COCOMO II Predicts the Effects of Collaborative Software Development and Sustaining Engineering

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Special acknowledgments to the members of the development team :
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Agenda

- **NASA Mission**
- **United Space Alliance**
- **Space Shuttle Telemetry Ground Station Upgrade**
- **Station Software Development**
  - **Background**
  - **Collaborative Process**
- **Expectations**
  - **Results (Empirical vs. ETC)**
  - **Why ? (Empirical vs. Model)**
- **Summary**

NASA Mission

- **Administrator's Strategic Outlook**

  In the coming years, NASA will implement programs to achieve a **three-part mission** encompassing Scientific Research, Space Exploration, and **Technology Development and Transfer**. This mission describes what we are required to do in **response to policy and legislative mandates**. **(hq.nasa.gov/office/nsp/outlook.htm)**

- **President's External Assessment**

  The Administration has placed a **priority** on supporting and promoting high technology for **economic growth** through **effective partnerships**, both within Government and with **industry** and academia. Therefore, NASA will work closely with other Federal agencies to ensure coordinated efforts in the areas of space and aeronautics science and technology. **With increased emphasis** on pressing **domestic needs**, we will ensure the **relevance of our programs** to national science and **technology priorities** and to other domestic goals in areas such as the environment, health, education, and aviation safety.

  (hq.nasa.gov/office/nsp/assess.htm)

United Space Alliance Background

- **United Space Alliance (USA) is one of the world's leading space operations companies. Established in 1996 as a joint venture between the Boeing Company and Lockheed Martin Corporation , the company employs people in Texas, Florida, Alabama, California and Washington, D.C..**
- **Space Flight Operations Contractor**
  - USA is chartered to manage and conduct space operations work involving the operation and maintenance of systems associated with NASA's Space Shuttle and Space Station.
  - While executing this contract USA is to improve development and operations processes, foster meaningful small business participation, and participate in the NASA Technology Transfer program.

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United Space Alliance Role and Prerequisites

- **USA is obligated to provide software engineering support for the Shuttle ground based information and checkout equipment.**
  - Fix code level problems any time during processing cycle.
  - Modify software to provide any required capability.
- **Partnering Relationship**
  - Rights to source code and development environment for the purpose of Shuttle telemetry ground station processing (under non-disclosure).
  - Developer training.
  - Collaborate to produce require additional capabilities.
  - Critical operations support (Launch Operations).
  - Critical developer support (Bug Fixes).
  - Ongoing collaborative development support.
  - No solicitation of personnel.

Shuttle Telemetry Ground Station Upgrade - Mission

Real Time Operational Support

- Processing Facilities and on-Orbit support provided for all 4 Orbiters simultaneously
- Over 40 Orbiter and ground support equipment data signals from *each* vehicle
- Over 100 Orbiter system and integrated procedures for *each* vehicle supported
- Numerous vehicle troubleshooting test supported for *each* vehicle
- All data signals available for processing and monitoring real-time or post-test
- Support pre-flight checkouts, verifications, and troubleshooting on each Orbiters flight recorder
- Process, post launch and post landing, RF data dumps from Operational Flight Recorders
- Support post landing dump of Modular Auxiliary Data System (MADS) Recorder

Shuttle Ground Station

Customers

Communications
Instrumentation
APU
GNC
EPD (Orbiter and GSE)
HYD
SSME
Payloads
CCMS
FCMS
Software Development (CLCS, SDC, etc.)
JSC
MSFC

Data Products and Troubleshooting Tools

- Numerous data products and troubleshooting tools provided to the engineering community for real-time or post test processing:

ex: snapshots, engineering unit dumps, bit by bit compares, status dumps, display recordings, frequency monitoring, voltage readings, raw data dumps, lock status, command verification, measurement lookup, data simulation, magnetic tape copies

- Provide data playbacks, of OPS Recorder data, to JSC and Firing Rooms
- Provide KSC/JSC/MSFC engineering, tape copies and data products of recorder data.
- Data products provided to engineering Launch Commit Criteria
- Orbiter Instrumentation and Engine data provided real-time and/or post test to JSC/MSFC

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Shuttle Telemetry Ground Station - Architecture

