, or Enhance
  6. Replace or Dismantle
  - First four of these phases within scope of COSYSMO
  - Phases 5 and 6 yielded too little data to calibrate

COSYSMO – Model Details

- **Four weighted size drivers calculate total system size**
  1. Requirements
  2. Interfaces
  3. Algorithms
  4. Operational Scenarios
- **Weighted as easy, nominal, or difficult**
- **Converted to equivalent nominal requirements and summed to get total system size**

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COSYSMO – Model Details

- **Fourteen cost drivers determine effort required to engineer a system of a certain size**

- **Requirements Understanding**
- **Architecture Understanding**
- **Service Requirement Level**
- **Migration Complexity**
- **Installation Platforms**
- **Recursive Levels**
- **Documentation**
- **Technology Risk**
- **Stakeholder Team Cohesion**
- **Team Capability**
- **Team Experience**
- **Process Capability**
- **Multisite Coordination**
- **Tool Support**

COSYSMO – Model Details

Center for Software Engineering

CO SYS MO 1.0

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

29-Jan-06

© 2005, 2006 Ricardo Valerdi

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	*Nominal*	*Difficult*	
# of System Requirements				0
# of System Interfaces				0
# of Algorithms				0
# of Operational Scenarios				0
				0

equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	**N**	1.00
Architecture Understanding	**N**	1.00
Level of Service Requirements	**N**	1.00
Migration Complexity	**N**	1.00
Technology Risk	**N**	1.00
Documentation	**N**	1.00
# and diversity of installations/platforms	**N**	1.00
# of recursive levels in the design	**N**	1.00
Stakeholder team cohesion	**N**	1.00
Personnel/team capability	**N**	1.00
Personnel experience/continuity	**N**	1.00
Process capability	**N**	1.00
Multisite coordination	**N**	1.00
Tool support	**N**	1.00
composite effort multiplier		**1.00**

SYSTEMS ENGINEERING PERSON MONTHS **0.00**

COSYSMO – Model Details

- **COSYSMO algorithm**

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k}\Phi_{e,k} + w_{n,k}\Phi_{n,k} + w_{d,k}\Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{14} EM_{j}$$

  - PM = effort in Person Months (Nominal Schedule)
  - A = calibration constant
  - K = {REQ, IF, ALG, SCN} size drivers
  - W = weight for size driver (easy, nom, difficult)
  - Φ_x = quantity of “k” size driver
  - E = diseconomy of scale exponent
  - EM = effort multiplier for cost drivers

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COSYSMO – Model Details

- **Ongoing efforts to improve COSYSMO**
  - Risk
  - Reused Requirements
  - Schedule spreading
  - Labor spreading
  - Additional Data
  - Incorporating Operate and Maintain phase into model

COSYSMO – SoS Capabilities

- **Estimates effort of systems engineering as defined by INCOSE**

  "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, then proceeding with design synthesis and system validation while considering the complete problem."

- **INCOSE definition for "System of Systems"**

  "an interoperating collection of component systems that produce results unachievable by the individual systems alone."

- **… which is probably why COSOSIMO is in development**

COSYSMO – Summary

- **Granularity**
  - Point estimate, guidance in Ricardo Valerdi's dissertation for breakdown
- **Tightness**
  - Standalone model (estimates SE cost only)
- **Coverage**
  - EIA 632 activities, IEC 15288 lifecycle phases
- **Strengths**
  - Open source (free)
  - Data driven
- **Weaknesses**
  - Not for SoS

COSOSIMO – History

- **Spring 2003 – Potential need for SoSE model identified**
- **Winter 2003 – Initial model developed based on SW size**
- **Fall 2004 – Early design model based on SoS architecture**
- **Spring 2005 – EIA 632 based survey conducted to determine differences between SoSE and SE**
- **Fall 2005 – SoSE WBS analysis**
- **Winter 2005 – 2 submodel version of COSOSIMO**
- **Spring 2006 – SoSE specific characteristics captured from SoSE conferences and workshops**
- **Spring 2006 – 3 submodel version of COSOSIMO proposed**

