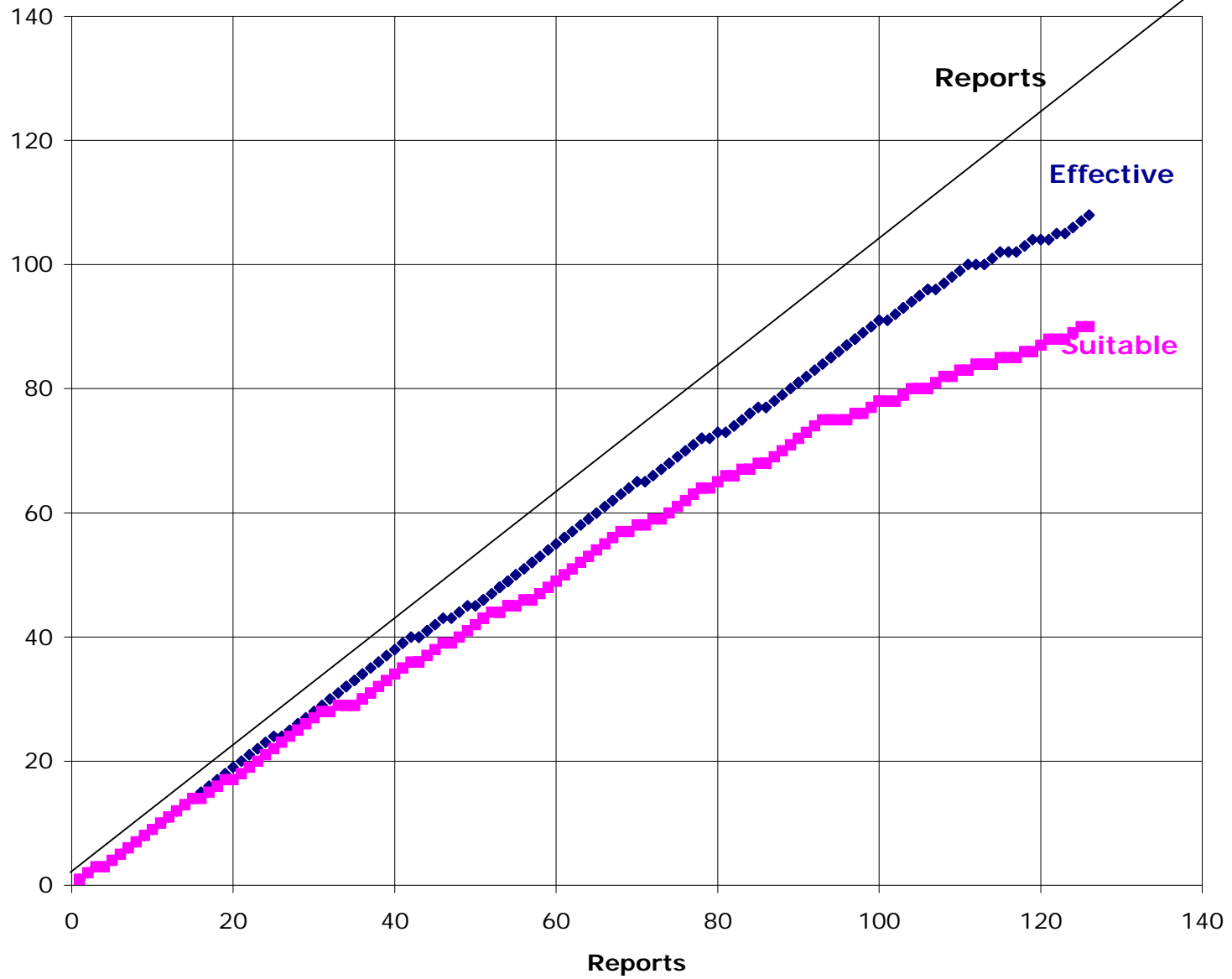


The Costs of Unsuitability and Benefits of Building in Reliability, Availability and Maintainability

Dr. Ernest Seglie,
Science Advisor, DOT&E
Ernest.Seglie@osd.mil

Cumulative Number



DoD IOT&E Results FY 2001 - 2003

Program	Service	ACAT	IOT&E Result		Reason
<i>FY 2001</i>					
F-15 TEWS	USAF	II	Effective	Not Suitable	Reliability, Maintainability, Availability
V-22 Osprey	Navy	1D	Effective	Not Suitable	Reliability, Availability, Maintainability (RAM), Human Factors, BIT
Joint Direct Attack Munitions (JDAM)	USAF	1C	Effective only with legacy fuses	Not Suitable	Integration with delivery platforms
M2A3 Bradley Fighting Vehicle	Army	1D	Effective	Suitable	
<i>FY 2002</i>					
Joint Primary Aircraft Training System (JPATS)	USAF	1C	Effective with deficiencies	Not Suitable	RAM, Safety, Human Factors
Cooperative Engagement Capability (CEC)	Navy	1D	Effective	Suitable	
Multiple Rocket Launcher System (MLRS)	Army	1C	Effective	Suitable	
MH-60S	Navy	1C	Effective	Not Suitable	RAM, excessive administrative and logistic repair time impacted RAM
<i>FY 2003</i>					
B-1B Block E Mission Upgrade Program	USAF	1D	Effective	Not Suitable	16% decrease in weapons release rate, reduction in accuracy of Mark 82 low drag weapons, 14% hit rate on moving targets
Sea wolf Nuclear Attack Submarine	Navy	1D	Effective	Suitable	Several requirement thresholds were not met but overall system effective and

DoD IOT&E Results FY 2004, 2005

Program	Service	ACAT	IOT&E Result	Reason
<i>FY 2004</i>				
Evolved Sea sparrow Missile	Navy	II	Effectiveness unresolved	Suitable Testing was not adequate to determine effectiveness.
Stryker	Army	1D	Effective	Suitable
Advanced SEAL Delivery System (ASDS)	Navy	1D	Effective with restrictions	Not suitable Effective for short duration missions; not effective for all missions and profiles. Not suitable due to RAM.
Tactical Tomahawk	Navy	1C	Effective	Suitable
Stryker Mortar Carrier-B (MC-B)	Army	1D	Effective	Not Suitable RAM and safety concerns.
<i>FY 2005</i>				
CH-47F Block I	Army	1C	Effective	Not Suitable RAM; communications system less suitable than CH-47D; did not meet Information Exchange Requirements for Block I.
F/A-22	USAF	1D	Effective	Not Suitable RAM; needed more maintenance resources and spare parts; BIT
Joint Stand-Off Weapon-C	Navy	1C	Not Effective	Not effective against moderately hardened targets; mission planning time was excessive.
Guided-MLRS	Army	1C	Effective	Suitable
High Mobility Attack Rocket System (HMARS)	Army	1C	Effective	Suitable
V-22 Osprey	Navy	1D	Effective	Suitable
EA-6B (ICAP III)	Navy	II	Effective	Suitable

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Technical Reason
<i>FY 2002</i>					
F-15 TEWS	USAF	II	Effective	Not Suitable	RAM

SE Issues		
Issue	SE Area	Rationale
Requirements	Reasonableness Verification	RAM requirements not fully defined. BIT architecture and subsystem reliability not designed into system. BIT system was a major requirement for the system.
Program Planning	Allocation Sufficiency	Program focused mainly on Band 1.5 and did not address newer SAM systems; inadequate processing capability. Systemic analysis was not performed; might have captured systems integration problems and identified root causes for inadequate processing.
Acquisition Strategy	Acceptability	Program integrated Electronic Warfare (EW) systems with known reliability issues without performing a systemic analysis prior to design and integration.
Technical Process	Requirements Development System Integration, Test, and Verification	Program did not establish sound independent technical review processes. Software assurance and metrics not sufficiently established. Technical entrance and exit criteria not established for Developmental Test (DT) reviews and decisions.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result	Technical Reason
<i>FY 2002</i>				
Joint Primary Aircraft Training System (JPATS)	USAF	1C	Effective with deficiencies	Not Suitable RAM; safety; human factors.