The Ground Station consists of two sets of equipment located in the Shuttle Launch Control Center (Set A and Set B)

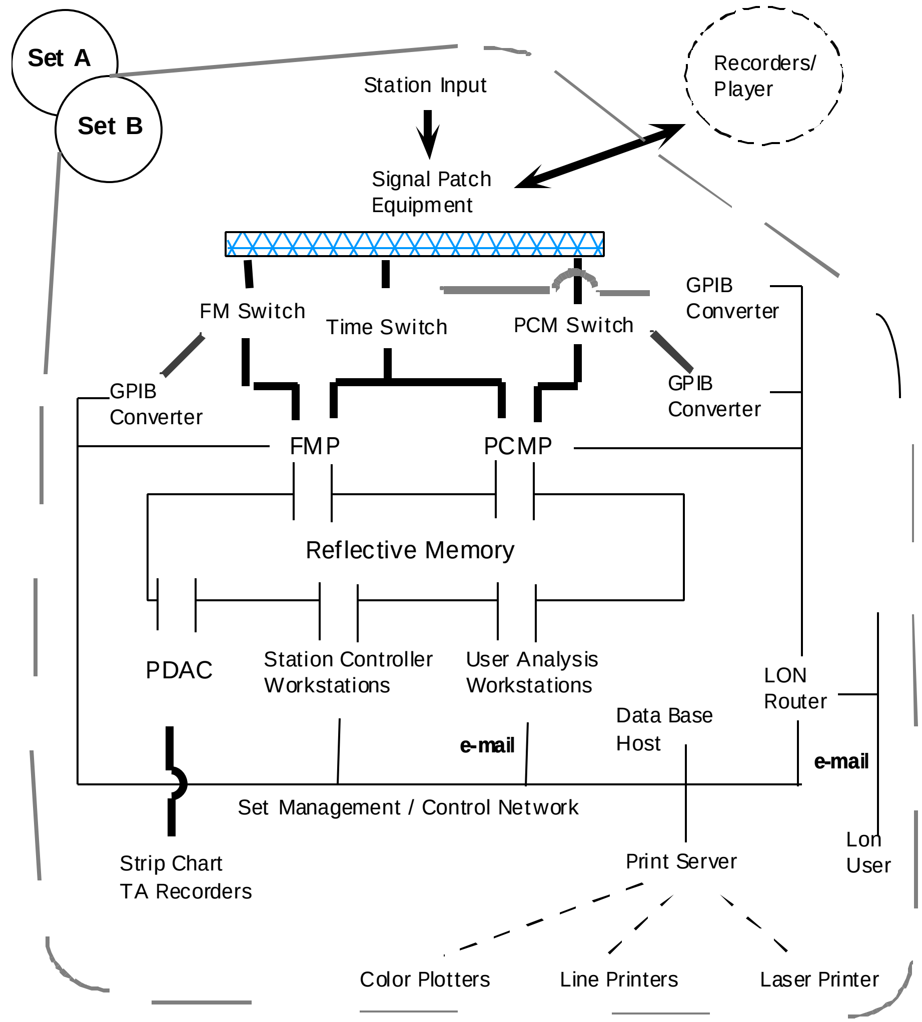
The station is fed signals from either a live source or recorders

Within a set, FM and PCM Signals are switched to and processed by any of 16 Pulse Code Modulation Processors (PCMPs) or Frequency Modulation Processors (FMPs)

These real time telemetry boxes are controlled and monitored from the station controllers

The station controller gets setup information from the data base host

Data is transferred to user analysis workstations or Programmable Digital to Analog Converters (PDACs) via reflective memory for data product production



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Shuttle Telemetry Ground Station - VME Chassis

Custom Software Evaluation

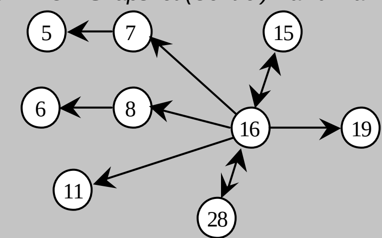
6 Years of Status Quo Development Produced

