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iTAP Methods, Processes and Tools

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Systems Engineering Research Center (SERC)

iTAP Methods, Processes and Tools

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Agenda

- End Vision
- Status
- Phase 4 Plans
  - Task 2: iTAP Methods and Tools Piloting and Refinement
  - Task 3: Next-Generation, Full-Coverage Cost Estimation Model Ensembles

Research Objectives

- Total Ownership Cost (TOC) modeling to enable affordability tradeoffs with integrated software-hardware-human factors
- Current shortfalls for ilities tradespace analysis
  - Models/tools are incomplete wrt/ TOC phases, activities, disciplines, SoS aspects
  - No integration with physical design space analysis tools, system modeling, or each other
- New aspects
  - Integrated costing of systems, software, hardware and human factors across full lifecycle operations
  - Extensions and consolidations for DoD application domains
  - Tool interoperability and tailorability (service-oriented)
- Can improve affordability-related decisions across all joint services

Approach

- Research and development
  - Create new ensemble of cost models with DoD stakeholders for broader coverage.
  - Enable interoperability with other toolsets and researchers (plug and play)
- Piloting and refinement
  - Engaging with DoD organizations to pilot the TOC methods, process and tools (MPTs); then refine them based on the results of the pilot applications

Progress

- Extended parametric cost models for breadth of engineering disciplines to include systems engineering, software engineering and hardware.
- Improved TOC capabilities by adding lifecycle maintenance models.
- Added Monte Carlo risk analysis for subset of cost parameters in integrated SE/SW/HW cost model.
- Initial extensions of general cost models for DoD system types starting with space systems and ships.
- Developed web service for Orthogonal Defect Classification Constructive Quality Model (ODC COQUALMO) supporting tool interoperability (costing in the cloud).
- Successful piloting and follow-on extensions of product line model at NAVAIR.

Product Line TOC Modeling

- Extending models and tools to analyze TOC for a family of systems. The value of investing in product-line flexibility using Return-On-Investment (ROI) and TOC is assessed with parametric models adapted from the Constructive Product Line Investment Model (COPLIMO).
- Models are implemented in separate tools for 1) System-level product line flexibility investment model and 2) Software product line flexibility investment model. The detailed software model includes schedule time with NPV calculations.

Example Product Line TOC and ROI

Open Sa

Aircraft
Ground Vehicle
✓ Missile
Ship

System Type

System Costs

Average Product Development Cost (Burdened $M) 5
Ownership Time (Years) 3
Annual Change Cost (% of Development Cost) 4
Interest Rate (Annual %) 7

Product Line Percentages

Unique % 40
Adapted % 30
Reused % 30

Relative Costs of Reuse (%)

Relative Cost of Reuse for Adapted 40
Relative Cost of Reuse for Reused 5

Investment Cost

Relative Cost of Developing for PL Flexibility via Reuse 1.7

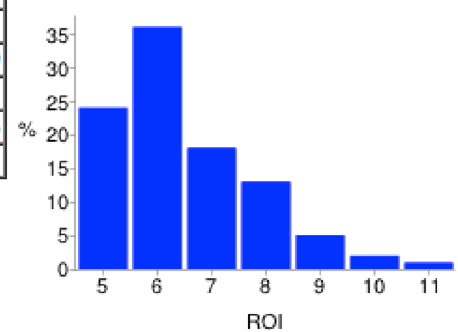
Calculate Monte Carlo On

Means

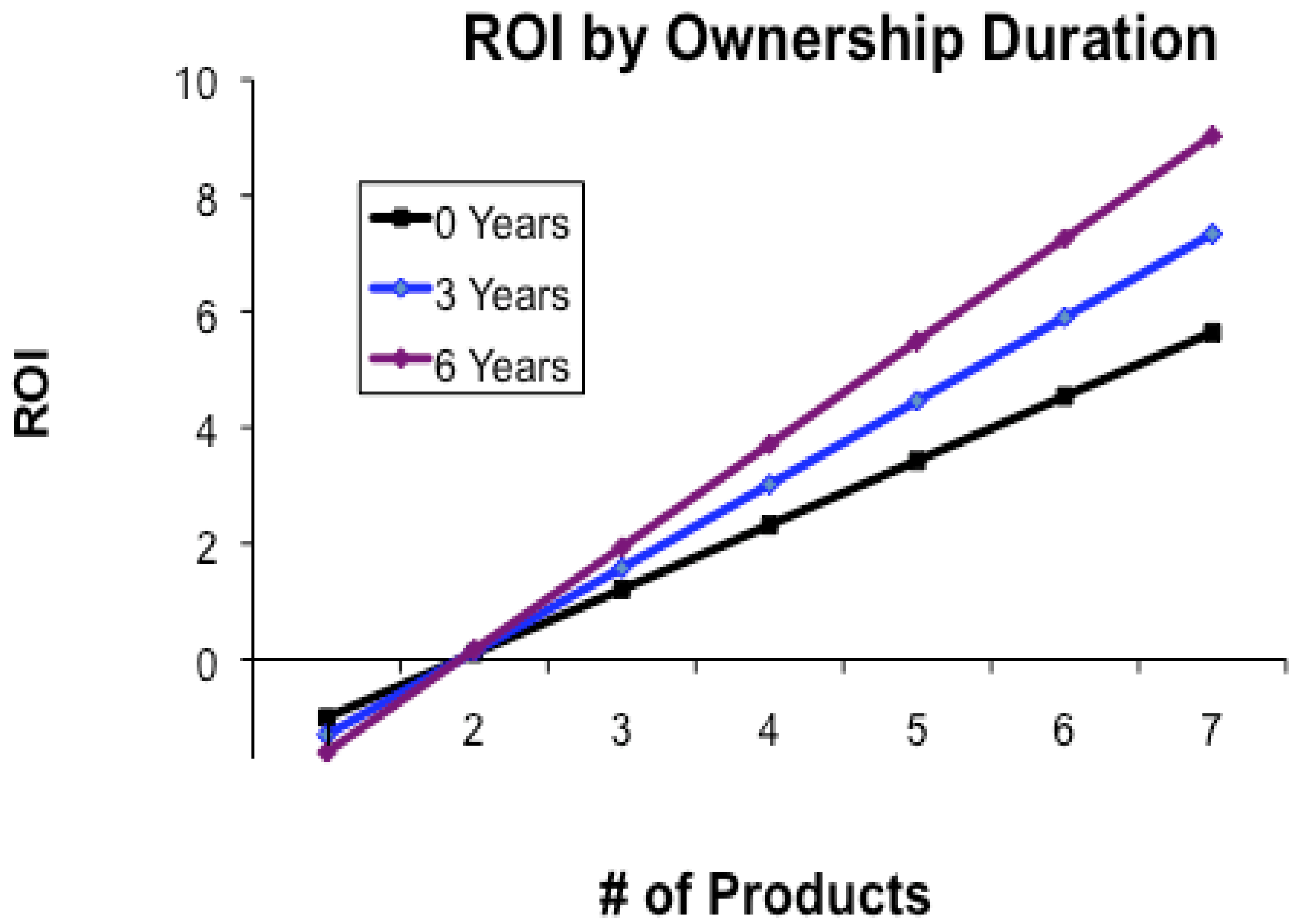
# of Products	1	2	3	4	5	6	7
Development Cost ($M)	$7.1	$2.7	$2.7	$2.7	$2.7	$2.7	$2.7
Ownership Cost ($M)	$0.9	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3
Cum. PL Cost ($M)	$8.0	$10.9	$13.9	$16.9	$19.9	$22.9	$25.9
PL Flexibility Investment ($M)	$2.1	$0	$0	$0	$0	$0	$0
PL Effort Savings	($2.4)	$0.3	$2.9	$5.5	$8.1	$10.7	$13.3
Return on Investment	-1.12	0.12	1.36	2.60	3.84	5.08	6.32

