Rule-Based Flight Software Cost Estimation

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Pasadena CA

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Outline

- Background
- Knowledge Engineering Approach
- Decision Graph
- Mapping to Project WBS
- Spreadsheet Details
- The Program
- Summary and Future Work

Background

- Cost Estimating Tasks
  - Proposal Estimates* (N_0 missions†)
  - Independent Cost Estimates (ICE's)
  - Cost Analysis Data Requirements (CADRe's)
- Cost Activities in support of Proposals
  - Provided software estimates for N_0 proposals
  - Tight schedule constraint
  - Limited resources
  - Provided results to individual proposal Cost Engineers

* Main focus of this presentation

† N_0 represents a numeric value

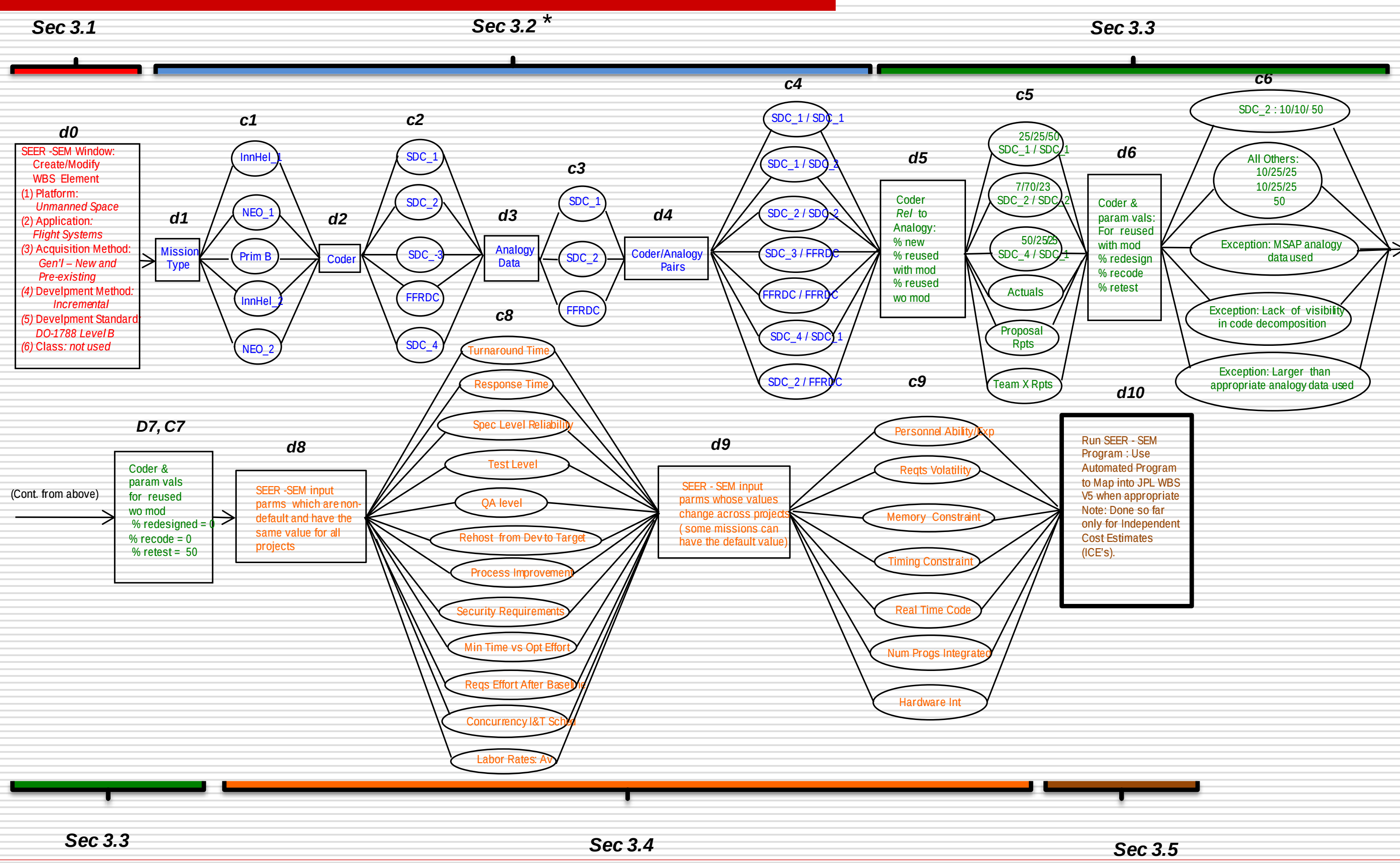
Knowledge Engineering Approach

- Experienced Software Cost Estimator
  - > 30 years in the Aerospace industry
  - Successfully engaged at many different technical facilities
  - Developing a software estimating tool for NASA
- Experienced Knowledge Engineer
  - Published and experienced in expert systems work
  - Brings a new perspective to the cost estimating profession
  - Organizes, makes consistent, and represents expert's analysis
- Built Decision Graph
  - More compact and intuitively palatable than decision tree
  - Sufficiently expresses high level relationships and concepts
  - ***Had its genesis from a Spreadsheet constructed to aid in the FSW cost estimation process (discussed later)***

Decision Graph

Sec numbering refers to the Section number in the IEEE paper cited in the References

Mission Type	Description
Inn_Hel_1	Inner Heliosphere Mission (examples: Venus, Mars)
Inn_Hel_2	Inner Heliosphere Mission (examples: Venus, Mars)
NEO_1	Near Earth Orbiter (examples: Earth , Moon)
NEO_2	Near Earth Orbiter (examples: Earth , moon)
Prim B	Primitive Body Encounter (examples: comets, asteroids)



* SDC=Software Development Contractor, FFRDC=Federally Funded Research and Development Contractor

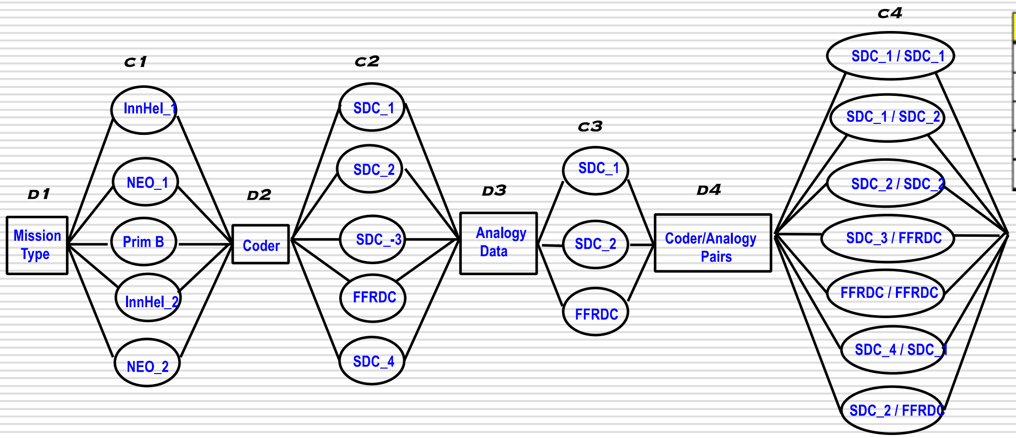
3.1 Initial SEER-SEM Input Data

D0

SEER -SEM Window:
Create/Modify
WBS Element
(1) Platform:
Unmanned Space
(2) Application:
Flight Systems
(3) Acquisition Method:
Gen'l – New and
Pre-existing
(4) Develpment Method:
Incremental
(5) Develpment Standard:
DO-1788 Level B
(6) Class: *not used*