COSOSIMO – General Information

- **Grew out of COCOMO family of cost models**
- **Being developed primarily by Jo Ann Lane of USC**
- **Estimates SoSE costs at the SoS level, not total SoS development costs**
  - i.e. it's basically there to complement other models lacking in SoS estimation capability
  - Based on premise that SoSE activities and costs are different than analagous activities at system level
- **Still a work in progress**
- **Shooting for availability in Fall 2007**

COSOSIMO – General Information

- **Characteristics of SoSs supported by COSOSIMO**
  1. Strategically oriented stakeholders interested in tradeoffs and costs
  2. Long-range architectural vision for SoS
  3. Developed and integrated by lead system integrator (LSI)
  4. System component independence

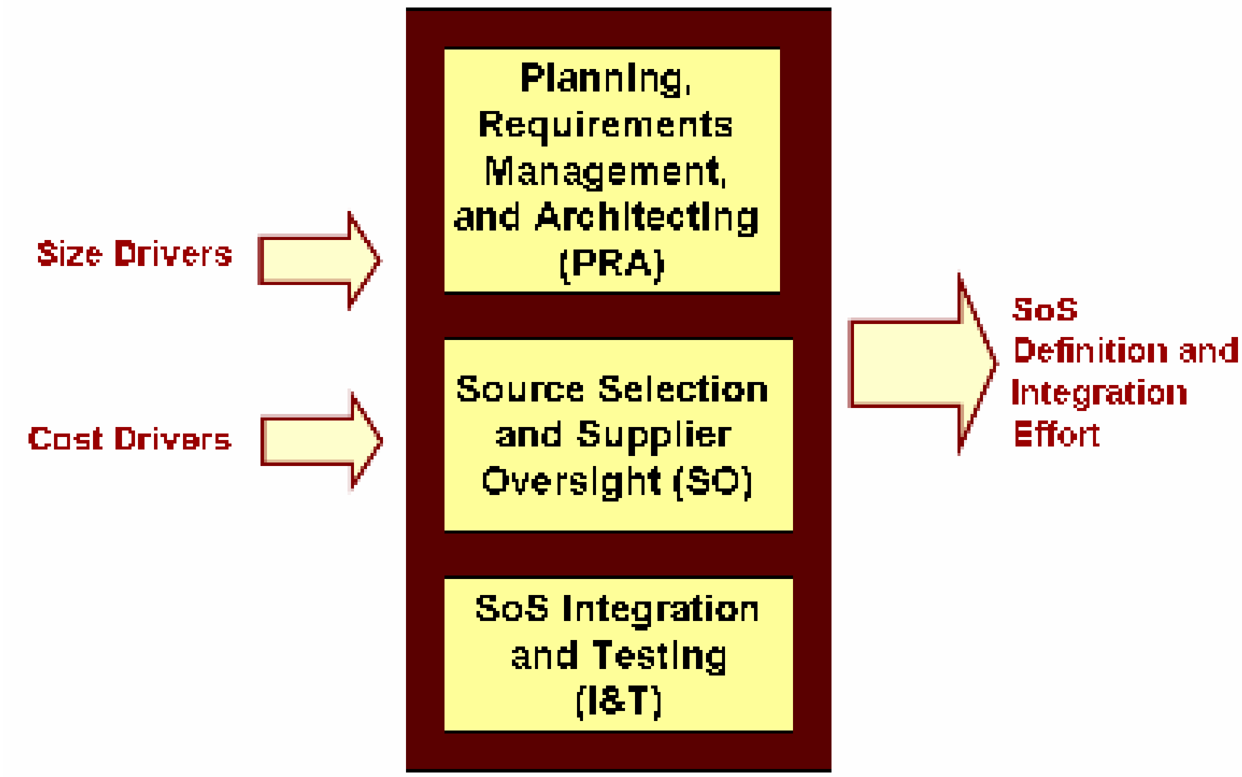
COSOSIMO – Model Details

- **Three submodels and related size drivers**

1. **Planning, Requirements Management, and Architecting**
   - # SoS Related Requirements
   - # SoS Interface Protocols
2. **Source Selection and Supplier Oversight**
   - # independent component system organizations
3. **SoS Integration and Testing**
   - # SoS Interface Protocols
   - # SoS User Scenarios
   - # Unique component systems