Monte Carlo Results

Mean=6.5 SD=1.3



Sensitivity Analysis Example



Product Line Extension

- Multi-mission, multi-platform needs call for extension of the top-level COPLIMO model to handle subsystems. Immediate pilot applications include:
  - NAVAIR avionics software product line modeling
  - USAF/SMC spacecraft and ground systems cost model development
- Each subsystem has respective cost factors and product line characteristics including
  - Fractions of system fully reusable, partially reusable and cost of developing them for reuse
  - Fraction of system variabilities and cost of development
  - System lifetime and rates of change

Extended Product Line Model

For Set of Products:

For each subsystem:

- Average Product Cost
- Annual Change Cost
- Ownership Time
- Percent Mission-Unique, Adapted, Reused
- Relative Cost of Developing for PL Flexibility via Reuse
- Relative Costs of Reuse

→ **Systems Product Line Model** →

As Functions of # Products, # Years in Life Cycle:

- PL Total Ownership Costs
- PL Flexibility Investment
- PL Savings (ROI)

Example Single System TOC

Systems Engineering | Software | Hardware | **Summary**

Systems Engineering Acquisition
Effort =1767.4 Person-months
Schedule = 17.7 Months
Cost = $17.7 M

Systems Engineering Maintenance (15 Years)
Annual Cost = $1.5 M
Total Cost = $23.1 M

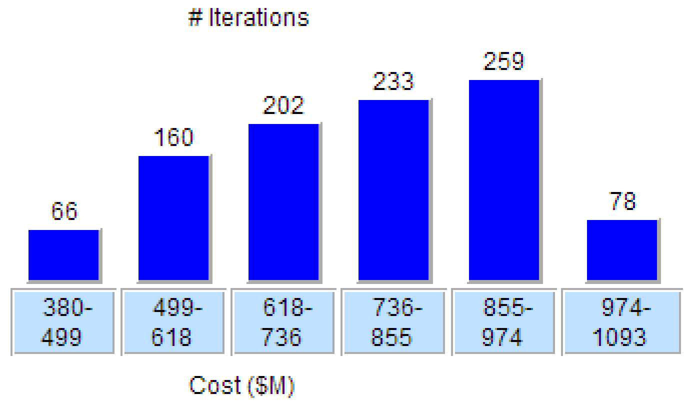
Software Development (Elaboration and Construction)
Effort = 11520.3 Person-months
Schedule = 80.3 Months
Cost = $115.2 M

Software Maintenance (15 Years)
Annual Cost = $8.5 M
Total Cost = $127.7 M

Hardware Development and Production
Cost = $481.6 M

Totals
Acquisition Cost = $614.4 M
Maintenance Cost = $150.8 M
Total Cost = $765.2 M

Total Cost Distribution Function



Total Cost Confidence Levels ($M)

10%	525.38
20%	600.83
30%	661.31
40%	721.87
50%	778.13
60%	827.96
70%	870.80
80%	913.87
90%	959.81
100%	1,093.48

Service-Oriented Tool Interoperability

- The ODC COQUALMO and Product Line TOC models/tools have been enhanced for interoperability and tailorability.
- Adaptations to the web-based tools enable other toolsets to plug-in, so their analyses can be cross-pollinated with cost, schedule and quality dimensions.
  - External applications can automatically send input parameters and/or files and receive results in lieu of manual user sessions.
  - Ability to modify or add internal model parameters for different scenarios (e.g. effort, schedule and quality calibration parameters; phase/activity distributions for effort and schedule; defect type distributions, etc.).
  - APIs demonstrated for multiple languages and platforms.

Phase 4 Plans – Task 2

- Collaboration with AFIT for a joint Intelligence, Surveillance and Reconnaissance (ISR) mission application involving heterogenous teams of autonomous and cooperative agents.

- NPS will provide cost modeling expertise, tools and Monterey Phoenix (MP) modeling support. A focus will be on translations between models/tools in MBSE, specifically mapping architectural elements into cost model inputs.

