Ground Vehicle Reliability
Design-for-Reliability

2007 DoD Maintenance Symposium
Orlando, Florida
November 13-16, 2007

Robert M. Cranwell, Manager
Center for Systems Reliability
System Sustainment & Readiness Programs
Sandia National Laboratories (SNL)
Albuquerque, NM 87185
(505) 844-8368 rmcranw@sandia.gov

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Technologies & Customer Base

System Sustainment & Readiness

- Design for Reliability/Maintainability
- Modeling & Simulation
- Optimization Algorithms
- Prognostics & Health Management
- Integrated Logistics
- Human Factors Engineering
- Risk Assessment/Management
- Sensitivity/Uncertainty Quantification

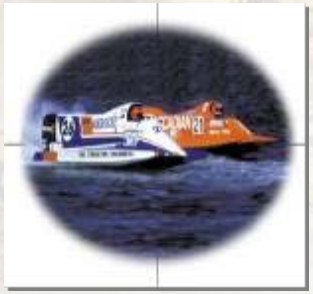
Technologies Support Broad Customer Base

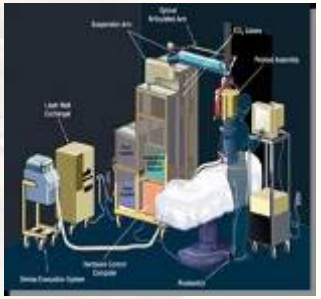
Defense

Machine Tool

Farming

Semiconductor


Boating


Health Care

Petroleum

Aviation

Automotive

Nuclear Power

Coal-Fired Power

Textile

Tools & Technologies Validated Through

Sandia National Laboratories

Semiconductor Industry

System Sustainment & Readiness Programs

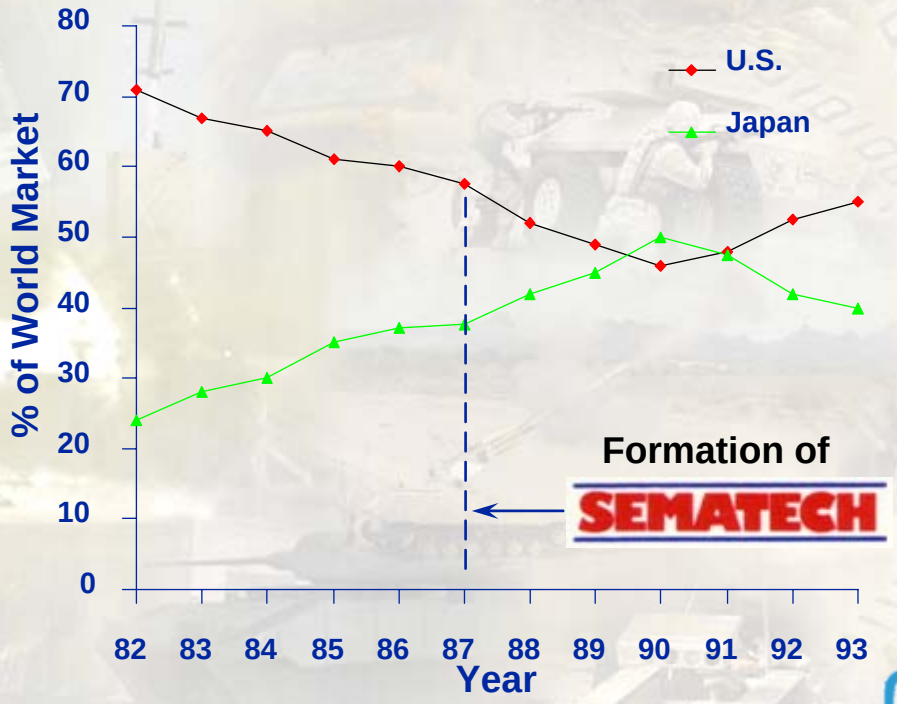
Supported semiconductor equipment manufacturers in improving reliability of semiconductor manufacturing equipment

Activities included:

- **Design-for-Reliability**
  - Reliability modeling
  - Optimal design trades
- **Equipment Upgrades**
  - Reliability prediction
  - Optimization studies
- **Maintenance Strategies**
  - Optimal strategies
  - Spares inventory analyses
- **Education & Training**
  - Reliability training courses
  - Reliability Guidelines

Results!!

- ✓ Up to sixfold improvement in equipment reliability!
- ✓ 15%-20% reduction in life-cycle cost!
- ✓ Increase % of world market share!



Sandia National Laboratories

Why Design for Reliability?