2 Custom code releases, written in VxWorks, using commercial drivers and operating systems.

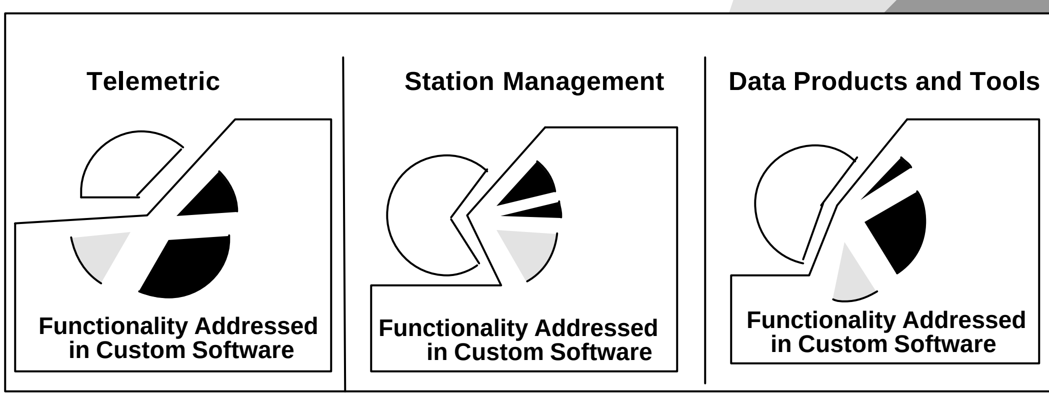
“Much User Resistance” (approximately 350KLOC)

Requirements Analysis

3.1 PCM Snapshot (Control) David Mann



The station controller (28) obtains load files and data from the DB Host (15) and loads, via Ethernet (16) the time and PCM Switches (5&6), the PCMP (11) and verifies the print server (19) is available.



- ■ - Available and Functional in First Two Releases
- ▨ - Available or Outlined in Code But Not Functional
- □ - Not Addressed in Software

Estimated additional 20 man-years over 5 years (20% growth probable, Virtual Re-Write)

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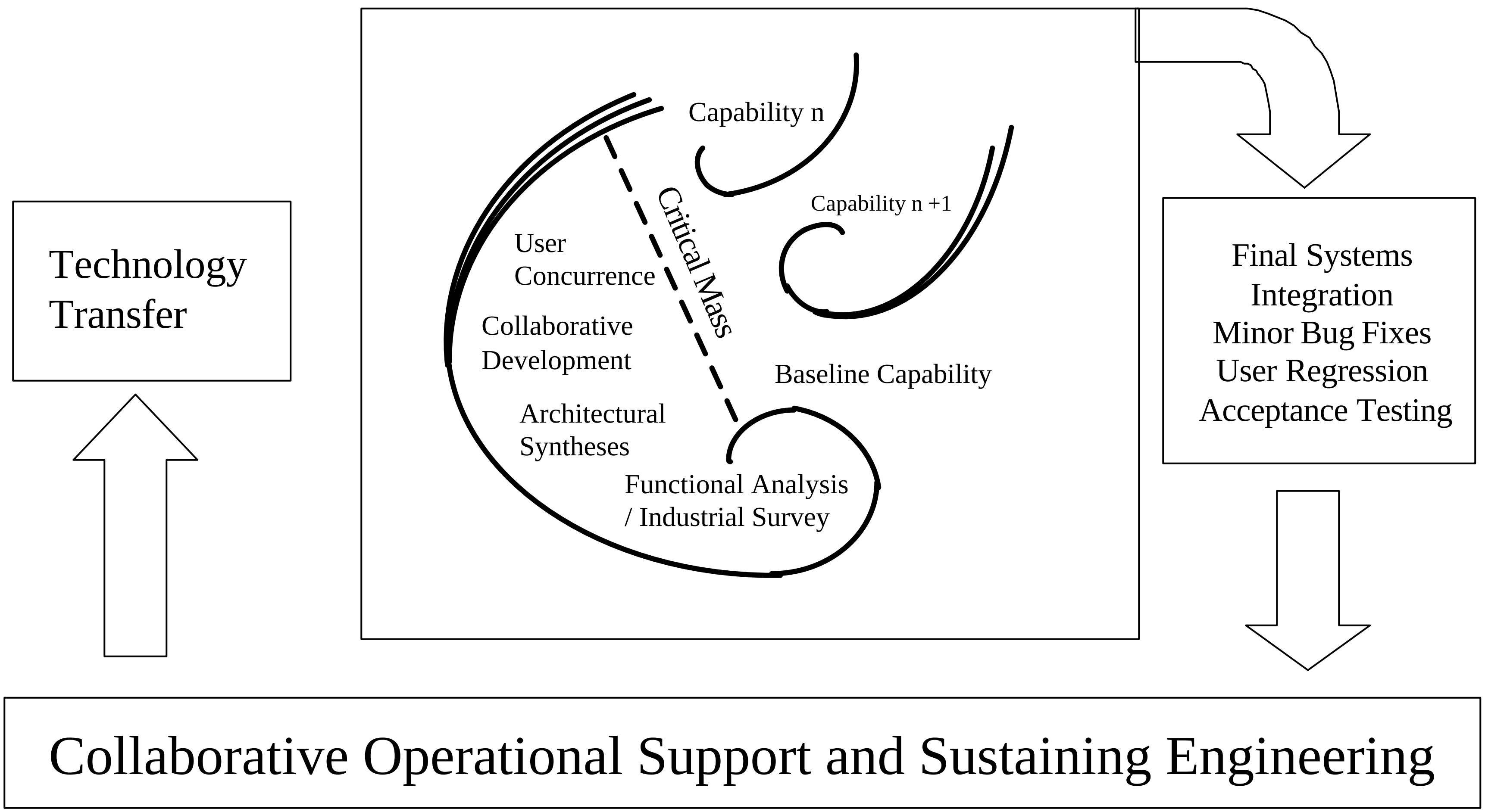
Development Process - Model