- Approach
  - Develop a baseline operational and system architecture to capture a set of military scenarios.
  - Transition the baseline architecture to the MP environment.
  - Utilize the executable architecture modeling framework of MP to perform automated assertion checking and find counterexamples of behavior that violate the expected system's correctness.
    - Operational scenarios will be cycled through the MP modeling process, whereby alternate events are captured for each actor in each scenario. This will produce a superset of scenario variants from the behavior models, suitable for input to tradespace analysis and cost models.
  - Design and demonstrate an ISR UAV tradespace.
  - Develop cost model interfaces for components of the architecture in order to evaluate cost effectiveness in an uncertain future environment.

Phase 4 Plans – Task 3

- Continue extending the scope and tradespace interoperability of cost models and tools from previous phases.

- Cost modeling will engage domain experts for Delphi estimates, evolve baseline definitions of cost driver parameters and rating scales for use in data collection, gather empirical data and determine areas needing further research to account for differences between estimated and actual costs.
  - Prototype cost models and tools will be extended accordingly for piloting and refinement.

- For tool interoperability we will integrate cost models in different ways with MBSE architectural modeling approaches and as web services. We will also automate systems and software risk advisors that operate in conjunction with the cost models.

- NPS will provide domain expertise for SysML cost model integration with Georgia Tech and USC to add software cost model formulas and the risk assessment capabilities.
  - This is also allied with Task 2 where we will assess Monterey Phoenix (MP) for automatically providing cost information from architectural models. MP will extract software sizing cost model inputs to compute costs, and we will assess mapping MP architectural elements into systems engineering cost model inputs.

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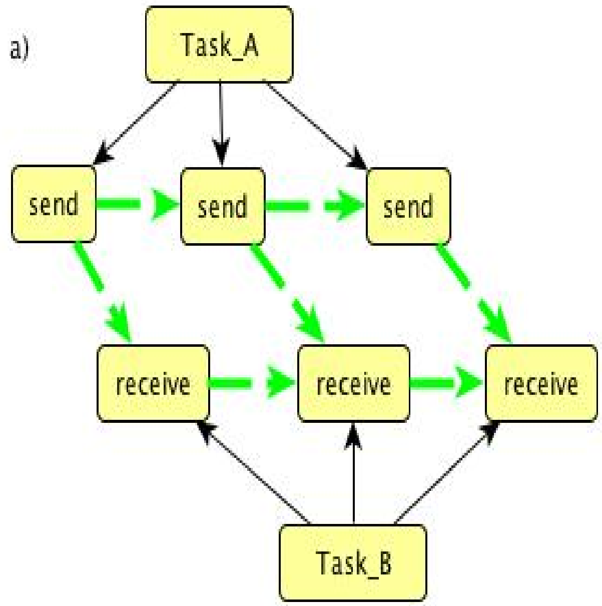
Monterey Phoenix Overview

- Monterey Phoenix (MP) is approach to formal software and system specification based on behavior models
- A view on the architecture model as a high level description of possible behaviors of subsystems and interactions between subsystems
- The emphasis on specifying the interaction between the system and its environment
- The behavior composition operations support architecture reuse and refinement toward design and implementation models
- Executable architecture models provide for system architecture testing and verification with tools
- See http://wiki.nps.edu/display/MP

MP Pipe/Filter Architecture Pattern Example

SCHEMA simple_message_flow
ROOT Task_A: (* send *);
ROOT Task_B: (* receive *);
COORDINATE $x: send FROM Task_A,
$y: receive FROM Task_B
DO ADD $x PRECEDES $y OD;



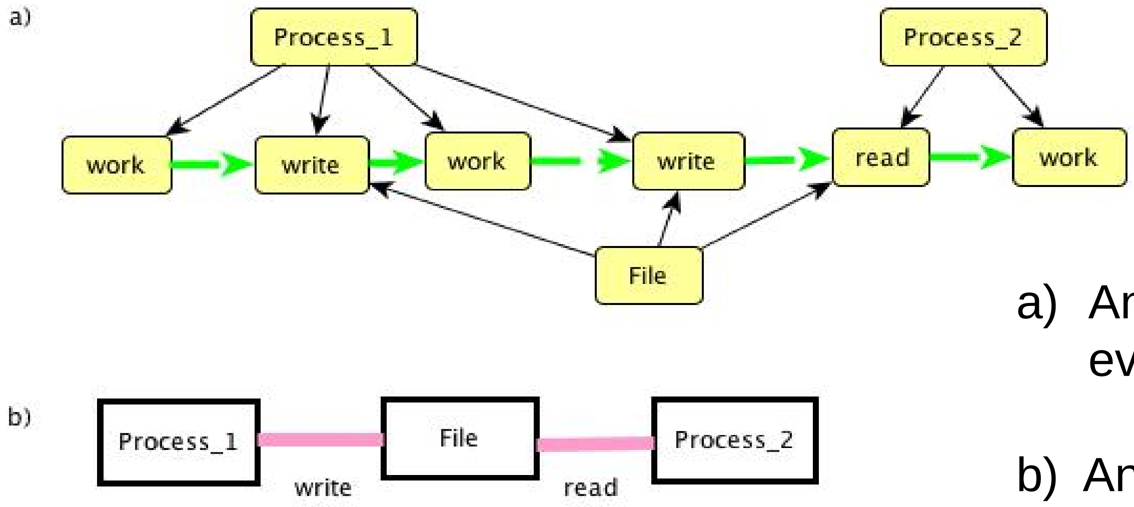
a) Example of composed event trace

b) An architecture view for the schema

MP Data Items as Behaviors

Data items are represented by actions that may be performed on that data

SCHEMA Data_flow
ROOT Process_1: (* work write *);
ROOT Process_2: (* (read | work) *);
ROOT File: (* write *) (* read *);
Process_1, File SHARE ALL write;
Process_2, File SHARE ALL read;



a) An example of composed event trace

b) An architecture view

Phase 4 References

- K. Giammarco and M. Auguston, “Well, You didn’t Say not to! A Formal Systems Engineering Approach to Teaching an Unruly Architecture Good Behavior”, Complex Adaptive Systems Conference, 2013
- M. Auguston and C. Whitcomb, "Behavior Models and Composition for Software and Systems Architecture", ICSSEA 2012, 24th International Conference on Software & Systems Engineering and their Applications, 2012
- R. Madachy and R. Valerdi, “Automating Systems Engineering Risk Assessment”, Proceedings of the 8th Annual Conference on Systems Engineering Research, 2010
- R. Madachy, *Heuristic Risk Assessment Using Cost Factors*, IEEE Software, May 1997