SE Issues		
Issue	SE Area	Rationale
Requirements	Reasonableness Verification	No ORD Thresholds for R&M; program measured against objectives.
Program Planning	Allocation Sufficiency	Acquisition Reform – pilot program. Designed as COTS program. Multiple slips: evidence of a schedule-driven nature. Requirements not fully defined and understood.
Acquisition Strategy	Acceptability	Simple COTS approach. “Militarization” not fully defined or understood. Multiple slips: evidence of schedule-driven nature.
Technical Process	Requirements Development System Integration, Test, and Verification	COTS mentality led to simplistic test approach (e.g., FAA cert, Contractor Qual Test approach led to insufficient DT). Multiple slips. Requirements not tracked/traced to a verification and test plan.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result	Reason
<i>FY 2001</i>				
Joint Direct Attack Munitions (JDAM)	USAF	1C	Effective only with legacy fuses	Not Suitable Excessive mission planning times (Navy); system reliability; B-52 load times; container deficiencies (stacking, carrier ops).

SE Issues		
Issue	SE Area	Rationale
Requirements	Reasonableness; Design Synthesis Verification	B-52 load times not reflective of new complexity. Navy carrier operability (ruggedness) not adequately captured/defined. Significant focus on capability (accuracy). Reliability relied heavily on “warranty.”
Acquisition Strategy	Acceptability	Acquisition Reform – pilot program. Small program office. Capability-based contracting strategy; significant SE contracted as result. Significant focus on capability (accuracy). Reliability relied heavily on “warranty.”
Technical Process	System Integration, Test, and Verification	Unrealistic load times; test team load crew experience, training; test team mission planning experience/training.
Reducibility and Production Planning	Quality Control (Plant Layout)	Storage reliability. Significant failures related to minor quality control errors (i.e., missing sealant, kit packed with wrong covers, etc.).

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result	Reason
<i>FY 2003</i>				
B-1B Block E Msn Upgrade Program	USAF	1D	Not Effective	Suitable 16% decrease in weapons release rate; reduction in accuracy of Mark 82 low drag weapons; 14% hit rate on moving targets.

SE Issues		
Issue	SE Area	Rationale
Requirements	Reasonableness Verification	Validity of effectiveness measures, based on comparison with prior block (not as complex; different release mechanism; different weapons mix; key requirement met: weapons flexibility).
Acquisition Strategy	Acceptability; Sufficiency	Software conversion oversimplified. Significant program growth. "Program clarity" - funded program did not address numerous "known issues"; resulted in re-identification of numerous issues (situational awareness, controls and displays, reliability).
Technical Process	System Integration, Test, and Verification	T&E measures not well founded in ORD/CDD.

Air Force IOT&E Results

Program	Service	ACAT	IOT&E Result		Reason
<i>FY 2003</i>					
F-22	USAF	1D	Effective	Not Suitable	RAM; needed more maintenance resources and spare parts; BIT.

SE Issues		
Issue	SE Area	Rationale
Requirements	Reasonableness Verification	RAM requirements not fully defined for IOT&E but for a mature aircraft at 100K flight hours. RAM and BIT requirements not tracked/traced to a verification or test plan.
Acquisition Strategy	Acceptability; Sufficiency	Program did not recognize or fully fund RAM requirements and software development, especially the maintenance software portion. Labs were insufficiently supported with hardware-in-the-loop.
Technical Process	System Integration, Test, and Verification	Program did not establish entrance/exit criteria for software development, verification, validation, and test. Software not adequately tested and fixed in the lab prior to flight test. Mission technical issues overshadow RAM issues and RAM resources diverted to technical mission issues. Program did not have a sound risk assessment program.

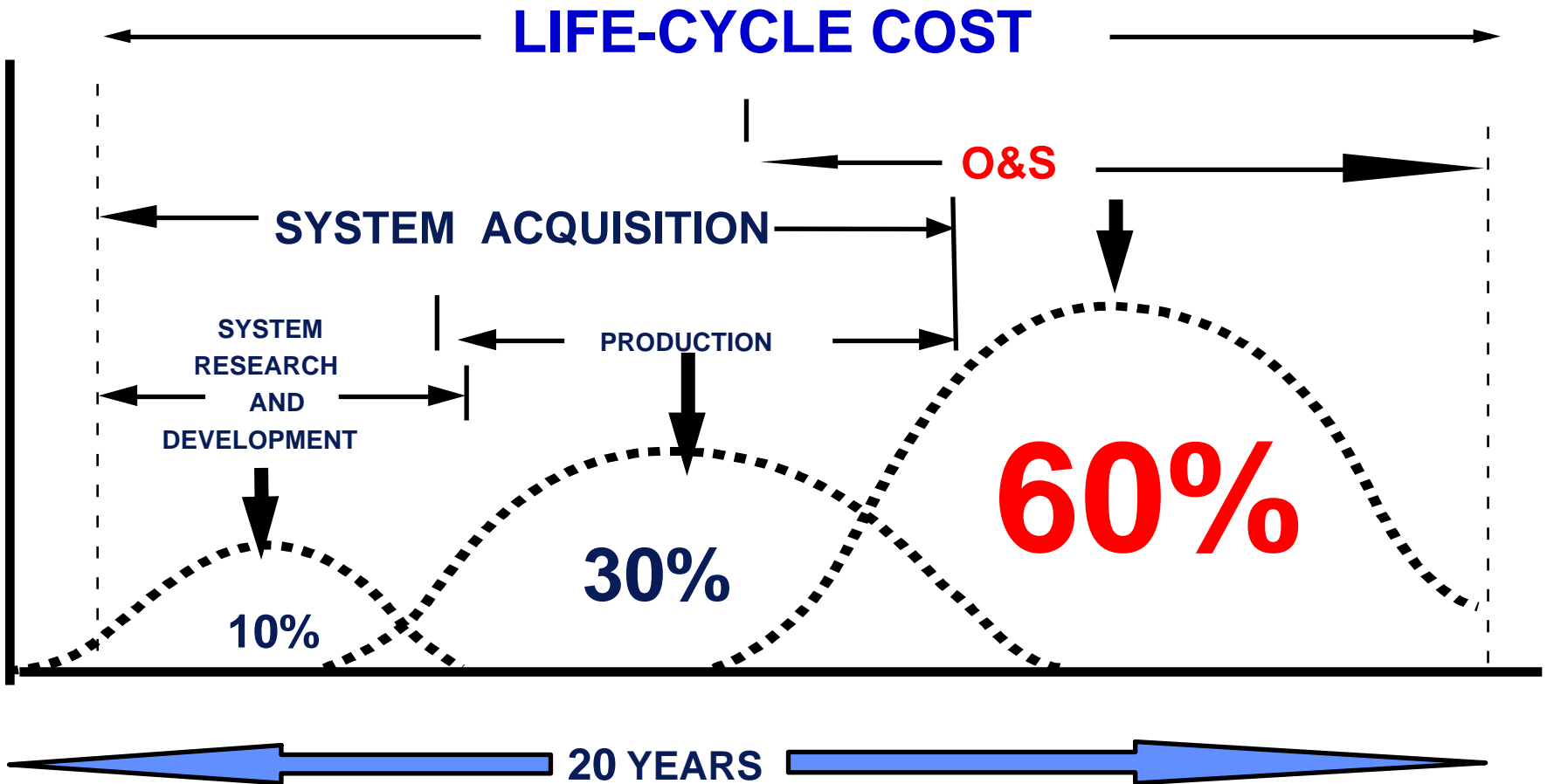
Additional Costs When a System is Judged Unsuitable (1)

- Some programs extended their SDD and added resources to redesign, reengineer and to retest till they became suitable
 - V-22 extended its SDD by five years and spent ~\$1B to resolve its suitability issues. (It had a catastrophic failure in 2000)
 - C-17 is likely to be another interesting case.
- When failure in OT&E delays the full production and the fielding of a new system, it may require extra cost to operate and support, and in some cases, even Service Life Extension Program (SLEP) on legacy systems.