COSOSIMO – Model Details

- **Proposed 3-submodel version of COSOSIMO**



COSOSIMO – Model Details

- **COSOSIMO cost drivers**
  - Requirements Understanding
  - Architecture maturity
  - Level of service requirements
  - Stakeholder team cohesion
  - SoS team capability
  - Maturity of LSI processes *
  - Tool support
  - Cost/schedule compatibility *
  - SoS risk resolution *
  - Component system maturity and stability *
  - Component system readiness *

*** Indicates driver is beyond scope of COSYSMO drivers**

COSOSIMO – Model Details

- **COSOSIMO algorithm**
  - Planning, Requirements Management, and Analysis submodel

$$SoS\ PRA_{PM} = A_{PRA}\left[\sum_{i=1}^{m} C_{REQ\,i} + \sum_{j=1}^{n} C_{IP\,j}\right]^{B_{PRA}}$$

  - PRA = LSI Planning, Requirements Management, and Analysis effort in person-months
  - A = SoSE calibration constant
  - C_REQ = complexity factor for each SoS Requirement
  - C_IP = complexity factor for each SoS Interface Protocol
  - M = number of SoS related Requirements
  - N = number of SoS related Interface Protocols
  - B = effort exponent based on cost drivers
    - Recall that the product of cost drivers was a multiplicative factor in COSYSMO

COSOSIMO – SoS Capabilities

- **COSOSIMO was designed specifically for estimating SoSE costs**
  - But NOT the total SoS development costs
  - Still need to use traditional non-SoSE cost models for SoS development costs
- **Currently exists as a standalone System of Systems estimating solution with three submodels**
  - Planning, Requirements Management, and Architecting (PRA)
  - Source Selection and Supplier Oversight (SO)
  - SoS Integration and Test (I&T)

COSOSIMO – Summary

- **Granularity**
  - Point estimate for each submodel
- **Tightness**
  - Standalone model (estimates SoSE effort only)
- **Coverage**
  - Three submodels (PRA, SO, I&T)
- **Strengths**
  - SoSE specific
  - COSYSMO strengths (open source, data driven)
- **Weaknesses**
  - Unavailable until Fall 2007

SECOST – History

- **Early 2001 – Raytheon affiliate builds initial version of COSYSMO (called "MyCOSYSMO")**
  - Leveraged off of a model called SWCOST developed at Raytheon's Intelligence and Information Systems (IIS) Garland, TX location
    - SWCOST used at Garland and other IIS sites for 8+ years
- **Early 2004 – SECOST developed as Raytheon's proprietary version of MyCOSYSMO**
  - Now deployed at several Raytheon business units to be used as a second opinion for proposals

SECOST – General Information

- **Suite of MS Excel spreadsheets**
- **Uses COSYSMO as the embedded engine**
- **Is basically COSYSMO tailored to Raytheon's business practices, with some additional capabilities that take advantage of Excel**
  - Interfaces with standard Raytheon pricing systems
  - Labor distributed among Raytheon Salary Grades
  - Capability to time phase build in by Raytheon using Excel

SECOST – Model Details

- **Uses COSYSMO as the embedded engine**
  - See COSYSMO slides for further information

SECOST – SoS Capabilities

- **SoSE estimation possible with recommended additions to COSYSMO size and cost drivers**
  - Additional Size Drivers
    - Software Requirements
    - Software Modules
  - Additional Cost Drivers
    - IV&V Factor
    - SoS Integration Factor