Backups

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Ship RDT&E Point Estimate

System Cost Model Suite

Options

Monte Carlo Risk: Off

Systems Engineering | Software | Hardware | Summary

Constructive Systems Engineering Cost Model (COSYSMO)

System Size

	Easy	Nominal	Difficult
# of System Requirements	120	185	48
# of System Interfaces	12	67	45
# of Algorithms	19	125	58
# of Operational Scenarios	3	14	8

System Cost Drivers

Requirements Understanding	High	Documentation	Nominal	Personnel Experience/Continuity	Nominal
Architecture Understanding	High	# and Diversity of Installations/Platforms	Very High	Process Capability	Nominal
Level of Service Requirements	Very High	# of Recursive Levels in the Design	Nominal	Multisite Coordination	Nominal
Migration Complexity	Nominal	Stakeholder Team Cohesion	Nominal	Tool Support	Nominal
Technology Risk	Nominal	Personnel/Team Capability	Nominal		

Maintenance Off

System Labor Rates

Cost per Person-Month (Dollars) 10000

Calculate

Ship RDT&E Point Estimate

Results
Systems Engineering
Effort =1767.9 Person-months
Schedule = 17.7 Months
Cost = $17679187

Total Size =2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

Phase / Activity	Conceptualize	Develop	Operational Test and Evaluation	Transition to Operation
Acquisition and Supply	34.7	63.1	16.1	9.9
Technical Management	66.1	114.2	75.1	45.1
System Design	180.3	212.2	90.2	47.7
Product Realization	34.5	79.6	84.9	66.3
Product Evaluation	98.6	148.0	219.2	82.2

Your output file is http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt

Ship RDT&E Point Estimate

Systems Engineering | **Software** | Hardware | Summary

Constructive Cost Model (COCOMO II)

Software Size Sizing Method: Source Lines of Code

	SLOC	% Design Modified	% Code Modified	% Integration Required	Assessment and Assimilation (0% - 8%)	Software Understanding (0% - 50%)	Unfamiliarity (0-1)
New	850000						
Reused	225000	0	0	50	4		
Modified	400000	10	15	60	4	20	.4

Software Scale Drivers

Precedentedness	Nominal	Architecture / Risk Resolution	Nominal	Process Maturity	Nominal
Development Flexibility	Low	Team Cohesion	High		

Software Cost Drivers

Product

Required Software Reliability	Very High
Data Base Size	Nominal
Product Complexity	High
Developed for Reusability	Nominal
Documentation Match to Lifecycle Needs	Nominal

Personnel

Analyst Capability	Nominal
Programmer Capability	Nominal
Personnel Continuity	Nominal
Application Experience	Nominal
Platform Experience	Nominal
Language and Toolset Experience	Nominal

Platform

Time Constraint	High
Storage Constraint	High
Platform Volatility	Nominal

Project

Use of Software Tools	Nominal
Multisite Development	Nominal
Required Development Schedule	Nominal

Maintenance Off

Software Labor Rates

Cost per Person-Month (Dollars) 10000

Calculate

Ship RDT&E Point Estimate

Systems Engineering | Software | **Hardware** | Summary

Advanced Missions Cost Model (AMCM)

Quantity	1
Dry Weight (lb.)	10000000
Mission Type	Ship - Amphib Assault
IOC Year	2013
Block Number	1
Difficulty	Average

Calculate

Results

Hardware Development and Production
Total Cost = $608 M

This is a simple advanced missions cost model (AMCM) for quick turnaround, rough-order-of-magnitude estimating. The model can be used for estimating the development and production cost of spacecraft, space transportation systems, aircraft, missiles, ships, and land vehicles. Initial model provided courtesy of NASA with extensions by NPS.

Ship RDT&E Point Estimate

Systems Engineering	Software	Hardware	Summary

Systems Engineering Acquisition
Effort =1767.9 Person-months
Schedule = 17.7 Months
Cost = $17.7 M

Software Development (Elaboration and Construction)
Effort = 10344.6 Person-months
Schedule = 77.5 Months
Cost = $103.4 M

Hardware Development and Production
Cost = $608 M

Total
System Cost = $744.4 M

Your output file is http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_07_42_42_618469.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Ship RDT&E Monte Carlo Risk Analysis

Results
Systems Engineering
Effort =1767.4 Person-months
Schedule = 17.7 Months
Cost = $17673532

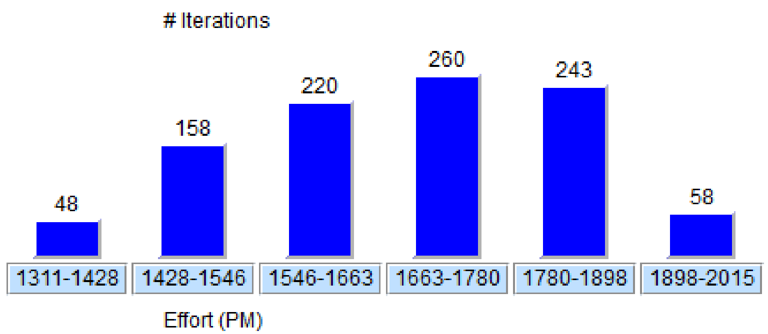
Total Size =2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

Phase / Activity	Conceptualize	Develop	Operational Test and Evaluation	Transition to Operation
Acquisition and Supply	34.6	63.1	16.1	9.9
Technical Management	66.1	114.2	75.1	45.1
System Design	180.3	212.1	90.1	47.7
Product Realization	34.5	79.5	84.8	66.3
Product Evaluation	98.6	147.9	219.2	82.2

Monte Carlo Results

Systems Engineering Effort Distribution Function



Systems Engineering Effort Confidence Levels

10%	1,480
20%	1,543
30%	1,610
40%	1,650
50%	1,703
60%	1,745
70%	1,785
80%	1,823
90%	1,876
100%	2,015