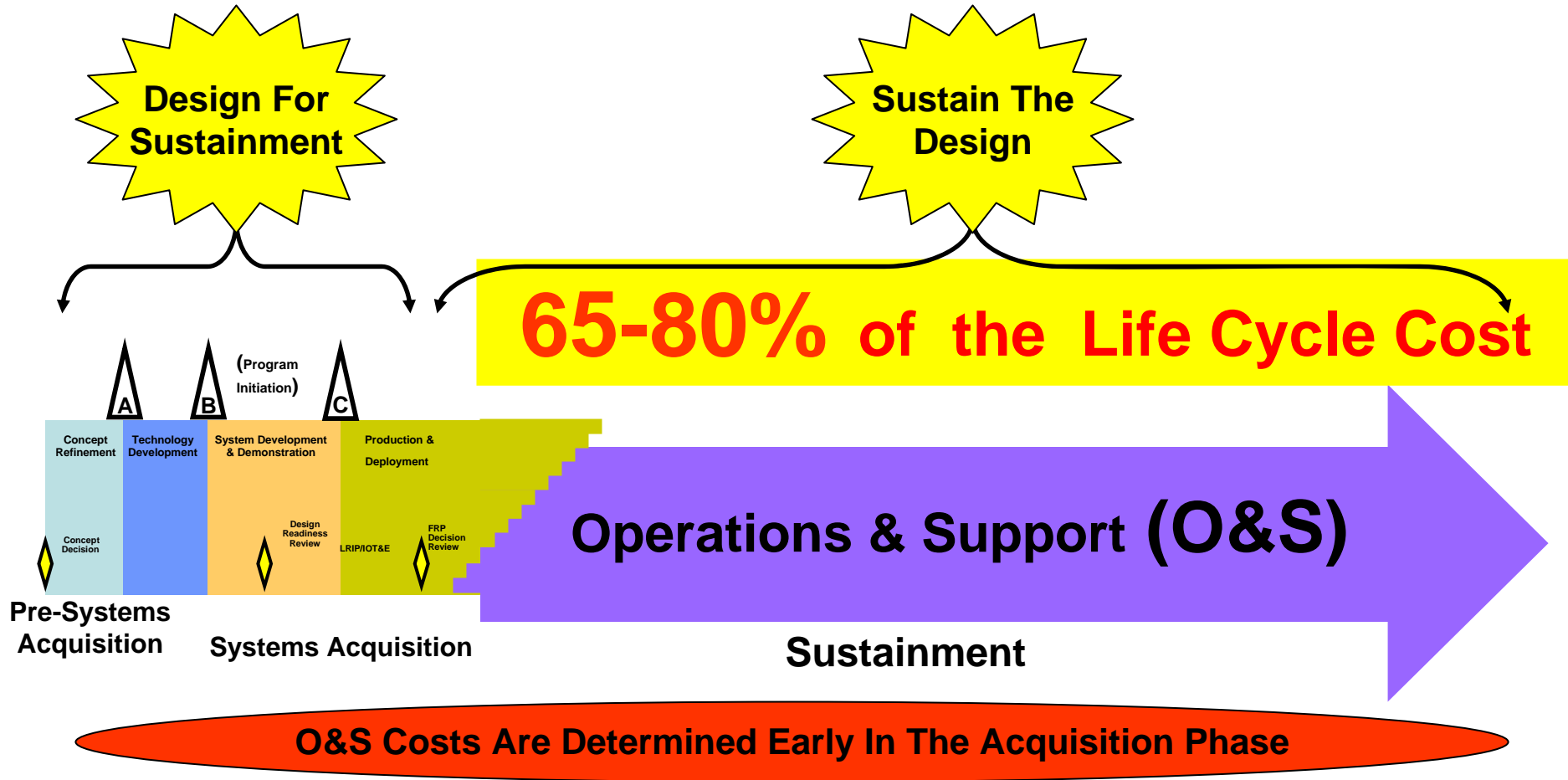
Additional Costs When a System is Judged Unsuitable (2)

- Some programs were granted FRP and delayed RAM remedial actions as Block Upgrades
 - Approach requires additional cost for RDT&E and retrofit. It is also more expensive to maintain and support several different configurations than one.
 - It turns to a spiral development approach.
 - Identify related RAM development and retrofit costs
 - Estimate additional operating and support costs for extra configurations
- Some programs are fielded with known RAM shortcomings
 - Extra costs for repair and maintenance or contractor logistic support when fielded at insufficient RAM level
 - Possible cost to procure and operate additional units to compensate for low availability to meet desired sortie rates or ton-mile capacity

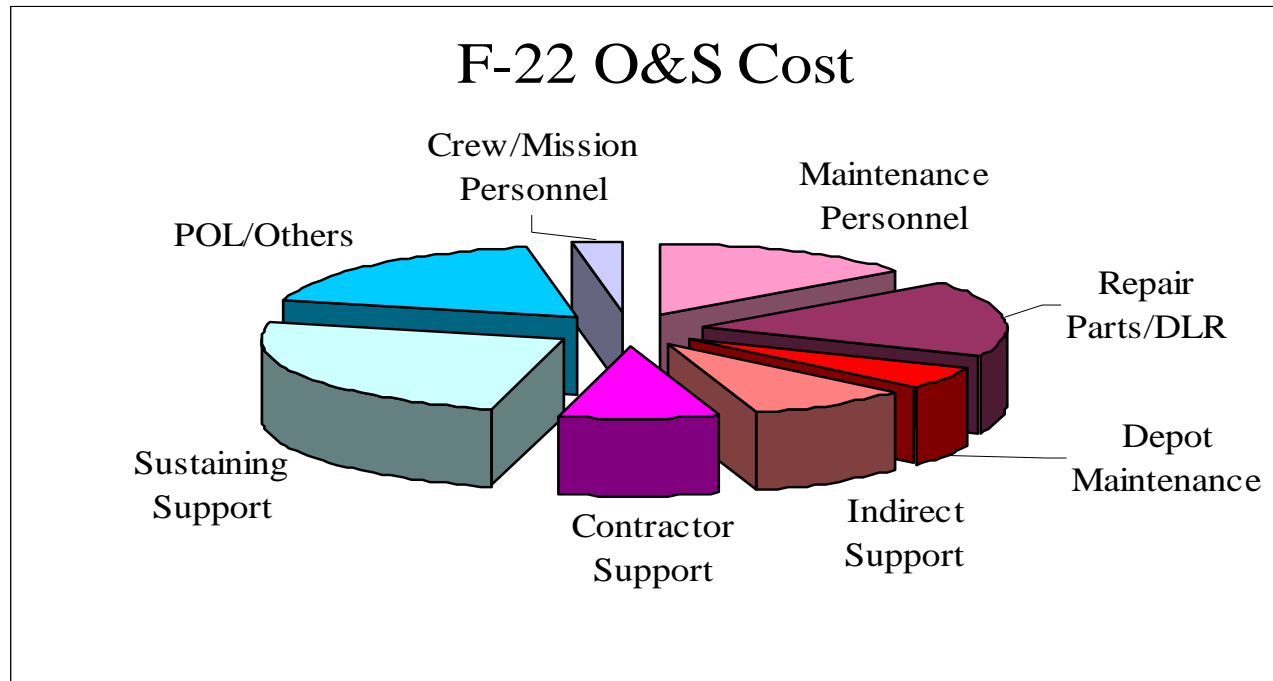
LCC Distribution



Life Cycle Management



R&M drives O&S Costs



R&M affects about half of F-22 O&S cost:

Maintenance personnel, repair parts/depot level repairables, depot maintenance, indirect support and contractor support

Four Causes

- No requirements
- Lack of incentives
- Attention elsewhere
- Poor Systems Engineering

JROC Memo: 17 Aug 2006

“MATERIEL AVAILABILITY” KPP for all
MDAPs and Select ACAT II and III

(KSAs):

- A. **Materiel Reliability KSA**
- B. **Ownership Costs KSA**

JROC Approved* Mandatory Sustainment KPP and KSAs

- Single KPP:
 - **Matériel Availability** ($= \frac{\text{Number of End Items Operational}}{\text{Total Population of End Items}}$)
- Mandatory KSAs:
 - **Matériel Reliability** (MTBF) ($= \frac{\text{Total Operating Hours}}{\text{Total Number of Failures}}$)
 - **Ownership Cost** (O&S costs associated w/materiel readiness)
- Ownership Cost provides balance; solutions cannot be availability and reliability “at any cost.”

*JROC Approval Letter JROCM 161-06 Signed 17 Aug 06;
Revised CJCS 3170 will put into Policy

Return on Investment

Estimate O&S and Initial Spares of Different F-22 MTBMs (Constant 2006 \$B)

Reliability Level at <u>Maturity</u>	MTBM in <u>Hours (1)</u>	O&S & Initial <u>Spares (2)</u>	Life Cycle Cost <u>Difference (3)</u>
FOT&E Actual (1a)	0.65	\$ 42B	\$ 7B
IOT&E Actual with Historical Growth (1b)	0.83	\$ 40B	\$ 5B
Air Force Program Reliability Projection (1c)	1.50	\$ 35B	

(1) Mean Time between Maintenance. F-22 ORD established MTBM threshold at 3 hours.

(1a) MTBM of 0.65 hours achieved in Follow-on Operational Test and Evaluation (FOT&E).

(1b) IOT&E MTBM score 0.45 hours. F-22 will achieve MTBM of 0.825 hours at maturity (100,000 FH), if its reliability growth rate is similar to the historical rates of existing fighter aircraft programs.

(1c) Air Force Program Office projects F-22 to achieve 1.5 hours MTBM at maturity.

(2) O&S cost for 148 Primary Aerospace vehicle Authorization (PAA), 336 flying hours per aircraft per year for 24 years.

Initial spares requirement for 182 Total Active Inventory (TAI), computed at \$120M recurring flyaway cost each.

(3) Baseline assumes the Air Force projected 1.5 hours MTBM at maturity. At the F-22 ORD MTBM threshold of 3 hours, the estimated life cycle cost would be \$4B lower than the baseline in constant 2006 dollars.

**F-22 life cycle cost could be \$5B – \$7B (constant 2006) more
if projected program reliability is not realized.**

Return of R&M Investment (Present Value 2006 \$B)

Reliability Level at <u>Maturity</u>	MTBM in <u>Hours (1)</u>	O&S & Initial <u>Spares (2)</u>	RDT&E & <u>Retrofit (3)</u>	Savings to <u>Investment Ratio</u>
FOT&E Actual	0.65	\$ 30B		
Air Force Program Reliability Projection	1.50	\$ 25B		
Potential Savings (4)		\$ 5B		
Budgeted Investment			\$ 0.7B	
Potential Return of Investment				7 : 1

(1) Mean Time between Maintenance. F-22 ORD established MTBM threshold at 3 hours.

F-22 Follow-on Operational Test and Evaluation (FOT&E) MTBM score 0.65 hours.

Air Force Program Office projects F-22 to achieve 1.5 hours MTBM at maturity.

(2) O&S cost for 148 Primary Aerospace vehicle Authorization (PAA), 336 flying hours per aircraft per years for 24 years.

Initial spares requirement for 182 Total Active Inventory (TAI), costed at \$120M recurring flyaway cost per aircraft.

(3) President Budget Submission (February 2005 and February 2006):

F-22 Reliability and Maintainability Maturation Program (RAMMP).

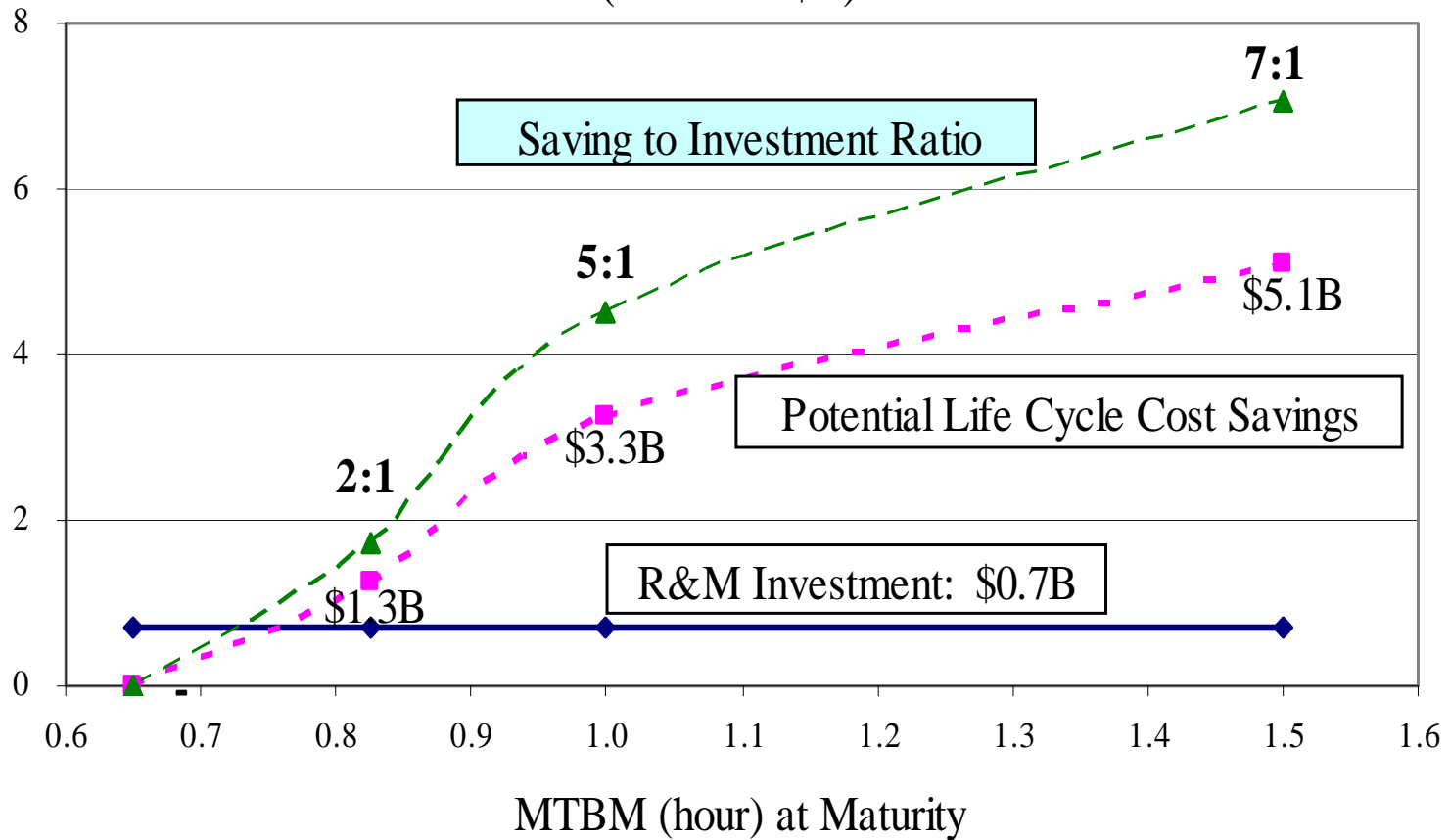
F119 engine Component Improvement Program (CIP).