Knowledge Base	Definition	Selection
(1) Platform	Establishes a collection of input parameter settings that characterize a particular host environment.	Unmanned Space
(2) Application	Establishes a collection of input parameter settings that characterize an application or application technology type.	Flight Systems
(3) Acquisition Method	Establishes a collection of input parameter settings that characterize from where the software will come.	New and Reuse
(4) Development Method	Establishes a collection of input parameter settings that characterize the particular Software Development Life Cycle method that will be used.	Incremental Development
(5) Development Standard	Establishes a collection of input parameter settings that characterize the software development process standard that will be used.	DO-178B Level B
(6) Class	A knowledge base calibrated to a specific set of data or domain.	Not used

3.2 Mission Type, Developer, and Data Decision Dynamics



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NEO_2	Near Earth Orbiter (examples: Earth , moon)
Prim B	Primitive Body Encounter (examples: comets, asteroids)

- Determine mission type
- Identify spacecraft provider (contractor)
- Obtain relevant data for contractor
  - Repositories
  - Proposal documentation
- Specify contractor/data pair

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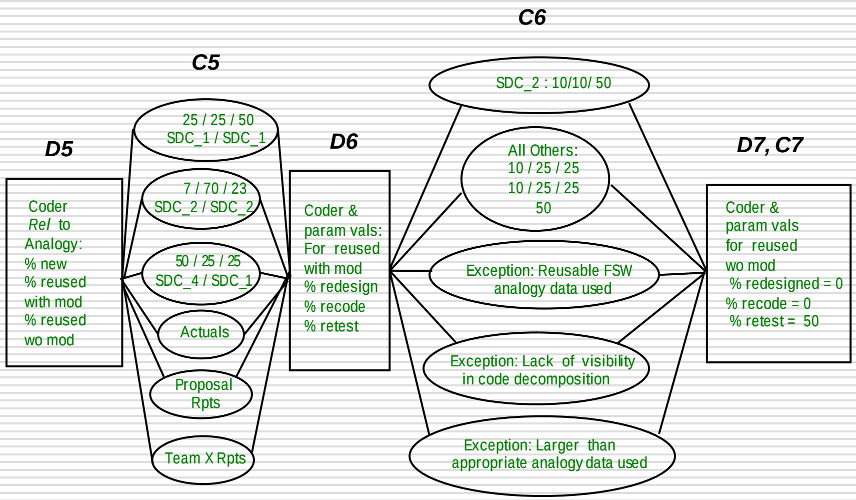
3.3 Quantitative Input Determination



SLOC value triplets

Vector 1 (v_1) : Applies to Total SLOC value

- v_1 = (%new, %reused with mods, %reused wo mods)
- Used from actuals, proposal reports and Team X reports, when possible
- Experience dictates predetermined set of values based on coder/analogy data pairs

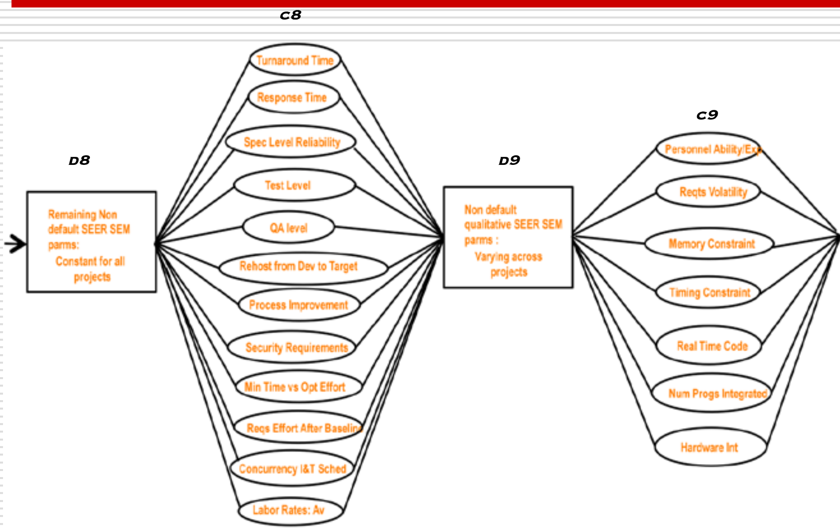
Vector 2 (v_2) : Applies to %*reused* ***with*** *mods)*

- v_2 = (%redesign, %recode, %retest)
- Experience dictates predetermined set of values based on coder
- Rare exceptions which cause a deviation from these values are noted and v_2 is altered accordingly

v2 is also related to %*reused* (***without*** *mods)*

- *v2* = (0 , 0, 50) in all cases
- 0% redesign and 0% recode
- Base upon the equation used in SEER-SEM, a value of 50% represents pure testing and integration (discussed in subsequent slide)

3.4 Non-Default Parameter Identification



- **D8** represents the decision that certain parameters (parms) have values (vals) which:

  (1) Differed from SEER-SEM KB
  and
  (2) Were held constant for all missions of Type X

  - Knowledge base values for these parameters as designated by SEER-SEM were not appropriate
  - For each parameter, the same value was given across all proposals
  - **C8** represents these parameters