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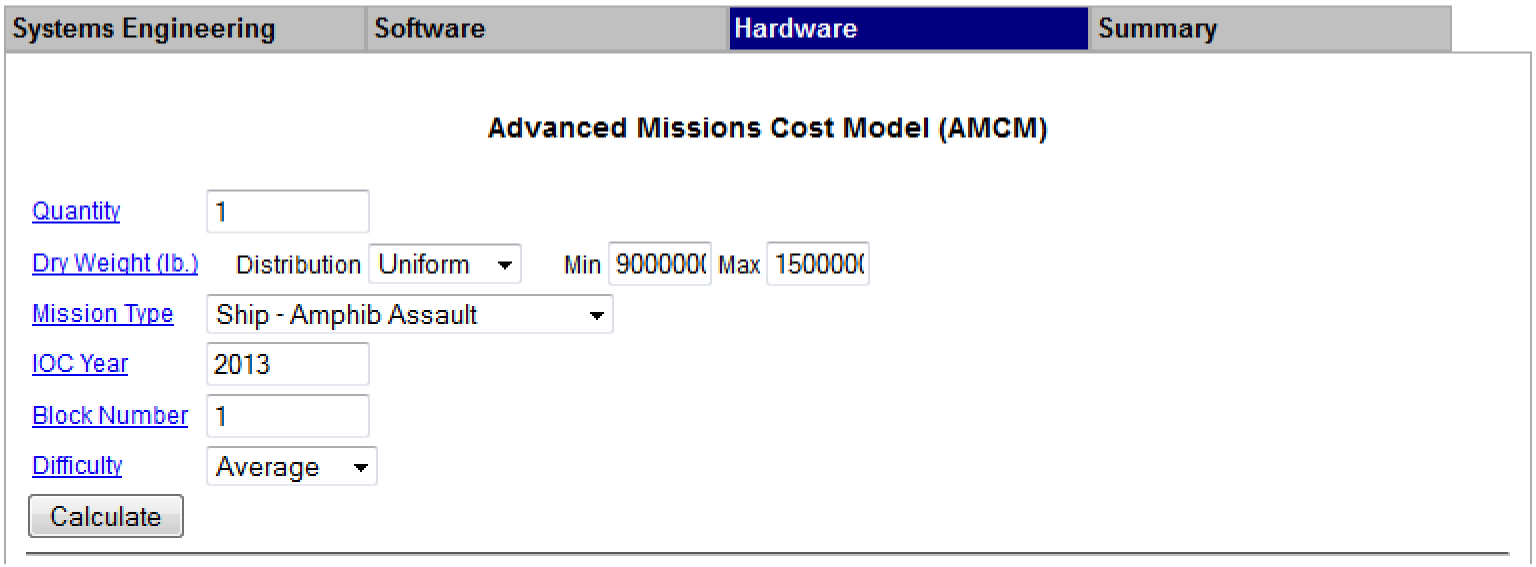
Ship RDT&E Monte Carlo Risk Analysis



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Ship RDT&E Monte Carlo Risk Analysis

Systems Engineering	Software	Hardware	**Summary**

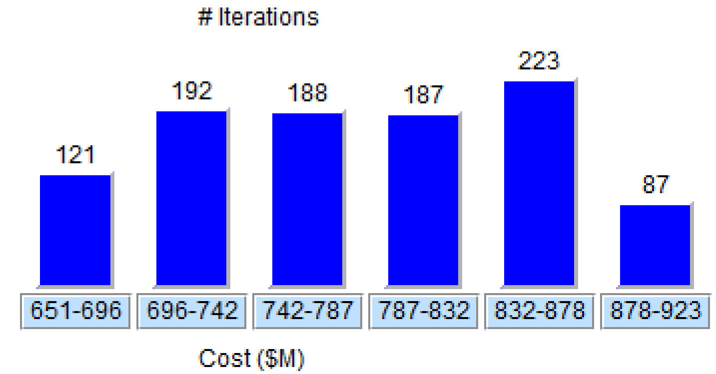
Systems Engineering Acquisition
Effort =1767.4 Person-months
Schedule = 17.7 Months
Cost = $17.7 M

Software Development (Elaboration and Construction)
Effort = 10344.6 Person-months
Schedule = 77.5 Months
Cost = $103.4 M

Hardware Development and Production
Cost = $685 M

Total
System Cost = $806.1 M

Total Cost Distribution Function



Total Cost Confidence Levels ($M)

10%	693.43
20%	716.06
30%	739.20
40%	762.84
50%	786.89
60%	815.19
70%	835.29
80%	855.01
90%	875.41
100%	923.45

System Maintenance

Systems Engineering | Software | Hardware | Summary

Constructive Systems Engineering Cost Model (COSYSMO)

System Size

	Easy	Nominal	Difficult
# of System Requirements	120	185	48
# of System Interfaces	12	67	45
# of Algorithms	19	125	58
# of Operational Scenarios	3	14	8

System Cost Drivers

Requirements Understanding	High	Documentation	Nominal	Personnel Experience/Continuity	Nominal
Architecture Understanding	High	# and Diversity of Installations/Platforms	Very High	Process Capability	Nominal
Level of Service Requirements	Very High	# of Recursive Levels in the Design	Nominal	Multisite Coordination	Nominal
Migration Complexity	Nominal	Stakeholder Team Cohesion	Nominal	Tool Support	Nominal
Technology Risk	Nominal	Personnel/Team Capability	Nominal		

Maintenance On Annual Change % 10 Maintenance Duration (Years) 15

System Labor Rates

Cost per Person-Month (Dollars) 10000

Calculate

System Maintenance

Results
Systems Engineering
Effort =1767.9 Person-months
Schedule = 17.7 Months
Cost = $17679187

Total Size =2650 Equivalent Nominal Requirements

Acquisition Effort Distribution (Person-Months)