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Development Process - Developing Critical Mass

Critical Mass - enabling software, baseline functionality and interface tools to allow for multiple independent development activities.

Functional Analysis / Industrial Survey

Modified Function Point, Product/ Functional Overlay
Vendor Lists, Overlap and initial contact

Architectural Syntheses / Trade Studies

Product Examination

Source, Functionality, Usability
Operations Testing / Critique
Holes definitions
User Concurrence

Architectural Design

Holes Definition, Interfaces, Teams ,
Technical Support Estimates
Compatibility verification
Project Planning

Contract Negotiations

Development: Right to Source,
Training, Development Collaboration
Rights: Buyout License Sustaining,
Launch Support, Bug Fixes, Contracting

Cost and Decision Analyses

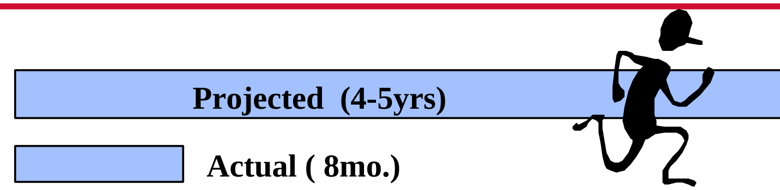
Collaborative Development to Produce Critical Mass

COTS Integration and Test (bug fixes and interfaces)
Systems Engineering on holes identified (interfaces, scope etc....)
Develop / acquire enabling software and tools
- Developer/User training
- Code / Development testing

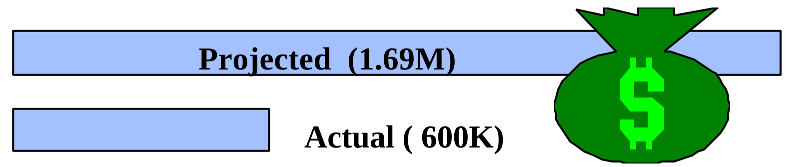
User Concurrence on Baseline Capabilities

Development Results

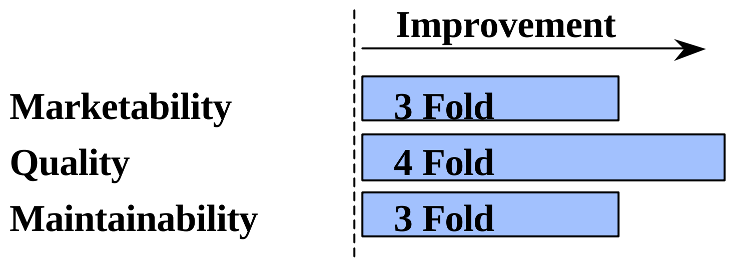
Time to Market
(80% Reduction)