R&M retrofits: air vehicle RAMMP modification and F119 engine CIP modification

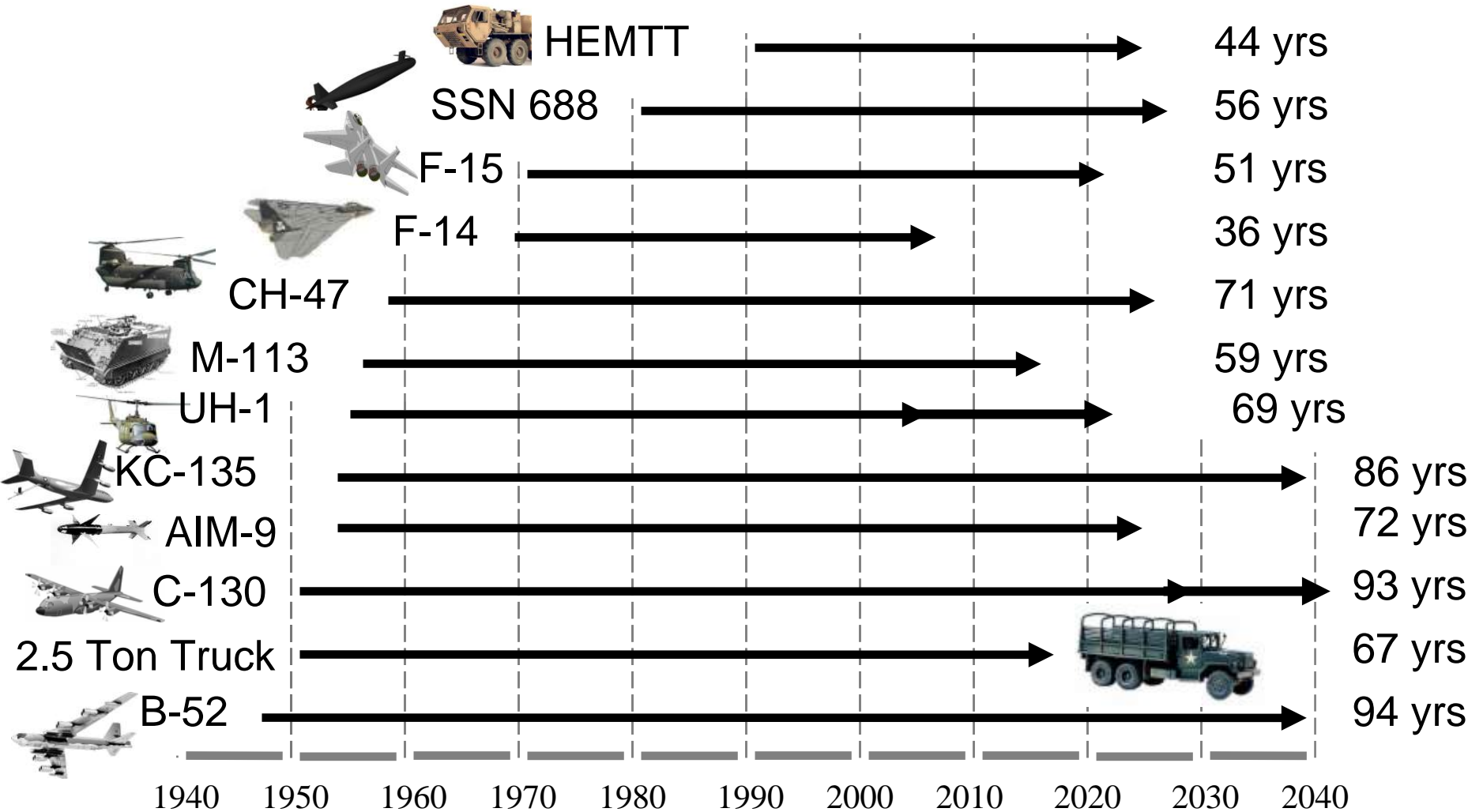
(4) Saving will be substantially lower if F-22 does not achieve MTBM of 1.5 hours at maturity.

R&M Investment and Savings

(PV 2006 \$B)



Defense System Life Cycles



Myths about Building-in Reliability, Availability and Maintainability

Myth 1: Building-in Reliability costs
money.

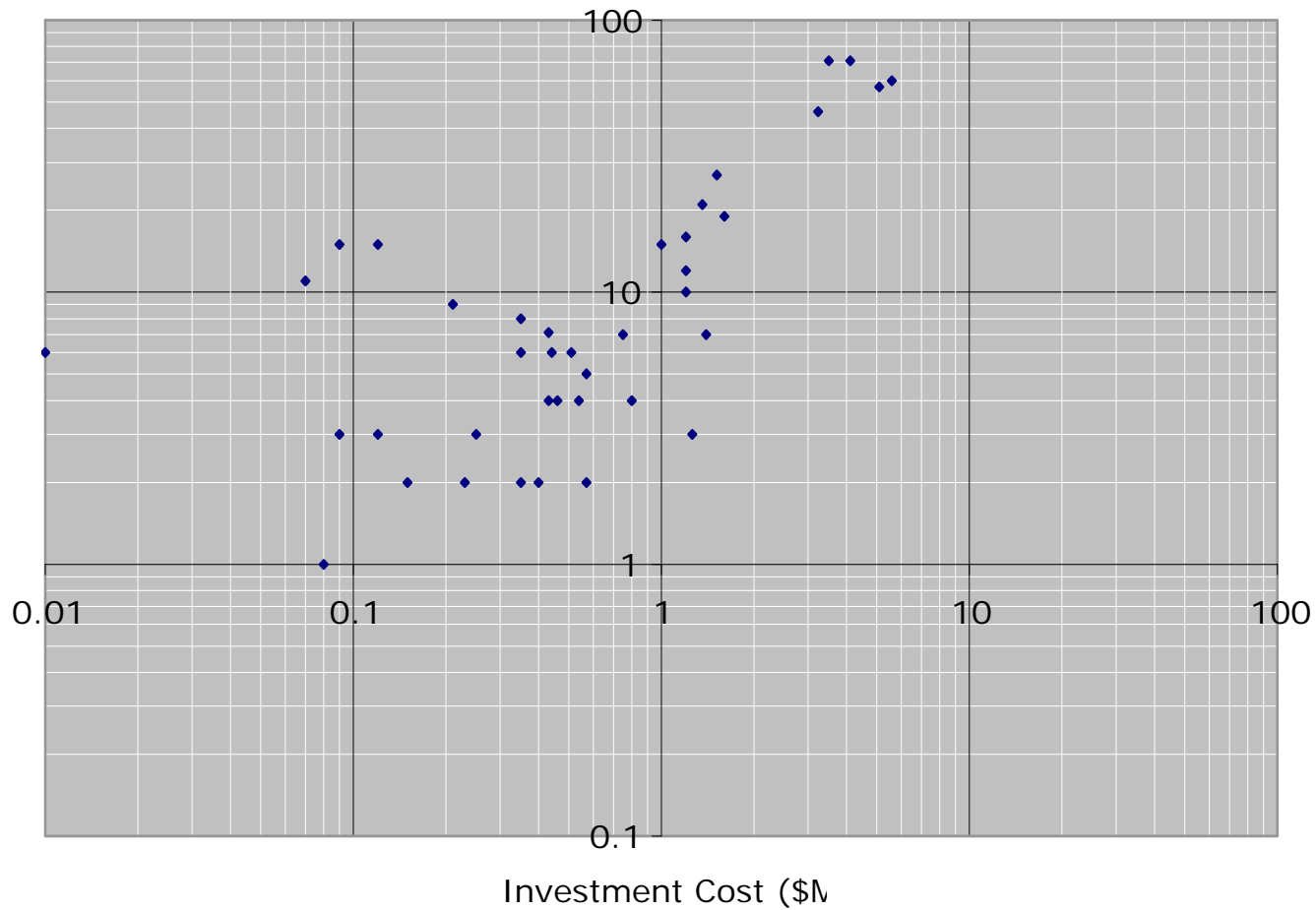
HH-60H and MH-60S Reliability and Cost Comparison