Phase / Activity	Conceptualize	Develop	Operational Test and Evaluation	Transition to Operation
Acquisition and Supply	34.7	63.1	16.1	9.9
Technical Management	66.1	114.2	75.1	45.1
System Design	180.3	212.2	90.2	47.7
Product Realization	34.5	79.6	84.9	66.3
Product Evaluation	98.6	148.0	219.2	82.2

Maintenance
Annual Maintenance Effort = 154.0 Person-Months
Annual Maintenance Cost = $1539792
Total Maintenance Cost = $23096893

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Software Maintenance

Systems Engineering | Software | Hardware | Summary

Constructive Cost Model (COCOMO II)

Software Size Sizing Method: Source Lines of Code

	SLOC	% Design Modified	% Code Modified	% Integration Required	Assessment and Assimilation (0% - 8%)	Software Understanding (0% - 50%)	Unfamiliarity (0-1)
New	850000						
Reused	225000	0	0	50	4		
Modified	400000	10	15	60	4	20	.4

Software Scale Drivers

Precedentedness	Nominal	Architecture / Risk Resolution	Nominal	Process Maturity	Nominal
Development Flexibility	Low	Team Cohesion	High		

Software Cost Drivers

Product

Required Software Reliability	Very High
Data Base Size	Nominal
Product Complexity	High
Developed for Reusability	Nominal
Documentation Match to Lifecycle Needs	Nominal

Personnel

Analyst Capability	Nominal
Programmer Capability	Nominal
Personnel Continuity	Nominal
Application Experience	Nominal
Platform Experience	Nominal
Language and Toolset Experience	Nominal

Platform

Time Constraint	High
Storage Constraint	High
Platform Volatility	Nominal

Project

Use of Software Tools	Nominal
Multisite Development	Nominal
Required Development Schedule	Nominal

Maintenance On

Annual Change Size (ESLOC)	80000	Maintenance Duration (Years)	15
Software Understanding (0%-50%)	25	Unfamiliarity (0-1)	.4

Software Labor Rates

Cost per Person-Month (Dollars) 10000

Calculate

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Total Ship Maintenance

Systems Engineering	Software	Hardware	Summary

Systems Engineering Acquisition
Effort =1767.9 Person-months
Schedule = 17.7 Months
Cost = $17.7 M

Systems Engineering Maintenance
Cost = $23.1 M

Software Development (Elaboration and Construction)
Effort = 10344.6 Person-months
Schedule = 77.5 Months
Cost = $103.4 M

Software Maintenance
Cost = $103.8 M

Hardware Development and Production
Cost = $608 M

Total
System Cost = $856.0 M

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Acquisition and Maintenance Monte Carlo Risk Results (1/3)

Systems Engineering | Software | Hardware | **Summary**

Systems Engineering Acquisition
Effort =1767.4 Person-months
Schedule = 17.7 Months
Cost = $17.7 M

Systems Engineering Maintenance (15 Years)
Annual Cost = $1.5 M
Total Cost = $23.1 M

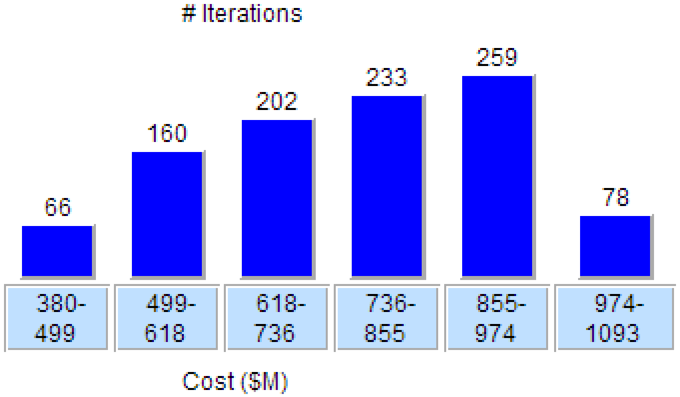
Software Development (Elaboration and Construction)
Effort = 11520.3 Person-months
Schedule = 80.3 Months
Cost = $115.2 M

Software Maintenance (15 Years)
Annual Cost = $8.5 M
Total Cost = $127.7 M

Hardware Development and Production
Cost = $481.6 M

Totals
Acquisition Cost = $614.4 M
Maintenance Cost = $150.8 M
Total Cost = $765.2 M

Total Cost Distribution Function



Total Cost Confidence Levels ($M)

10%	525.38
20%	600.83
30%	661.31
40%	721.87
50%	778.13
60%	827.96
70%	870.80
80%	913.87
90%	959.81
100%	1,093.48

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Acquisition and Maintenance Monte Carlo Risk Results (2/3)

Acquisition Monte Carlo Results

Systems Engineering Cost Confidence Levels ($M)

10%	14.80
20%	15.57
30%	16.15
40%	16.59
50%	17.07
60%	17.45
70%	17.78
80%	18.23
90%	18.76
100%	20.16

Software Engineering Cost Confidence Levels ($M)

10%	88.90
20%	98.85
30%	105.11
40%	110.15
50%	113.94
60%	120.28
70%	125.38
80%	133.06
90%	139.49
100%	178.62

Hardware Cost Confidence Levels ($M)

10%	239.39
20%	319.04
30%	379.37
40%	437.89
50%	490.02
60%	542.82
70%	592.04
80%	635.48
90%	679.27
100%	721.17

Acquisition and Maintenance Monte Carlo Risk Results (3/3)

Maintenance Monte Carlo Results

Systems Engineering Maintenance Cost Confidence Levels ($M)

10%	19.34
20%	20.34
30%	21.10
40%	21.68
50%	22.30
60%	22.80
70%	23.23
80%	23.82
90%	24.51
100%	26.33

Software Engineering Maintenance Cost Confidence Levels ($M)

10%	98.56
20%	109.59
30%	116.53
40%	122.12
50%	126.32
60%	133.35
70%	139.00
80%	147.52
90%	154.65
100%	198.03

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Satellite RDT&E Point Estimate