SECOST – SoS Capabilities

… and recommended modifications to COSYSMO size and cost drivers

- Size Drivers requiring modification
  - System Interfaces Complexity
- Cost Drivers requiring modification
  - Requirements Understanding
  - Migration Complexity
  - Installation Platforms
  - Recursive Levels
  - Documentation
  - Stakeholder Team Cohesion
  - Personnel Experience

SECOST – Summary

- **Granularity**
  - EIA 632 activities, Raytheon salary grades
    - COSYSMO point estimate broken out using EXCEL
- **Tightness**
  - Single Excel workbook (15 steps to estimate)
- **Coverage**
  - EIA 632 activities, IEC 15288 lifecycle phases
- **Strengths**
  - COSYSMO+ (takes advantage of Excel capabilities)
- **Weaknesses**
  - Raytheon specific

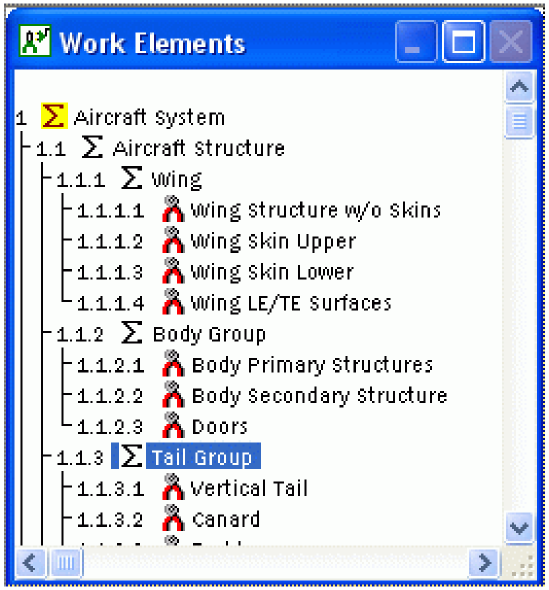
SEER-H with TSV – History

- **August 2001 - May 2002 – studied 45 out of 120 NAFCOM projects along with limited data from other sources**
  - Partially funded by NASA IPAO
  - Goal of identifying system level costs & characterize statistical relationships to other project costs and parameters to develop CERs
- **October 2005 – modification of SEER-H completed**
  - Abandoned CER development approach in favor of using a percentage
    - Hardware Development cost to estimate development system level costs (SLC)
    - First unit production costs to estimate production SLC
  - SLC adjusted based on team experience, system complexity, and for additional production quantities

SEER-H with TSV – General Information

- **Added capability to SEER-H of providing system level cost inputs at any rollup level**
  - System cost based on percentage of hardware subsystem costs
    - Only HW because NAFCOM doesn't break out SW cost
  - Production and development SLC costs adjusted based on inputs
    - System complexity
    - Team Experience

Yellow shading of the sigma symbol indicates a system level assignment at a rollup.



SEER-H with TSV – General Information

- **Costs at rollups may be created for any of five SLC components**
  1. System Engineering and Integration (SEI)
  2. Integration, Assembly, and Test (IAT)
  3. System Program Management (SPM)
  4. System Test Operations (STO)
  5. System Support Equipment (SSE)

  – Based on 5 of the 6 NAFCOM cost categories
  – All five categories appropriate for development
  – First three categories appropriate for production

SEER-H with TSV – SoS Capabilities

- **More than one system level assignment can be made in a given work element structure**
  - i.e. nested rollups – each of which can calculate any of the five applicable SLCs for development or production
- **Integration with software estimates available through capability of ADDIN cost element usage**
  - A feature of SEER-H
- **More applicable to compact systems than distributed systems**
  - Aircraft
  - Ships
  - Ground stations

SEER-H with TSV – Summary

- **Granularity**
  - Five activities (NAFCOM), two resources (development, production)
- **Tightness**
  - SEER-H with plugin for TSV and/or SEER-SEM
- **Coverage**
  - NAFCOM cost categories
- **Strengths**
  - Straightforward and simple
- **Weaknesses**
  - System costs based only on hardware