HH-60H			MH-60S		
Component	MFHBR	PUC (FY07\$K)	Component	MFHBR	PUC (FY07\$K)
CPU159/A AFCS COMPUTER	582	\$180	CPU133/A DIGITAL COMPUTER	1,944	\$86
AUXILIARY POWER SYSTEMS	2,160	\$86	ACFT POWER UNIT	* >10,000	\$80
SECT'S 2/3/4 DRIVE SHAFT ASSY	6,480	\$4	SECTIONS 2/3/4 DRIVE SHAFT ASSY	* >10,000	\$4
CP1820/ASN150 NAV COMPUTER	434	\$99	CP-2428/A DIGITAL DATA COMPUTER	2,236	\$84
STABILATOR AMPLIFIER INSTALL	549	\$34	AMPLIFIER INSTALLATION	1,351	\$43
MLG DRAG BEAM/AXLE ASSY	* >10,000	\$24	BEAM-AXLE ASSEMBLY	* >10,000	\$26
FLOOR ASSEMBLY	* >10,000	\$10	AIRCRAFT FLOOR	* >10,000	\$20
T1360()/ALQ144(V) TRANSMITTER	582	\$52	LIGHT, INFRARED TRANSMITTER	* >10,000	\$5

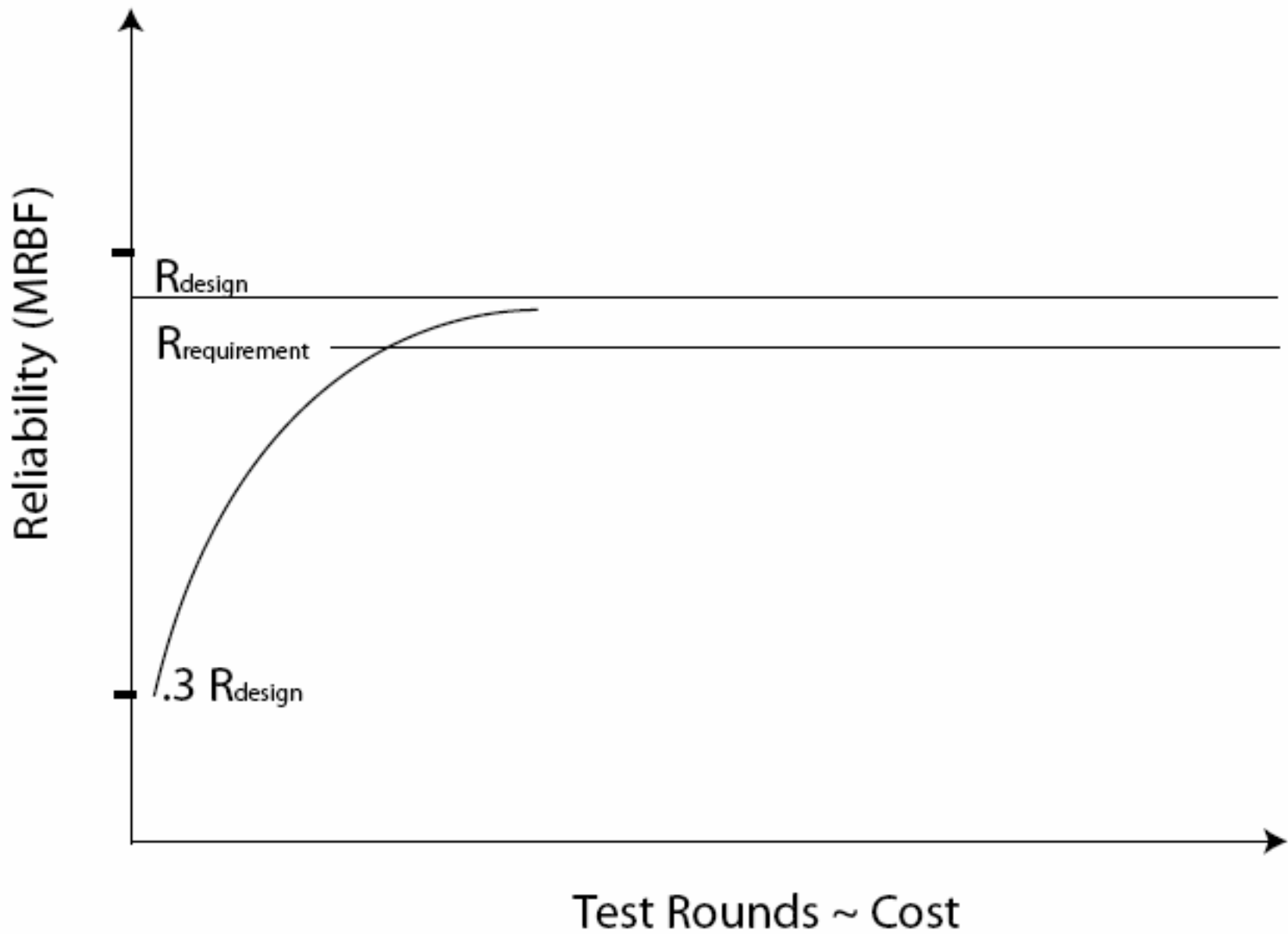
* 0 failures observed in one year

When to Invest?