System Cost Model Suite

Project Name: MiniSat System Type: Satellite

Options
Monte Carlo Risk: Off

Systems Engineering | **Software** | **Hardware** | **Summary**

Satellite Hardware RDT&E

Element	Parameter		Cost
1. Payload			
1.1 Visible Light Sensor	Aperture diameter (m)	1.0	$128,827
2. Spacecraft			
2.1 Structure	Structure weight (kg)	245	$15,098
2.2 Thermal	Thermal weight (kg)	40	$4,100
2.3 Electrical Power System	X1 = EPS weight (kg)	420	$26,528
	X2 = BOL power (wt)	100	
2.4 Telemetry, Tracking and Command	TT&C weight (kg)	50	$10,698
2.5 Attitude Determination and Control	ADCS weight (kg)	110	$27,315

Calculate

Your output file is http://diana.nps.edu/~madachy/tools/data/cost_model_suiteSeptember_17_2013_08_46_43_265739.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

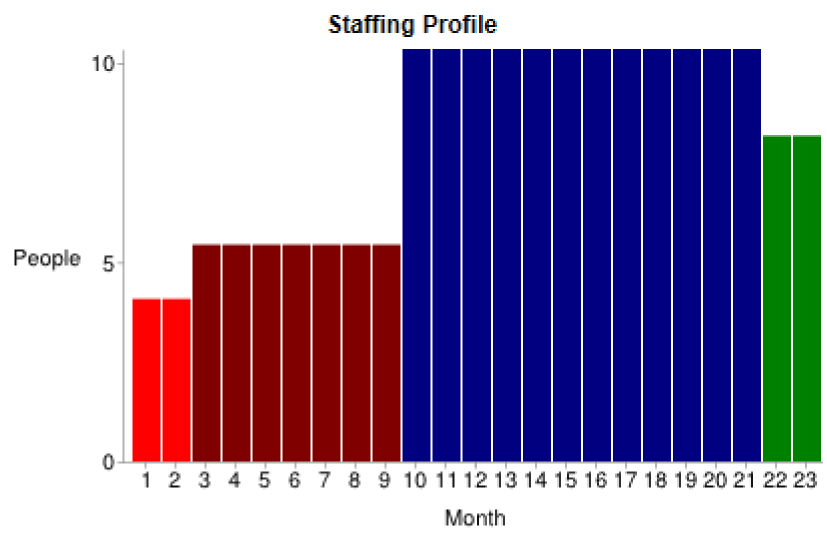
Software Cost Estimate Details

Results

Software Development (Elaboration and Construction)

Effort = 169.9 Person-months
Schedule = 20.0 Months
Cost = $1698762

Total Equivalent Size = 40000 SLOC



Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	10.2	2.5	4.1	$101926
Elaboration	40.8	7.5	5.4	$407703
Construction	129.1	12.5	10.3	$1291060
Transition	20.4	2.5	8.2	$203852

Software Activity Distribution (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	1.4	4.9	12.9	2.9
Environment/CM	1.0	3.3	6.5	1.0
Requirements	3.9	7.3	10.3	0.8
Design	1.9	14.7	20.7	0.8
Implementation	0.8	5.3	43.9	3.9
Assessment	0.8	4.1	31.0	4.9
Deployment	0.3	1.2	3.9	6.1

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AMCM Overview

- **The Advance Missions Cost Model (AMCM**) predicts development, recurring and mission operations costs of ground vehicles, ships, aircraft, helicopters, missiles, launch vehicles, spacecraft, and human explorations missions.

- It is a system level cost model appropriate for large scale programs requiring many different systems that will be integrated to perform a complex mission. The model is most useful in the pre-conceptual and conceptual design phases of a program when the actual design of the systems is not known and many factors are being traded off.

AMCM Description

- The AMCM is a two equation, multi-variable cost estimating relationship. The first equation predicts the development and production cost of the system based of various technical and programmatic factors. The second equation predicts the basic mission operations cost of the system.
- Both equations are fitted to a large historical database that spans 50 years of systems development. Most of the systems are US Government developed, but some commercial and European systems are included.
  - Database of land, water, air and space systems. The data includes 54 spacecraft, 22 space transportation systems, 61 aircraft, 86 missiles, 29 ships, and 18 ground vehicles. All of the data points are from programs that were completed through IOC.