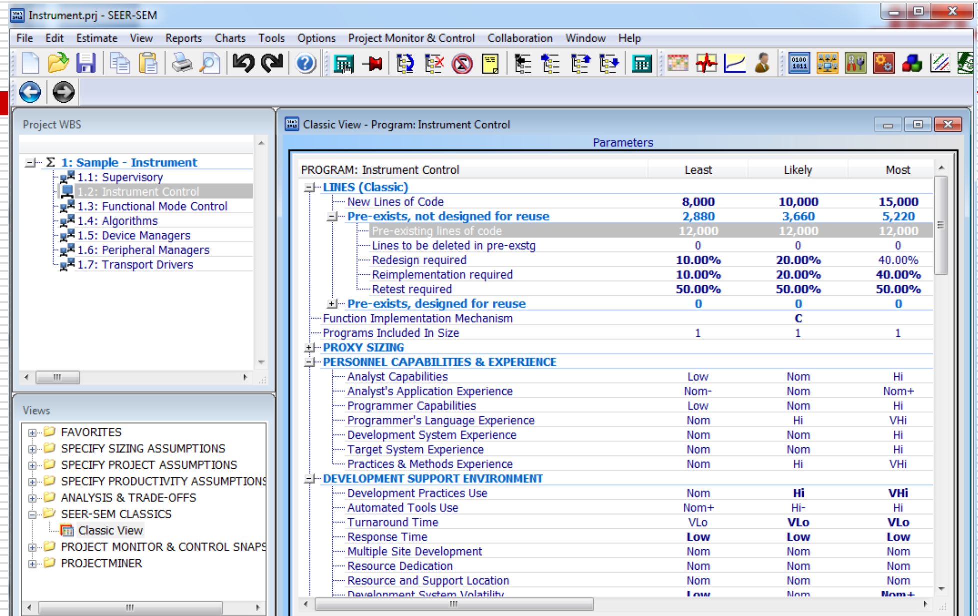
- **D9** represents decision that certain parameters were to have vals which varied across proposals (although for some proposals, the value could be a SEER-SEM default value)

  - **C9** represents these parameters

3.5 Program Output Mapping

D10

Run SEER - SEM Program : Use Automated Program to Map into JPL WBS V5 when appropriate Note: Done so far only for Independent Cost Estimates (ICE's).



Reports

Quick Estimate | Basic Estimate | **Person Hours by Labor Category**

Activity	Proj Mgr	Analyst	Design	Program	Data	Test/QA	CM/RM	QC Lead
System Requirements Design	27	117	31	0	13	27	4	4
S/W Requirements Analysis	79	303	92	40	40	79	13	13
Preliminary Design	176	160	656	192	128	224	32	32
Detailed Design	332	302	1,237	362	241	423	60	60
Code & Unit Test	337	145	289	2,651	289	723	193	193
Component Integrate & Test	365	91	182	1,778	365	1,322	228	228
Program Test	50	12	25	243	50	180	31	31
System Integrate Thru OT&E	467	117	233	1,108	58	3,441	292	117

Sample Data

Mapping SEER Output

- Goal is to map the SEER model output into the Project's WBS FSW elements
  - Total software activity cost
  - Individual WBS elements where possible
- Mapping Tool developed that performs computations and row and column operations to parse the SEER output
  - Parses total software activity to get costs for Project's WBS elements: *Management*, *Systems Engineering*, and *I&T*
  - Computes WBS element *Software Testbed* using 4% of total software cost

SEER-SEM Mapping

Description	FY$08K Total System Cost	Basis of Estimate
Flight Software		**Roll-up**
Equipment		Factor based on number of computers
Facilities		Factor based on number of square feet
Flight Software		**Roll-up**
Software Management		SEER-SEM Mgmt total less System I&T
Software Systems Engineering		SEER-SEM SW Req and SW Design total less System I&T
C&DH		SEER-SEM Flight Systems Software less Engineering Models and Payload & Instrument Control (less portion og mgmt, se, i&t)
GN&C		
Engineering Models		SEER-SEM Flight Modeling and Simulation (less portion of mgmt, se, i&t)
Payload & Instrument Control Software		SEER-SEM Payload Code total less System I&T (less portion of mgmt, se, i&t)
Systems Services Software		SEER-SEM Services total less Modeling and Simulation (less portion of mgmt, se, i&t)
Software Testbed		4% added to the SEER-SEM Flight Software estimate to account for Testbed software
Software I&T		SEER-SEM I&T total for Flight Software

Estimated from historical data

Core Software development effort

50% of CM covered by SW developers

COST by LABOR Category

PROJECT - C:\Documents and Settings\sastokes\Local Settings\Temporary Internet Files\OLK2DB\JNS 3-25-091.PRJ

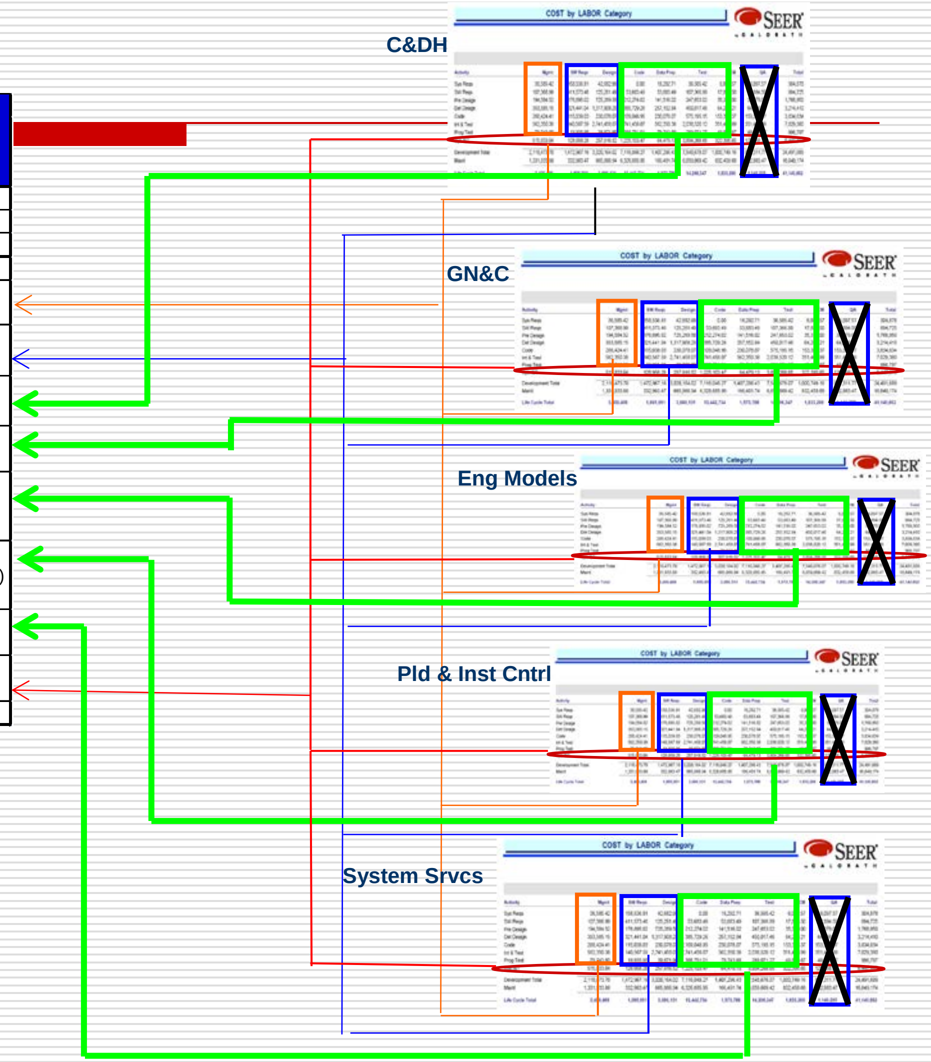
1 - Project - SMAP Flight Software - Phase A