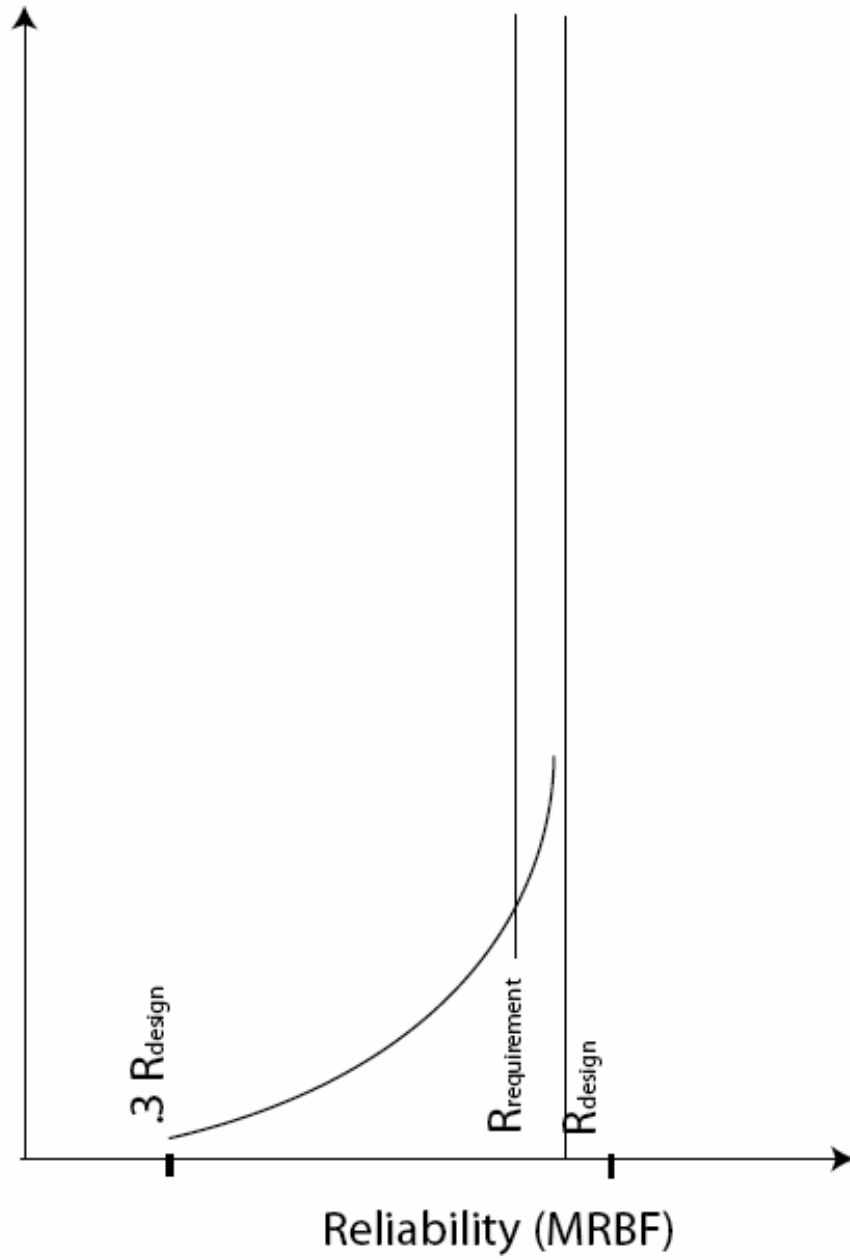
Return on Investmer

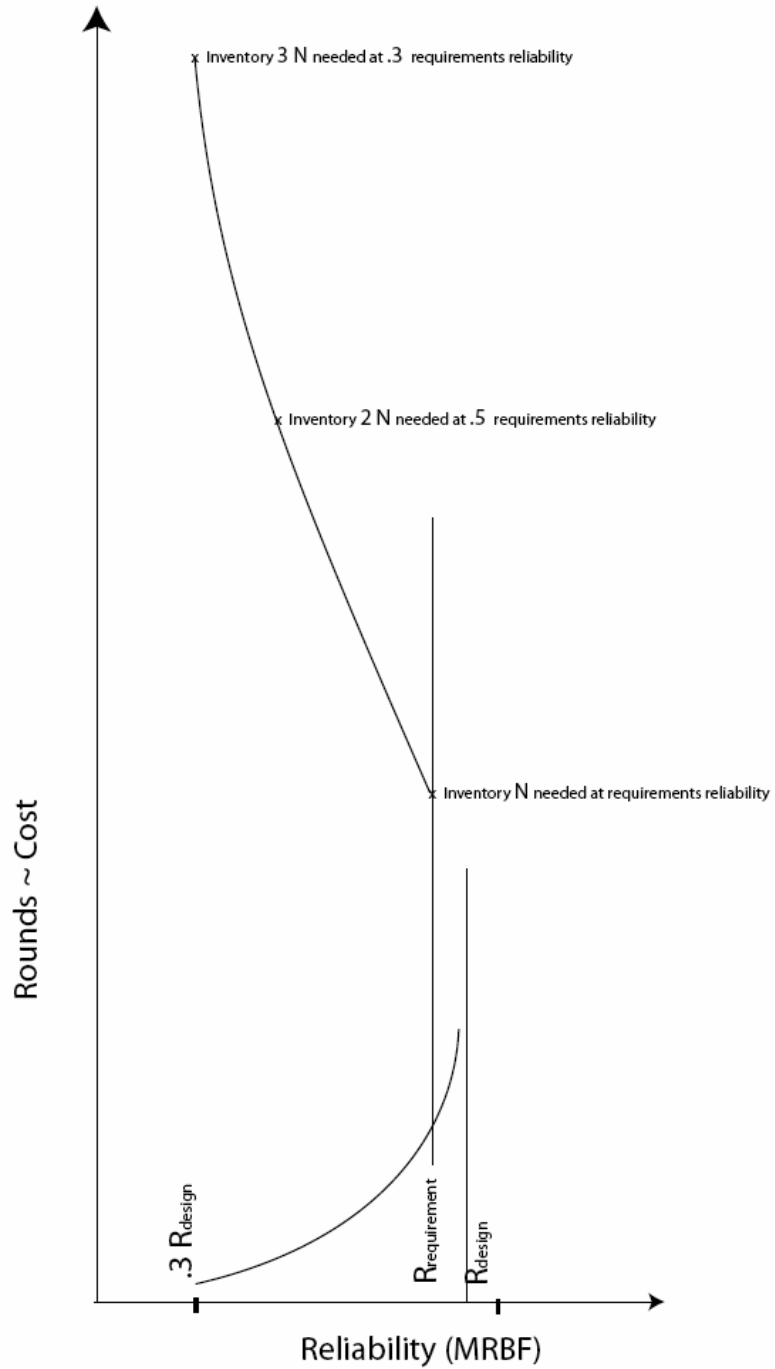


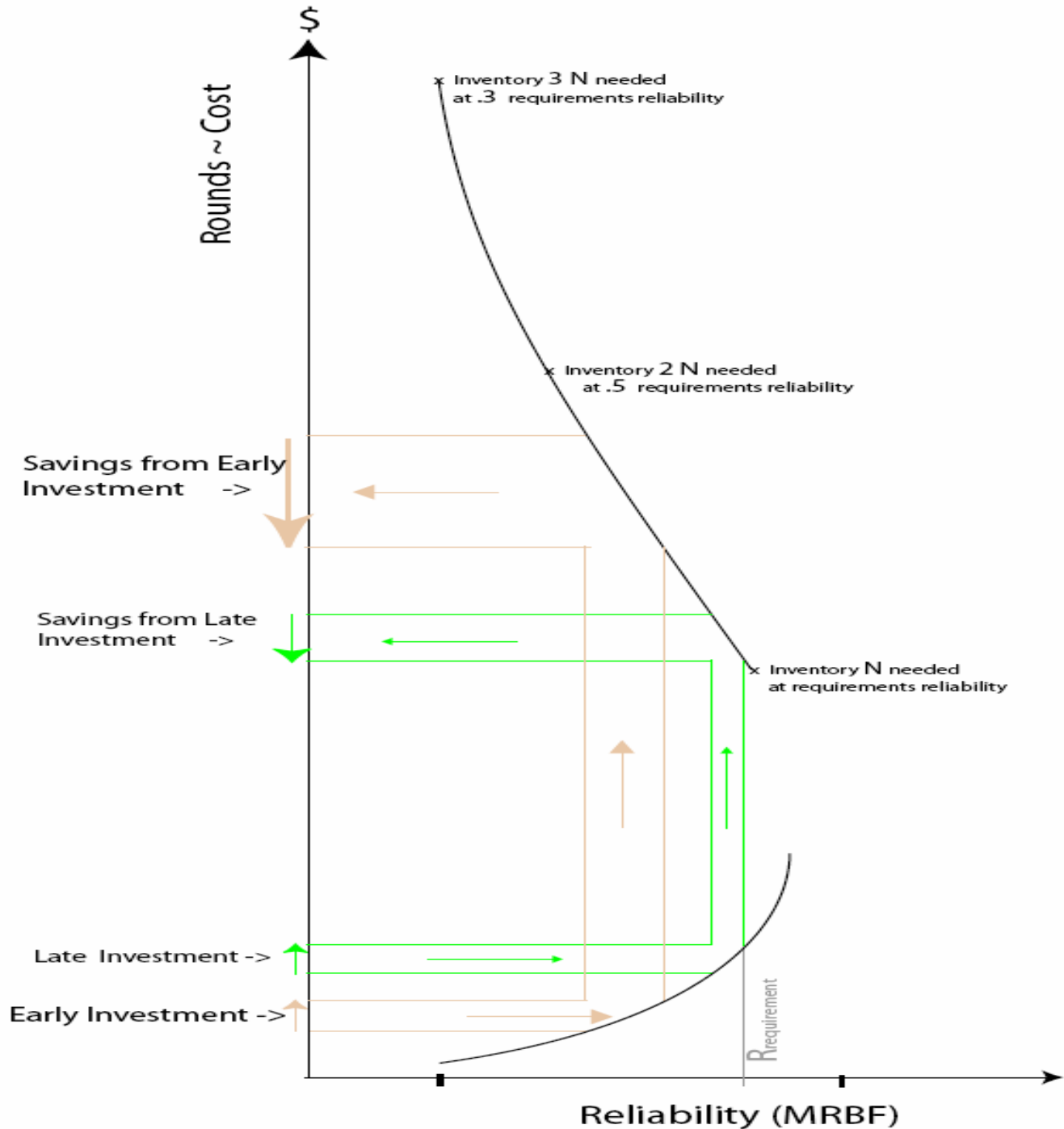
◆ Series1



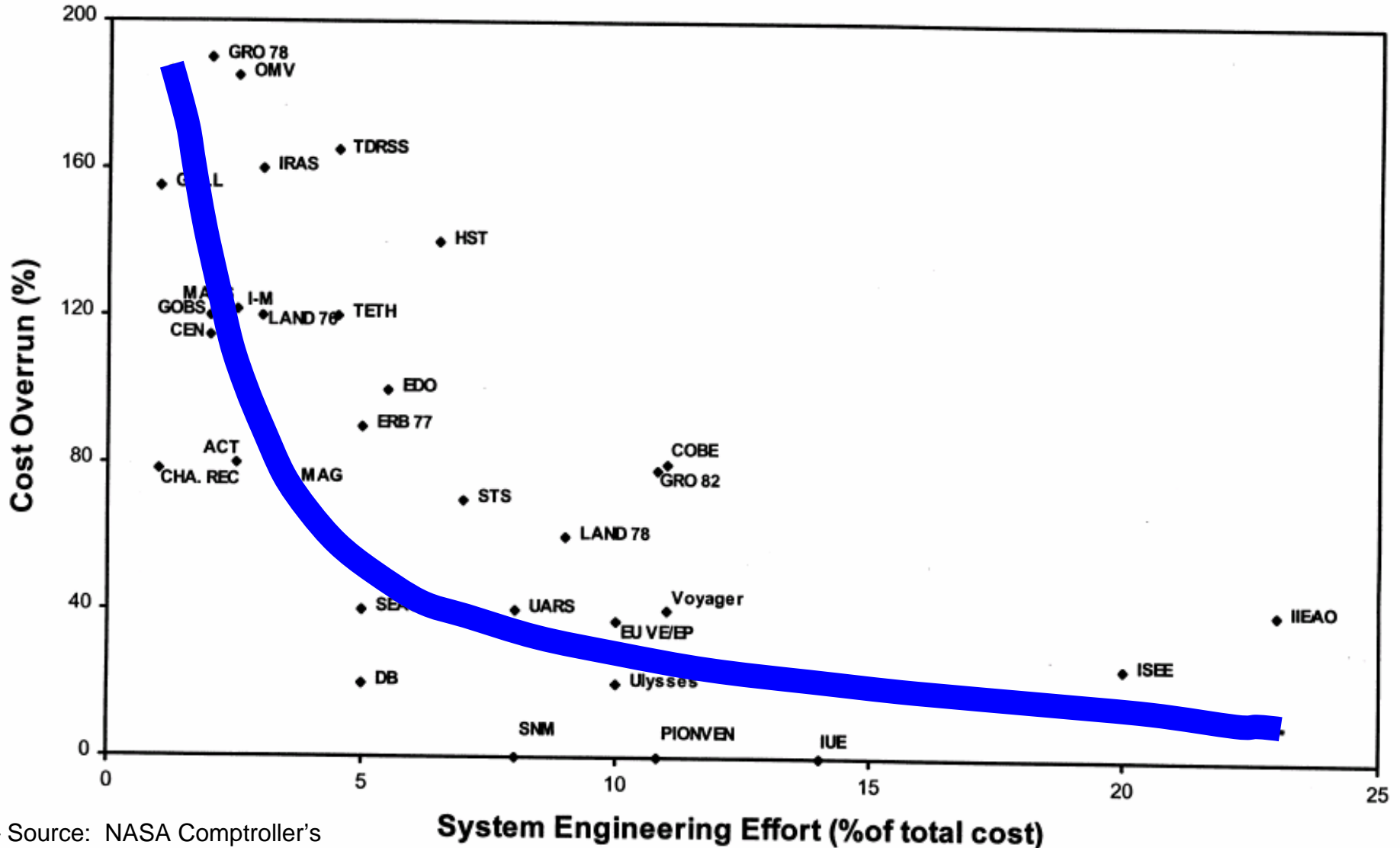
Test Rounds ~ Cost







The Value of SE



- Source: NASA Comptroller's Office, 1980s

The Value of SE (cont.)

LTV Aerospace and Defense Company

study on the benefits of the SE process – 1992

- Product development time reduced by as much as 60%
- Engineering change orders reduced by 50%
- Redesign and rework effort reduced by as much as 75%
- Manufacturing costs reduced by as much as 40%

Benefits of Systems

Launch (Project)	# of Points	Cost (\$K)	\$ / Point	Use SE?
System 1	12,934	30,000	2,319	No
System 2	10,209	14,904	1,460	Yes
System 3	4,678	6,614	1,414	Yes
System 4	8,707	18,075	2,076	No
System 5	1,223	2,400	1,962	No
System 5	4,600	10,309	2,241	Yes
Total/Average	42,351	82,302	1943	N/A
Total/Average with SE	19,487	31,827	1,633	Yes
Total/Average without SE	22,864	50,475	2,208	No
Percent improvement			35.17%	