Costs
(60% Reduction)



Product Attributes
(Survey Results: Delivered Vs. Custom)



Industrial Partnering

Technology Transfers
- **4 Development**
- **2 Since Completion**

(ref: KSC-12100 to 103, 12171 and 12181)

Industrial Exposure
- **ITC 1999**
- **Space Congress 2000**
- **Cross Talk (August 2000)**
- **NASA Tech Brief (Fall 2000)**

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Why was this process so effective? (Intuition/COCOMO II)

- **Intuition**
  - **Skill mix of the development team was improved.**
    - USA Problem Domain Expertise.
    - APLabs Information Technology and RT Platform Expertise.
    - Training and Mentoring.
  - **Leveraged Commercial Product Capabilities (Adaptation).**
    - Economies of Scale.
    - Reuse of Code.
    - Improved development environment.
    - Install base Bug Fixes.
    - Install base usability refinement.
    - **Critical Mass Achieved Early.**
      - Small development efforts.
      - Little architectural modifications.
      - If it works don't redesign it.
- **COCOMO II 1999 Model - developed by graduate student programming teams under the leadership of Dr. Ellis Horowitz. Director, Distance Education and Information Technology Programs University of Southern California. Original COCOMO model was first published by Dr. Barry Boehm in 1981. (sunset.usc.edu/COCOMOII/)**

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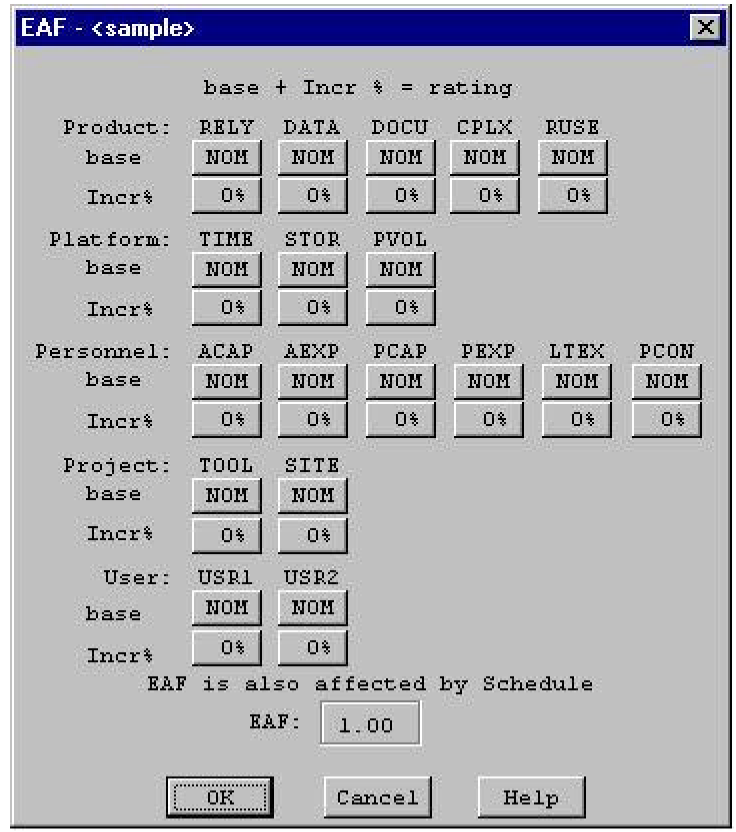
Skill Mix

United Space Alliance – Strong in Problem Domain expertise weak in Platforms and Languages

APLabs – Strong in Platforms and Languages and weak in the Problem Domain expertise

Skill Attributes	**USA**	**USA/APLabs**
Analyst Capability	VH	VH
Applications Experience	VH	VH
Programmer's Capability	Nom	H
Platform Experience	L	H
Language and Tool Expertise	L	H