Activity	Mgmt	SW Reqs	Design	Code	Data Prep	Test	CM	QA	Total
Sys Reqs	36,585.42	158,536.81	42,682.99	0.00	18,292.71	36,585.42	6,097.57	6,097.57	304,878
SW Reqs	107,366.99	411,573.46	125,261.49	53,683.49	53,683.49	107,366.99	17,89[illegible].50	17,894.50	894,725
Pre Design	194,584.52	176,895.02	725,269.58	212,274.02	141,516.02	247,653.02	35,379.00	35,379.00	1,768,950
Det Design	353,585.15	321,441.04	1,317,908.29	385,729.26	257,152.84	450,017.46	64,28[illegible].21	64,2[illegible]8.2[illegible]	3,214,410
Code	268,424.41	115,039.03	230,078.07	2,109,048.95	230,078.07	575,195.15	153,38[illegible].37	153,38[illegible].37	3,834,634
Int & Test	562,350.38	140,587.59	2,741,458.07	2,741,458.07	562,350.38	2,038,520.12	351,46[illegible].99	351,46[illegible].99	7,029,380
Prog Test	79,743.80	19,935.95	39,871.90	388,751.01	79,743.80	289,071.27	49,83[illegible].87	49,8[illegible]9.[illegible]7	996,797
Sys I&T	515,833.04	128,958.26	257,916.52	1,225,103.47	64,479.13	3,804,268.65	322,395.65	128,958.2[illegible]	6,447,913
Development Total	2,118,473.70	1,472,967.16	3,020,164.02	7,116,048.27	1,407,296.43	7,548,678.07	1,000,749.16	80[illegible],311.77	24,491,689
Maint	1,331,933.88	332,983.47	665,966.94	6,326,685.95	166,491.74	6,659,669.42	832,458.68	[illegible]32,983.47	16,649,174
Life Cycle Total	**3,450,408**	**1,805,951**	**3,686,131**	**13,442,734**	**1,573,788**	**14,208,347**	**1,833,208**	**1,140,295**	**41,140,862**

Covered by a non-Software organization

SEER-SEM Subsystem Mapping

WBS	Description	FY$08K Total System Cost	Basis of Estimate
6.12	**Flight Software**		**Roll-up**
	Equipment		Factor based on number of computers
	Facilities		Factor based on number of square feet
6.12	**Flight Software**		**Roll-up**
06.12.01	Software Management		SEER-SEM Mgmt total less System I&T
06.12.02	Software Systems Engineering		SEER-SEM SW Req and SW Design total less System I&T
06.12.03	C&DH		SEER-SEM C&DH (less portion of mgmt, se, i&t)
06.12.04	GN&C		SEER-SEM GN&C (less portion of mgmt, se, i&t)
06.12.05	Engineering Models		SEER-SEM Flight Modeling and Simulation (less portion of mgmt, se, i&t)
06.12.06	Payload & Instrument Control Software		SEER-SEM Payload Code (less portion of mgmt, se, i&t)
06.12.07	Systems Services Software		SEER-SEM Services total (less portion of mgmt, se, i&t)
06.12.08	Software Testbed		4% added to the SEER-SEM Flight Software estimate to account for Testbed software
06.12.09	Software I&T		SEER-SEM I&T total for Flight Software



Spreadsheet Summary

- Single source for compiling cost data for all proposals
- Consists of 3 major sections
  - Descriptive data
  - Size data
  - Attribute data
- Allows for quick relative comparison of all input data and output results
- Spreadsheet preceded and gave rise to the decision graph during the FSW cost estimating process

One picture is worth 1,000 words

Descriptive Data

Category	Inn_Hel_1			Inn_Hel_2	
Proposal Name	1	2	3	4	5
Cost Lead	A	B	C	D	D
Spacecraft Provider	SDC_1	SDC_1	SDC_2	SDC_3	FFRDC
Analogy Program(s) Used	from SDC_1	from FFRDC	from FFRDC	from FFRDC	from FFRDC
Contractor/Analogy Data	SDC_1/ SDC_1	SDC_1/ SDC_2	SDC_2/ SDC_2	SDC_3/ FFRDC	FFRDC/ FFRDC
Software Cost Estimates (SEER-SEM) (FY$10M) (excludes testbed, equip, facilities)	$XX	$XX	$XX	$XX	$XX
SEER-SEM (- ATLO, SQA, CM 50%)	$XX	$XX	$XX	$XX	$XX
Team X Estimate (for reconcilliation)	$XX	$XX	$XX	$XX	$XX
Software Duration (SEER-SEM) (mo)	27	30	23	30	26
Knowledge Bases					
SEER-SEM Window Name: (Create/Modify WSB Element)					
Platform (Operating Environment)	Unmanned Space	Unmanned Space	Unmanned Space	Unmanned Space	Unmanned Space
Application	Flight Systems	Flight Systems	Flight Systems	Flight Systems	Flight Systems
Acquisition Method	New/Reuse	New/Reuse	New/Reuse	New/Reuse	New/Reuse
Development Method	Incremental	Incremental	Incremental	Incremental	Incremental
Development Standard	DO-178B Level B	DO-178B Level B	DO-178B Level B	DO-178B Level B	DO-178B Level B

Sample Data

Size Data

Category	Inn_Hel_1			Inn_Hel_2	
Proposal Name	**1**	**2**	**3**	**4**	**5**
Software Size (SLOC)					
Size BoE	Used actual SLOC counts from SDC_1. Assumed 25% new, 25% reused "as is", and 50% reused modified.	Used an average actuals from FFRDC projects with the inheritance percentages fromFFRDC.	Used SDC_2-derived SLOC values for new, reused, reused modified. Added correction factor to convert code counts.	Used FFRDC TDP information.	Used FFRDC size estimates. Duplicated reasoning used for FFRDC estimate.
ESLOC	69,888	92,238	61,848	85,533	61,450
Delivered Software (SLOC) - most likely	153,812	202,000	204,990	221,664	180,000
Software Size (SLOC)					
New SLOC - most likely	38,453	60,600	25,000	46,404	30,000
% of new SLOC	**25%**	**30%**	**12%**	**21%**	**17%**
Reuse SLOC (as is - no mod) - most likely	38,453	35,350	97,700	117,424	70,000
% of reused (as is) SLOC	**25%**	**17%**	**48%**	**53%**	**39%**
% re-design	0	0	0	0	0
% re-implementation (Re-coding)	0	0	0	0	0
% re-test	50%	50%	50%	50%	50%
Reuse SLOC (modified) - most likely	76,906	106,050	82,290	57,836	80,000
% of reused (modified) SLOC	**50%**	**53%**	**40%**	**26%**	**44%**
% re-design	10%, 25%, 25%	10%	10%	10%, 25%, 25%	10%
% re-implementation (Re-coding)	10%, 25%, 25%	10%	10%	10%, 25%, 25%	10%
[illegible]t	50%	50%	50%	50%	50%