SYSTEMS ENGINEERING Research Center

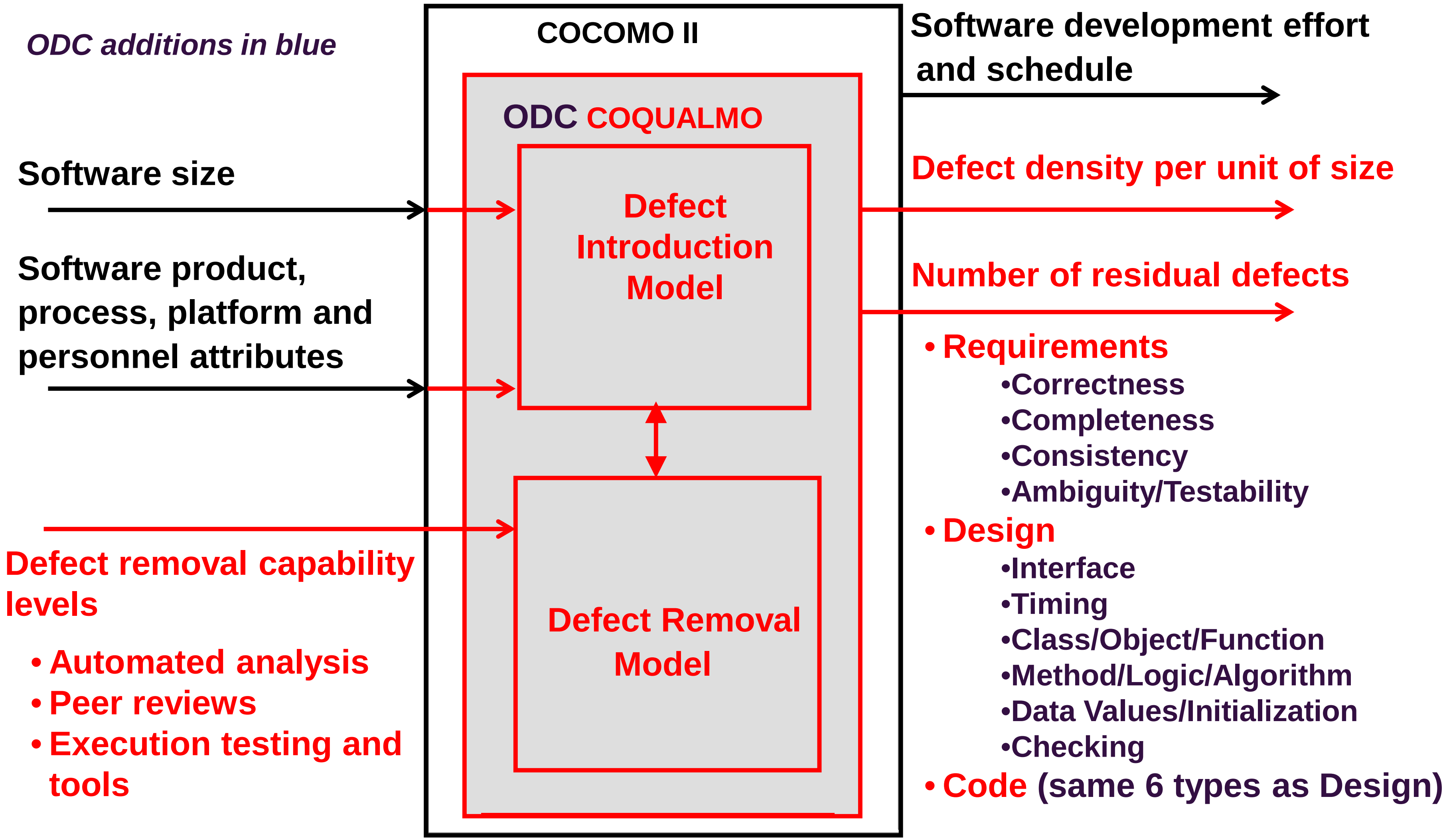
COQUALMO Background

- Cost, schedule and quality are highly correlated factors in software processes
- Thus the COnstructive QUALity MOdel (COQUALMO) was created to predict defects as an extension of the COCOMO II software cost model [Chulani, Boehm 1999]
  - Uses COCOMO II cost estimation inputs with defect removal parameters to predict the numbers of generated, detected and remaining defects for requirements, design and code
- Provides insights into cost/schedule/quality tradeoff analyses, quality investment payoffs, interactions amongst quality strategies, and likely schedule
- Enables what-if analyses that demonstrate the impact of
  - Defect removal techniques for automated analysis, peer reviews, and execution testing on defect types
  - Effects of **product**, personnel, project, and platform characteristics on software quality
- ODC COQUALMO is a further extension that predicts software defects introduced and removed classifying them with Orthogonal Defect Classification (ODC) defect types

ODC COQUALMO Overview

COQUALMO extensions to COCOMO II in red

ODC additions in blue



ODC Extension

- ODC COQUALMO decomposes defects using ODC categories [Chillarege et al. 1992]
  - Enables tradeoffs of different detection efficiencies for the removal practices per type of defect
- The ODC taxonomy provides well-defined criteria for the defect types and has been successfully applied on NASA projects and others
- With more granular defect definitions, ODC COQUALMO enables tradeoffs of different detection efficiencies for the removal practices per type of defect.
  - V&V techniques have different detection efficiencies for different types of defects, and may have overlapping capabilities between them
- ODC defect types can be mapped to technical performance parameters for trade analysis

ODC COQUALMO Outputs

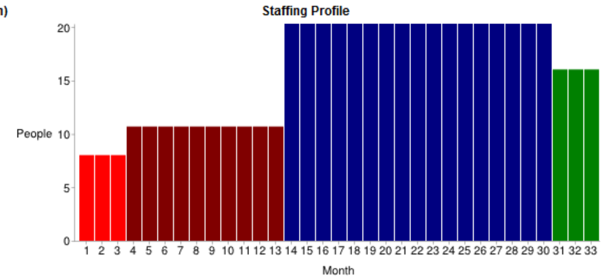
Software Development (Elaboration and Construction)

Effort = 465.3 Person-months
Schedule = 27.9 Months
Cost = $4653152

Total Equivalent Size = 100000 SLOC

Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	27.9	3.5	8.0	$279189
Elaboration	111.7	10.4	10.7	$1116757
Construction	353.6	17.4	20.3	$3536396
Transition	55.8	3.5	16.0	$558378



Software Effort Distribution for RUP/MBASE (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	3.9	13.4	35.4	7.8
Environment/CM	2.8	8.9	17.7	2.8
Requirements	10.6	20.1	28.3	2.2
Design	5.3	40.2	56.6	2.2
Implementation	2.2	14.5	120.2	10.6
Assessment	2.2	11.2	84.9	13.4
Deployment	0.8	3.4	10.6	16.8

Requirements Defects

	Introduced	Removed	Remaining
Ambiguity/Testability	70	28	42
Completeness	230	92	138
Consistency	170	76	93
Correctness	530	204	325

Design Defects

	Introduced	Removed	Remaining
Checking	146	62	83
Class/Object/Function	254	43	210
Data Values/Initialization	510	239	270
Interface	510	134	375
Method/Logic/Algorithm	580	309	270
Timing	0	0	0

Code Defects

	Introduced	Removed	Remaining
Checking	219	94	124
Class/Object/Function	381	65	315
Data Values/Initialization	765	359	405
Interface	765	201	563
Method/Logic/Algorithm	869	463	406
Timing	0	0	0

Your output file is https://diana.nps.edu/MSAcq/tools/data/COQUALMO_July_16_2012_21_08_56_333443.txt

Created by Ray Madachy at the Naval Postgraduate School. For more information contact him at rjmadach@nps.edu

Where?

- General cost modeling tool currently available at
  http://diana.nps.edu/~madachy/tools/cost_model_suite.php
  http://csse.usc.edu/tools/cost_model_suite.php