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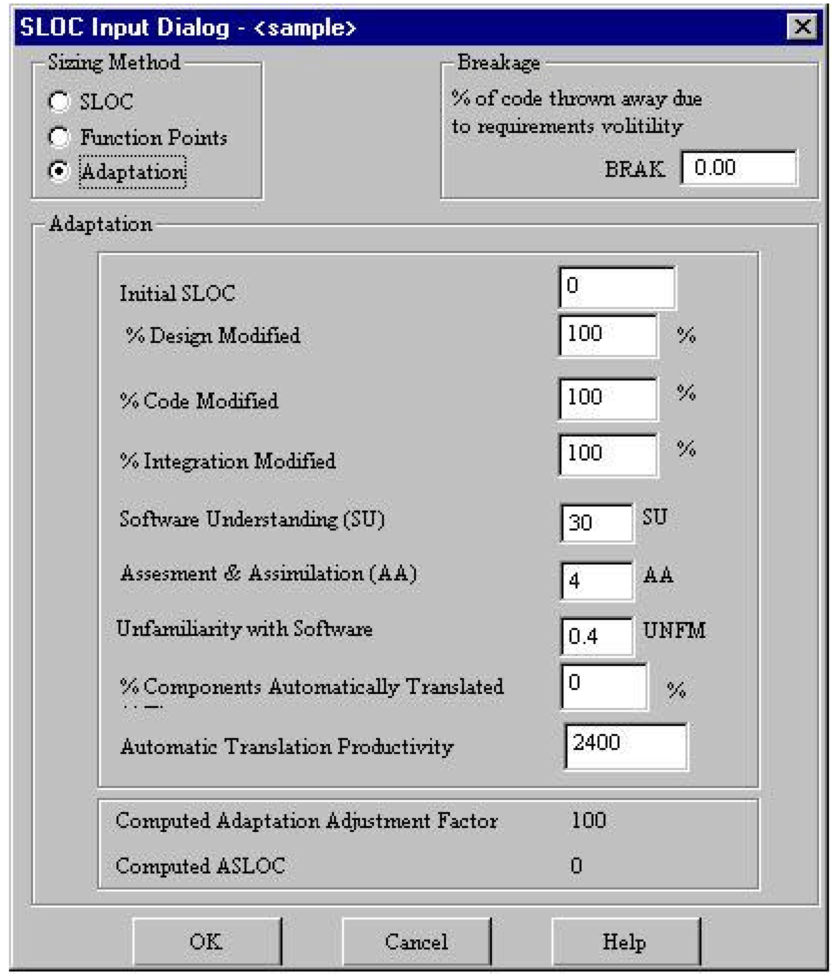
Adaptation (Reuse Model)

- **0 - requirements were static based on old system**
- **300-900KLOC – new code in system is estimated at 450KLOC**
- **Few architectural modifications**
- **Custom code lacked cohesion and structure**
- **Leveraged years of bug fixes and documentation**
- **USA programmers were completely unfamiliar with new code**

Reuse Factors	Before	After
Design Modification	75	5
Code Modifications	80	30
Integration Modification	60	10
Software Understanding	40	20
Assessment and Assimilation	2	6
Programmer Unfamiliarity	0.6	1



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Project Costs and Estimated Avoidance

Project Charges

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
A007212KM	54	33	6	5			410	703	787	790	700	
A007212K1	91	129	192	186	597	405	174					
Mhours/month	145	162	198	191	597	405	584	703	787	790	700	5262
Myears												2.7
						Technical Support Contract $						37000
							Labor Rate $/H					47
						Technical Support Hours						787
							Equivalent Hours					6049
							Equivalent Man-Years					3.2

Avoidance

	Low	High	Average
Labor ETC	20	24	
Equivalent Man Years	3.2	3.2	
Labor Avoidance	16.8	20.8	
Cost per Man-year	90000	90000	
Project projected cost	1800000	2160000	
Cost Avoidance	1512000	1872000	
% Avoidance	84%	87%	85%
Non Labor Penalty	360000	360000	
Penalty as % of Avoidance	24%	19%	22%

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COCOMO II Prediction and Comparison