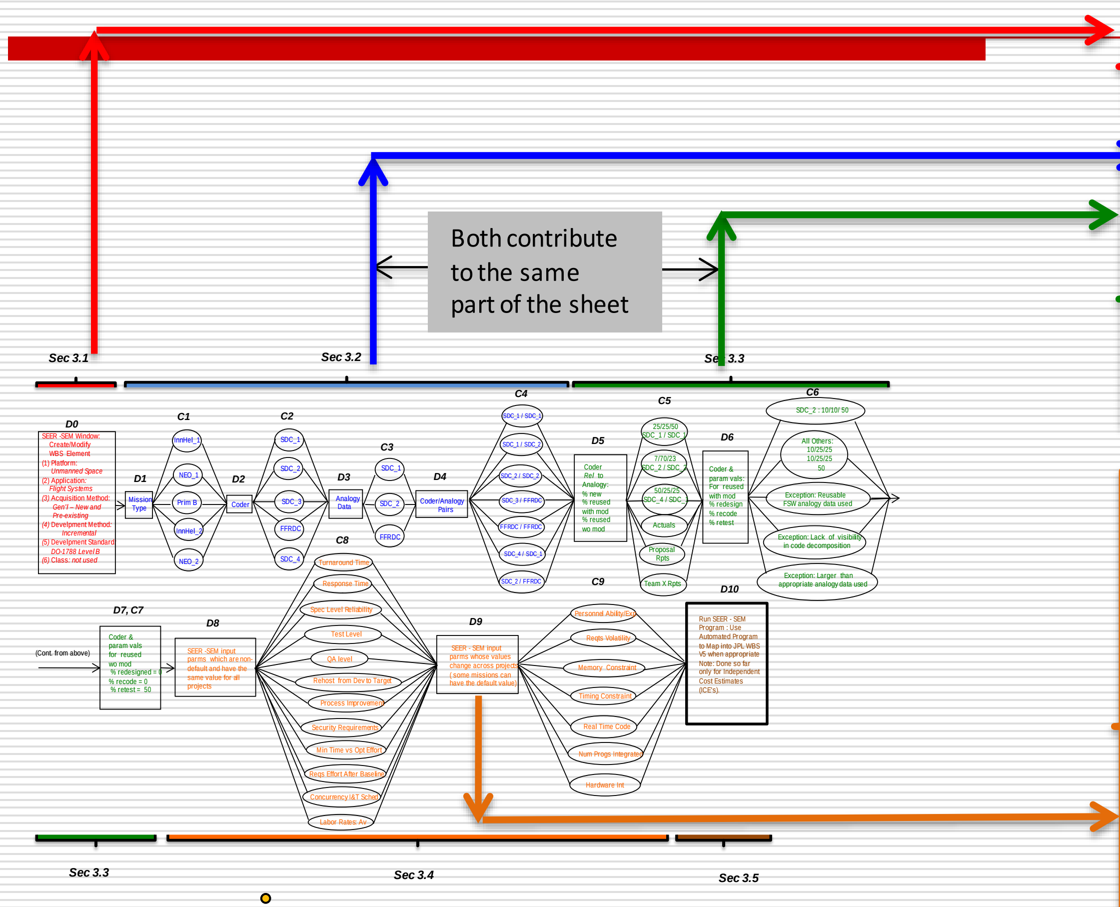
Sample Data

Attribute Data

Parmeter Settings Notes					
Personnel Capabilities & Experience (7 parameters)	Leave at KB setting. This reflects an industry average which is appropriate since we do not know the composition of the software development team so early in the proposal process.				
Analyst Capability					NOM-
Analyst's Application Experience					NOM
Programmer Capabilities					NOM-
Programmer's Language Experience					VHI
Developkent System Experience					HIGH
Target System Experience					VHI
Practices & Methods Experience					VHI
Development Support Environment	Leave at KB settings with the exception of:				
turnaround time	VLO	VLO	VLO	VLO	VLO
response time	LOW	LOW	LOW	LOW	LOW
Product Development Requirements	Leave at KB settings with the exception of:				
requirements volatility	HIGH	HIGH	HIGH	HIGH	HIGH
spec level - Reliability	HIGH-	HIGH-	HIGH-	HIGH-	HIGH-
test level	HIGH	HIGH	HIGH	HIGH	HIGH
quality assurance level	HIGH	HIGH	HIGH	HIGH	HIGH
rehost (development to target)	HIGH-	HIGH-	HIGH-	HIGH-	HIGH-
Product Reusability Requirements	Should always be NOM (no reusability required by the contract). If the parameter is set to NOM the percentage value is meaningless.				
Development Environment Complexity	Leave at KB settings with the exception of:				
process improvement	NOM	NOM	NOM	NOM	NOM
Target Environment	Leave at KB settings with the exception of:				
memory constraint	NOM	NOM	NOM	NOM	NOM
timing constraint	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-	NOM+,NOM +,HIGH-	NOM+,NOM+,HIGH-
real time code	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+
security requirements	NOM	NOM	NOM	NOM	NOM
Schedule & Staffing Constraints	Leave at KB settings with the exception of:				
start date	11/25/2012	11/25/2012	11/25/2012	11/25/2012	11/25/2012
Min Time vs Optimal Effort	Always start with **Optimal Effort**. Where possible, verify that the schedule duration is achievable. If not, evaluate schedule constraints to accommodate the estimated schedule. If the software development time is less than the **Minimal Time**, the SEER-SEM model contends that it is not possible to complete the software. Identify this as a significant risk issue!				
Confidence Levels	Both effort and schedule should be run at 50% and 70% confidence. SQI recommends the 70%				
Requirements	Leave at KB settings with the exception of:				
requirements after baseline	YES	YES	YES	YES	YES
System Integration					
number of programs being integrated	5	5	7	5	5
concurrency of I&T	Hi	Hi	Hi	Hi	Hi
hardware integration	N-, N, N+	N-, N, N+	N-, N, N+	N-, N, N+	N-, N, N+
Ecomonic Factors	Labor rate based on NASA Center contractor developed software survery conducted in FY08. Escalated to FY$10 using the NASA New Start Inflation index (5.6%).				
cost base year	2010	2010	2010	2010	2010
labor rate (FY$2010) work months	$xx	$xx	$xx	$xx	$xx