PRICE PES SoS – History

- 1975 – PRICE Hardware Acquisition cost model introduced
- 1976 – PRICE Hardware Lifecycle cost model introduced
- 1977 – PRICE Software Development cost model introduced
- 1979 – PRICE Software Lifecycle cost model introduced
- 1983 – PRICE Microcircuit cost model introduced
- 1998 – PRICE Excel Solution introduced

PRICE PES SoS – General Information

- **Use of individual PRICE models to estimate individual component systems**
- **Results must be totaled outside any of the models**
  - Won't include any additional effort beyond each estimate on its own
- **Excel based solutions for integration and SoSE activities**

PRICE PES SoS – SoS Capabilities

- **Effort outside scope of individual models must be accounted for by additional means**
  - Systems and System of Systems Engineering costs
  - At the discretion of the estimator
    - Excel Solution

PRICE PES SoS – Summary

- **Granularity**
  - PES for components
  - Excel for system level
    - Level of detail up to estimator
- **Tightness**
  - PRICE H, PRICE S, Excel
- **Coverage**
  - Engineering, Manufacturing by Production, Development
- **Strengths**
  - System level costs infinitely customizable
- **Weaknesses**
  - Little built-in SoSE capability

PRICE TruePlanning Systems – History

- **Available as BETA in Q4 2006**
- **Designed specifically to enable cost model integration**
- **Sources of data and research**
  - PRICE Systems KnowledgeNetwork
  - University of Southern California
  - Cranfield University
  - SEI
  - Aerospace Corporation
  - DAU
  - MIT

PRICE TruePlanning Systems – General Information

- **Is a TruePlanning catalog and collection of Cost Objects**
  - Catalogs
    - True S
    - True H
    - True IT
    - True COCOMO
    - True COSYSMO
    - True Systems
  - True Systems Cost Objects
    - Assembly
    - System
    - Folder
    - Purchased Good
    - Purchased Service
    - Other Cost
- **Assembly, System, and Folder are parent type Cost Objects**
  - i.e. they obtain needed information from children components

PRICE TruePlanning Systems – General Information

- **Assembly Cost Object**
  - Accounts for cost of technical activities
  - Activities occur during development of a system
    - System Requirements
    - System Design
    - Integration and Test
- **System Cost Object**
  - Accounts for cost of project level oversight and control activities
  - Activities are not direct component development activities
    - Project Management
    - Quality Assurance
    - Configuration Management

PRICE TruePlanning Systems – General Information

- **Systems Engineering Size Drivers**
  - Information from children components
    - This includes children Systems and Assemblies
  - Labor totals rolled up
    - By child component type (Hardware or Software)
    - By child activity type (Development, Production, Operation and Support)
  - Integration Sizes and Complexities
  - Systems Engineering related System/Assembly inputs
    - Number of Requirements
    - Number of Interfaces
    - Number of Operational Scenarios
    - Number of Vendors

PRICE TruePlanning Systems – General Information

- **Systems Engineering Cost Drivers**
  - Inputs to System and Assembly
    - System Complexity
    - Requirement Stability
    - Operating Specification
    - Stakeholder Involvement
    - Multiple Site Development
  - Some Cost Drivers are specific to one Cost Object
    - Stakeholder Involvement, Vendor Interface Complexity for System
    - Hardware Platform Stability and Availability for Assembly

PRICE TruePlanning Systems – General Information

- **Component level estimation by other Cost Objects**
  - Hardware Component (True H)
  - Hardware COTS (True H)
  - Software Component (True S)
  - Software COTS (True S)
  - Purchased Goods (True Systems)
  - Purchased Services (True Systems)
  - Various IT components (True IT)

PRICE TruePlanning Systems – Summary

- **Granularity**
  - 17 activities, 18 resources
- **Tightness**
  - Single framework, possibly multiple models in use
- **Coverage**
  - Development, Production
- **Strengths**
  - Thorough, customizable
  - Works with existing True components
- **Weaknesses**
  - Needs feedback

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Thank you!

Any Questions?