Model Prediction

SLOC	Skills				Adaptation			Composite		
	Nom	Before	After	Percent Effort Reduction	Custom Code Continuation	Leverage VMEWindows Code	Percent Effort Reduction	USA Skills Custom Code	USA/APLabs VMEWindows Code	Percent Effort Reduction
300000	**1557.5**	**1064.2**	**612.5**	42%	**1118.5**	**265.3**	76%	**764.2**	**126.4**	83%
400000	**2137.1**	**1460.3**	**840.4**	42%	**1534.7**	**364.1**	76%	**1048.6**	**173.4**	83%
500000	**2731.5**	**1866.4**	**1074.1**	42%	**1961.5**	**465.3**	76%	**1340.3**	**221.6**	83%
600000	**3338**	**2280.7**	**1312.6**	42%	**2397**	**568.6**	76%	**1637.8**	**270.8**	83%
700000	**3954.6**	**2702.1**	**1555**	42%	**2839.9**	**673.7**	76%	**1940.4**	**320.8**	83%
800000	**4580.1**	**3129.5**	**1801**	42%	**3289**	**780.2**	76%	**2247.3**	**371.6**	83%
900000	**5213.5**	**3562.2**	**2050.1**	42%	**3743.9**	**888.1**	76%	**2558.1**	**423**	83%

Model Prediction is within 2% of Empirical Estimated Avoidance

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Expectations - Economies of Scale and Affinity

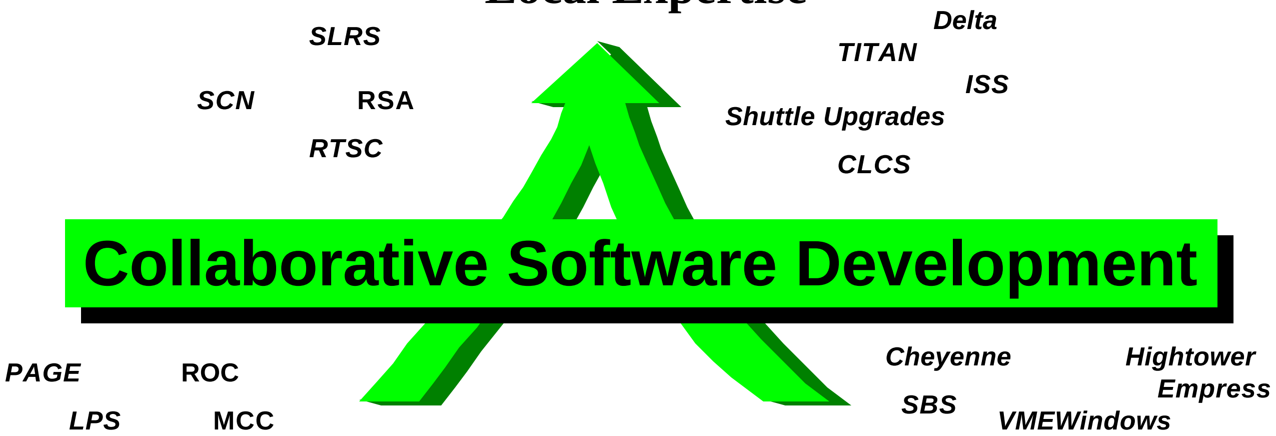
- **Penalties (Cost Approximately 22% of Savings)**
  - Product and premium for source and development tools
  - Collaboration technical support Costs
  - Team building and training
  - Special operational support clauses
- **Example: on a $5M similar software development effort you could save roughly 85% or $4.25M in effort and pay a penalty of 22% or $1.1M, for a total savings of roughly $3.15M or 63%**
- **Need for further study to; estimate savings and long term impacts**

  Functional similarity (affinity metrics) , documentation, multi-partner collaborations, interfacing, competitive advantage and connective code.

Best of Both Worlds

Collaborative Software Solution

+ Economies of Scale
+ Superior Products
+ Focused Solution
+ Local Expertise



Custom Software Solution

+ Focused Solution
+ Local Expertise
- From Scratch
- Minimal Functionality

COTS Software Solution

+ Economies of Scale
+ Superior Products
- Vendor Only Support
- Generalized Solution