Sample Data

Notional Retrospective



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Acquisition Method	New/Reuse	New/Reuse	New/Reuse	New/Reuse	New/Reuse
Development Method	Incremental	Incremental	Incremental	Incremental	Incremental
Development Standard	DO-178B Level B	DO-178B Level B	DO-178B Level B	DO-178B Level B	DO-178B Level B
Software Size (SLOC)					
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Analyst's Application Experience					NOM
Programmer Capabilities					NOM-
Programmer's Language Experience					VHI
Developkent System Experience					HIGH
Target System Experience					VHI
Practices & Methods Experience					VHI
Development Support Environment	Leave at KB settings with the exception of:				
turnaround time	VLO	VLO	VLO	VLO	VLO
response time	LOW	LOW	LOW	LOW	LOW
Product Development Requirements	Leave at KB settings with the exception of:				
requirements volatility	HIGH	HIGH	HIGH	HIGH	HIGH
spec level - Reliability	HIGH-	HIGH-	HIGH-	HIGH-	HIGH-
test level	HIGH	HIGH	HIGH	HIGH	HIGH
quality assurance level	HIGH	HIGH	HIGH	HIGH	HIGH
rehost (development to target)	HIGH-	HIGH-	HIGH-	HIGH-	HIGH-
Product Reusability Requirements	Should always be NOM (no reusability required by the contract). If the parameter is set to NOM				
Development Environment Complexity	Leave at KB settings with the exception of:				
process improvement	NOM	NOM	NOM	NOM	NOM
Target Environment	Leave at KB settings with the exception of:				
memory constraint	NOM	NOM	NOM	NOM	NOM
timing constraint	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-	NOM+,NOM+,HIGH-
real time code	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+	NOM, NOM, NOM+
security requirements	NOM	NOM	NOM	NOM	NOM
Schedule & Staffing Constraints	Leave at KB settings with the exception of:				
start date	11/25/2012	11/25/2012	11/25/2012	11/25/2012	11/25/2012
Min Time vs Optimal Effort	Always start with **Optimal Effort**. Where possible, verify that the schedule duration is achievable. If not, evaluate schedule constraints to accommodate the estimated schedule. If the software development time is less than the **Minimal Time**, the SEER-SEM model contends that it is not possible to complete the software. Identify this as a significant risk issue!				
Confidence Levels	Both effort and schedule should be run at 50% and 70% confidence. SQI recommends the 70%				
Requirements	Leave at KB settings with the exception of:				
requirements after baseline	YES	YES	YES	YES	YES
System Integration					
number of programs being integrated	5	5	7	5	5
concurrency of I&T	Hi	Hi	Hi	Hi	Hi

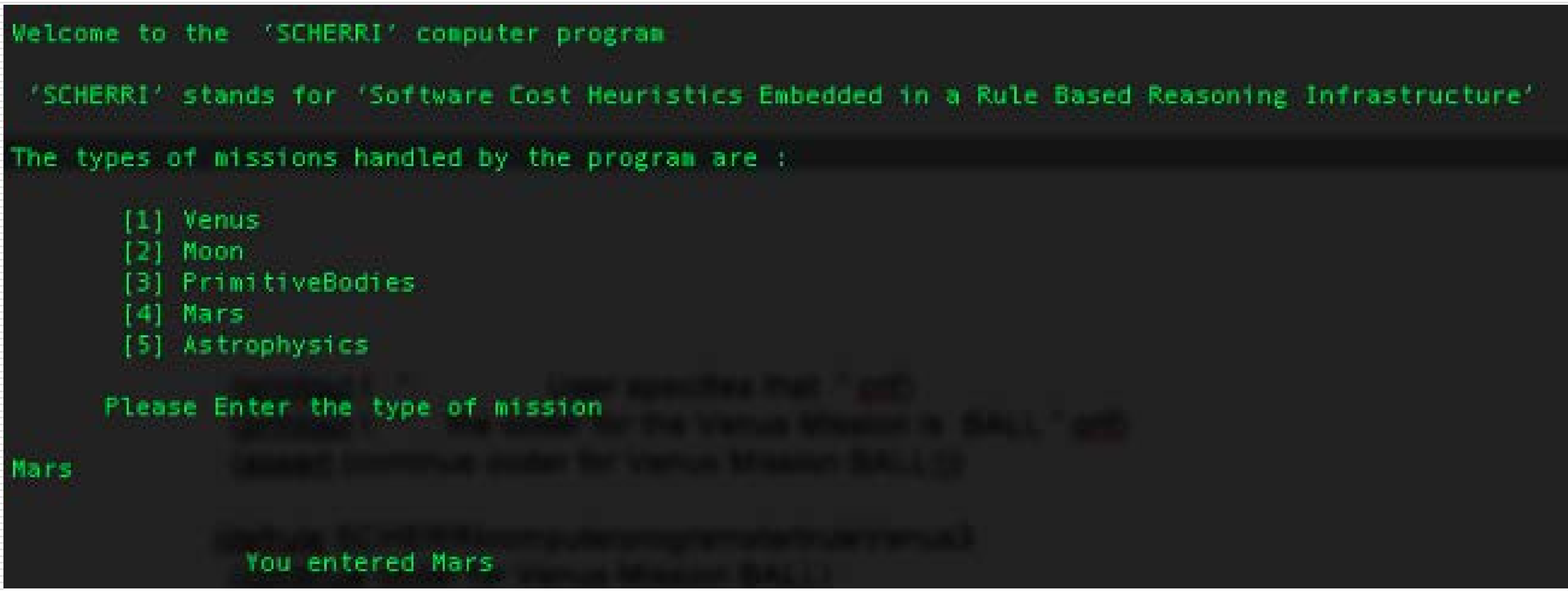
Sample Data

The Program

Software Cost Heuristics Embedded in a Rule-Based Reasoning Infrastructure (SCHERRI)

- Incorporates ideas presented thus far
- Rule-based system/expert system
  - Programmed in CLIPS
  - Comprised of ~100 rules
  - 1700 source lines of code
- Queries user for input
- Produces output used to run estimating models
- States the Basis of Estimate (BoE)

SCHERRI Initial Screen



Basis of Estimate

```
            User specifies that
 the astrophysics mission is Type X

  Since

  (1) The mission is for Astrophysics Type X

   WISE code from the PDR CADRe will be used
    for SEER/SEM input
    together with new reused and modified % allocations
    Fault protection SLOC from JPL is also used

   The % breakouts are as follows:
   % of new SLOC : 25%
   % of reused (as is) SLOC = 25%;
   % of reused (modified) SLOC = 50%

   These values will be repeated at
   the end of the program together with
   the other rule based derived SEER SEM inputs


Enter the totalcode
```