Over a two year span, IBM has seen a 35% cost saving (productivity improvement) in large-scale integration projects that use the Systems Engineering process.

Summary

- How to Address Problems
- Size of ROIs
- When to invest

THE END

Weapon Systems

CH-47
Multiple
UH-60
AH-64
CH-47 & AH-64
H-47/H-64
Ground Support
Patriot Missile
B-1B
A-10
F-16
C-130
B-52
C-5A/F-15
F-15
F-15/Multiple
F-15 & F-16
KC-135
F100/F-119
Minuteman
Multiple (Fuel)

F/A-18
Multiple (Navy)
EA-6B
H-60
AV-8B
T-64
F404
AH-1/H-46
C-130/P-3
CH-46
E2-C-2
EA-6B, E-2/C-2
F/A-18 & E2/C2
H-1
HMMWV
T-58
T700
UH-1

Assessing Cost and R&M

- Models to link Mean Time Between Maintenance and other R&M metrics to requirements for
 - Maintenance manpower
 - Sustaining spares
 - Initial spares
- F-22 example
 - Compare the O&S cost and initial spares requirement for a range of reliability assumptions, following established analytical approaches for other F-22 Studies.
 - Tabulate the trade-off between budgeted F-22 R&M investment (RDT&E and retrofit) and potential O&S and initial spares savings.