SCHERRI Output

```
Enter the totalcode

1000

Total Delivered Code =  1000
     % of new SLOC =    250.0
     % of reused (as is) SLOC =    250.0
     % of reused (modified) SLOC =  500.0


The reused mod SLOC has the following input %s :
    the re-design SLOC %s are: 10 %, 25%, 25%
    the re-code SLOC %s are: 10 %, 25%, 25%
    the re-test SLOC % is : 50%


The reused as is SLOC has the following input %s :
    the fraction of the SLOC that is re-designed =  0 %
    the fraction of the SLOC that is re-coded =  0 %
    the fraction of the SLOC that is re-tested =  50 %


DEVELOPMENT SUPPORT ENVIRONMENT parameters :

    turnaround time is VLO
    response time is LOW

PRODUCT DEVELOPMENT REQUIREMENTS parameters :

    requirements volatility is HIGH
    spec level - Reliability is HIGH-
    test level is HIGH
    quality assurance level is HIGH
    rehost (development to target) is HIGH-

PRODUCT REUSABILITY REQUIREMENTS parameter :
reusability level required is  NOM
user note: the nom value for this parameter renders the
  percentage input in this section meaningless
```

```
DEVELOPMENT ENVIRONMENT COMPLEXITY parameter :
process improvement is NOM

TARGET ENVIRONMENT parameters :
    memory constraint is NOM
    timing constraint is NOM
    real time constraint is NOM  NOM   NOM+
    security requirements is NOM

SCHEDULE AND STAFFING CONSTRAINTS parameters :
start date is user's choice
min time vs optimal effort is optimal effort

CONFIDENCE LEVELS parameters :
The following 2 parameter values are recommended by JPL SQI
effort probability is 70%
schedule probability is 70%

REQUIREMENTS parameter :
requirements after baseline is YES

SYSTEM INTEGRATION  parameters :
    number of programs being integrated  is 5
    concurrency of I&T is  is HI
    hardware integration is is NOM-  NOM   NOM+

ECONOMIC FACTORS  parameters :
    cost base year is user's choice is present year
    labor rate is  is $26,281
```

Sample Rules in SCHERRI

```
(defrule SCHERRIsloccomputationruleVenus8
    (comp rule seq Venus BALL BALL 1)
 =>
  (printout t   "       "        crlf)
  (printout t  " Enter the totalcode   " crlf )
  (printout t   "       "        crlf)
  (assert (TotalLogSloc (read)))
)

(defrule SCHERRIsloccomputationruleVenus9
   (comp rule seq Venus BALL BALL 1)
   (TotalLogSloc ?x)
 =>
  (printout t   "       "        crlf)
  (printout t  " Total Delivered Code =  " ?x crlf )
  (printout t  "     % of new SLOC =    "  (* .25 ?x) crlf)
  (printout t  "     % of reused (as is) SLOC =    "  (* .25 ?x) crlf)
  (printout t  "     % of reused (modified) SLOC =  "  (* .50 ?x) crlf)
  (printout t   "       "        crlf)
  (assert(trigger reused mod sloc)))
```

The Program:
Additional Comments

- Program provides a proof of concept
- Encapsulates only the techniques and data used thus far
- Plan to expand the program to include
  - Additional mission types
  - More concise and extensive BOEs
  - Additional data from recently completed projects
  - User friendly interface

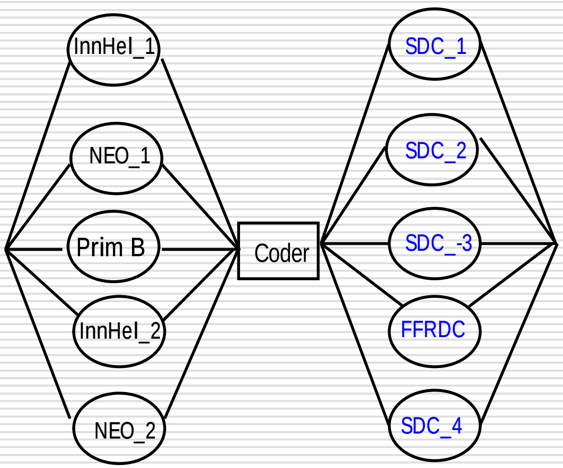
Summary
The Evolution of the Graph

- Efficient and Effective Methodologies for Consistency Checking had to be established
- There evolved a Dynamic : An Interplay of Data/Reason for Data
- Thinking Process is Compartmentalized and Formalized

“*Necessity is the Mother of Invention*”

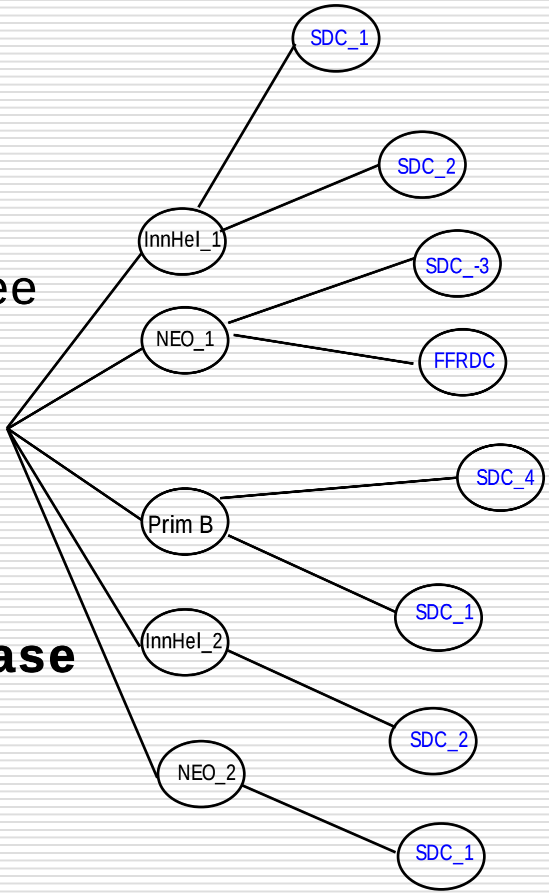
- Decision Graph represents the expert knowledge

From Decision Graph to Expert System



Portion of Decision Graph
with underlying Decision Tree

------------------------- >>



Decision Tree implies an expert system rule-base

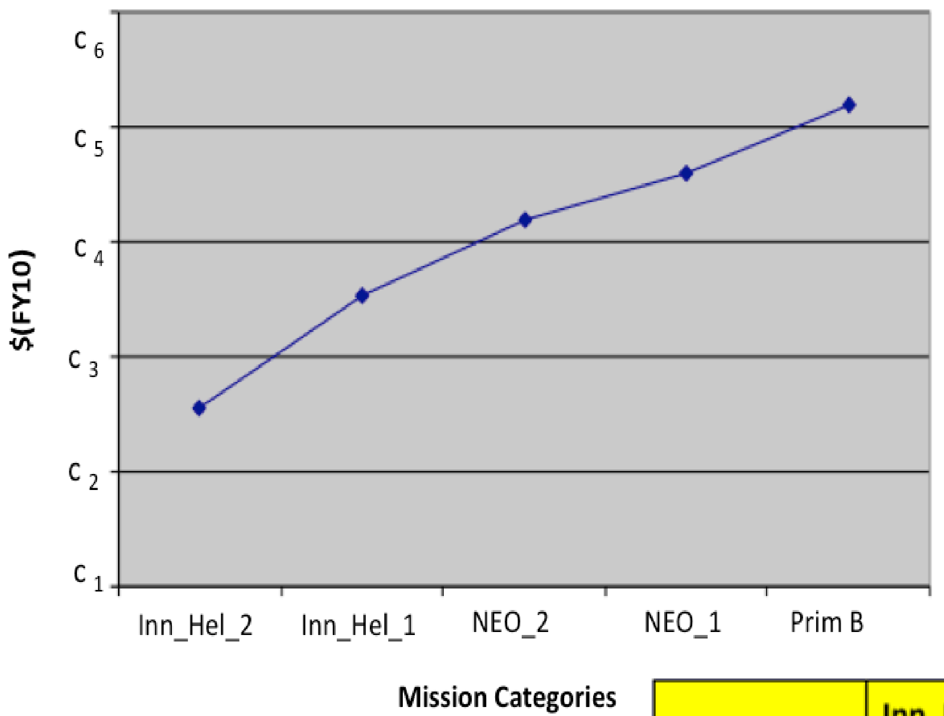
- Used to determine cost of a proposal of interest
- Computer explains reasoning for costs
- Rule-base design facilitates expert modification
- Rules were extracted and implemented

Future Work - Formulation of Trend Line with Justification

- **Inner Heliosphere Mission 2**
  - Both organizations experienced in this type of flight software development
  - One was a product line
- **Inner Heliosphere Mission 1**
  - Contractors slightly less than product line
- **Near Earth Object 2**
  - Higher cost based on high new code percentage
  - Higher costs due to variation in contractor pairing
- **Near Earth Object 1**
  - Costs based on inherited internal JPL project code
  - Higher costs due to large amount of inherited code
- **Primitive Bodies**
  - Higher costs due to variation in contractor pairing

Rule-based system designed to capture the characteristics of estimating processes for computer explanation

Mission Category Trend Line



	Inn_Hel_2	Inn_Hel_1	NEO_2	NEO_1	Prim B
Average ESLOC	#	#	#	#	#
ESLOC Range	# - #	# - #	# - #	# - #	# - #
# of Missions	#	#	#	#	#

Useful Resources and Web Sites

- "*The Genesis of a Formal Tool for Reasoning about Flight Software Cost Analysis,* Dr. John Spagnuolo, Jr. and Sherry Stukes, 2012 IEEE Aerospace Conference, Big Sky, MT, March 2012
- "*Software Cost Estimation Using a Decision Graph Process: A Knowledge Engineering Approach",* Sherry Stukes and Dr. John Spagnuolo, Jr., ISPA SCEA Joint Annual Conference & Training Workshop, June 2011
- SEER-SEM, v8.0.14, Galorath Inc., El Segundo, CA, 2011
- CADRe data – Eric Plumer, NASA Headquarters, (202) 358-5178
- RedStar Library – Mary Ellen Harris, SAIC, (256) 971-6425
- NASA Cost Estimating Handbook (2004 & 2008) (http://nasa.ceh.gov)
- Logical Foundations for Rule-Based Systems (Studies in Computational Intelligence) 2nd Edition, Antoni Ligeza, Springer-Verlag Berlin Heidelberg, 2006, pages 91-97

Author Biographies

Sherry Stukes

Ms. Stukes is a Software Systems Engineer/Cognizant Engineer at The Jet Propulsion Laboratory in Pasadena, California. She specializes in software estimating and software data collection in support of JPL Independent Cost Estimates, proposals, and CADRe development. Ms. Stukes manages a research project that will provide a software estimating tool for NASA Headquarters, which is not dependant on software lines of code.

Some of Ms. Stukes prior accomplishments include: development and maintenance of two large databases for the Air Force Space and Missile Systems Center (AF SMC): the Software Database (SWDB) and the Operations and Support Database (OSDB); instructor for the Army Logistics Management College (ASDC_2C) Software Estimating Models course; and advisor to Air Force Institute of Technology (AFIT) students conducting thesis projects in the area of software model calibration. Ms. Stukes was the 1997 International Society of Parametric Analysts (ISPA) Parametrician of the year.

Ms. Stukes holds a BS degree in Business Administration from California State University, Long Beach and an MBA from California Lutheran University.

Dr. John Spagnuolo, Jr.

Dr. Spagnuolo is presently serving as an Engineering Cost Analyst in the Engineering Cost Estimation Group at The Jet Propulsion Laboratory in Pasadena, California. He specializes in the preparation of Cost Estimation Data Requirements (CADRes), Cost Estimating relationships (CERs) and software cost estimation and analysis. He holds degrees in mathematics from Clarkson College of Technology, University of California at Los Angeles, and the Doctor's degree from Rensselaer Polytechnic Institute.

In the past, Dr. Spagnuolo has received several awards and certificates of recognition relating to his work in neural networks and solar physics. He received the Space Act Award for his paper on the Computation and Visualization of Archimedean spirals in 3 dimensions. Along with numerous conference and journal articles, he has published several abstracts in the NASA Tech Briefs Journal. He also developed an architecture for a hierarchical planning system for computerized military war gaming and an expert system for use in automated decision making in a computer war game for which he won best session paper at the Military Operations Research Society (MORS) Conference.

Presently, Dr. Spagnuolo is studying Newton's Principia from a mathematical perspective and doing research in mapping cognition onto an artificial neural network

List of Terms

ATLO	Assembly, Test, Launch Operations
BoE	Basis of Estimate
CADRe	Cost Analysis Data Requirement
C&DH	Command and Data Handling
CEH	Cost Estimating Handbook
CER	Cost Estimating Relationship
CLIPS	C Language Integrated Production System
EM	Engineering Model
ESLOC	Equivalent (new) Source Lines of Code
FFRDC	Federally Funded Research and Development Center

List of Terms

FSW	Flight Software
FY	Fiscal Year
GN&C	Guidance, Navigation and Control
GSW	Ground Software
ICE	Independent Cost Estimate
I&T	Integration and Test
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
KB	Knowledge Base
LCC	Life Cycle Cost

List of Terms

Mgmt	Management
NPR	NASA Procedural Requirement
ONCE	One NASA Repository
S/C	Spacecraft
SCHERRI	Software Cost Heuristics Embedded in a Rule-Based Reasoning Infrastructure
SDC	Software Development Contactor
SE	Systems Engineering
SEER-SEM	System Evaluation and Estimation Review – Software Estimation Model
SLiC	Software Line Counter (code counter)

List of Terms

SLOC	Source Lines of Code
SMART	Software Measurement Analysis Repository Tool
SQI	Software Quality Improvement
SW	Software
WBS	Work Breakdown Structure