System Sustainment & Readiness Programs

- **"The emphasis in the new process will be 'design for reliability'" – Col. William Taylor, PEO for Marine Corps land systems (in reference to the troubled Expeditionary Fighting Vehicle (EFV) program)**
- **Mr. Charles McQueary, the Pentagon's chief operational tester is advocating that the services invest more upfront to improve the reliability of new weapon systems so that the costs of maintaining them over their lifetime will be much less**
- **"The investment of money in the upfront RDT&E period on meeting reliability, maintainability and availability objectives is really highly leveraged money." – Charles McQueary,**

"Operational testing should be a period of confirmation, not a period of discovery"

McQueary, 2007

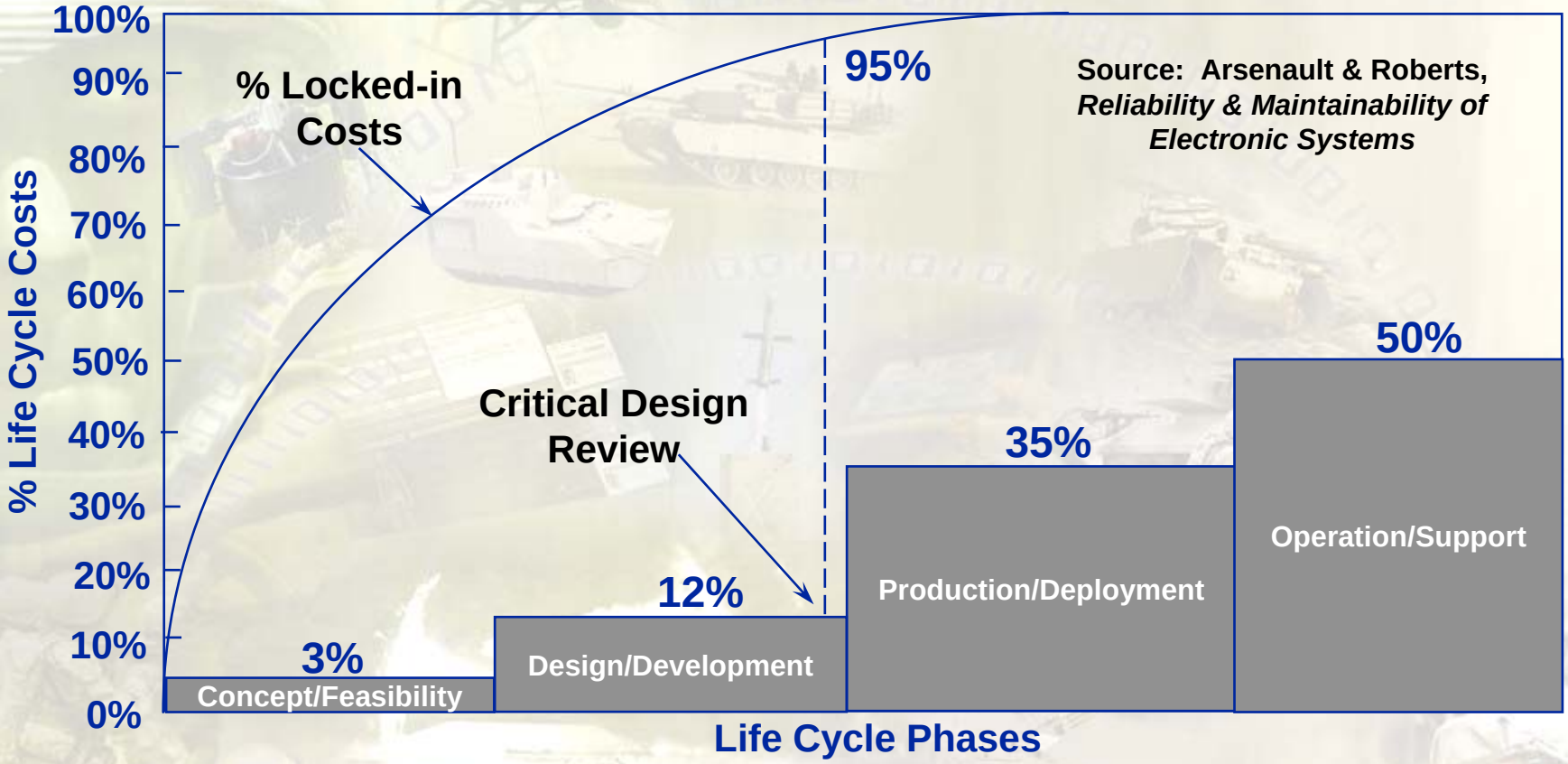
Sandia National Laboratories

Design for Reliability
Supplier Cost Implications

System Sustainment & Readiness Programs

"*Reliability* should be built into products at the earliest possible stages of design"

Source: *Made in America,* MIT Commission on Industrial Productivity



"Over 90% of all Reliability and Quality costs in the U.S. are being spent to correct product design inadequacies and defects after they have occurred, while less than 10% are being spent to make products right in the first place."

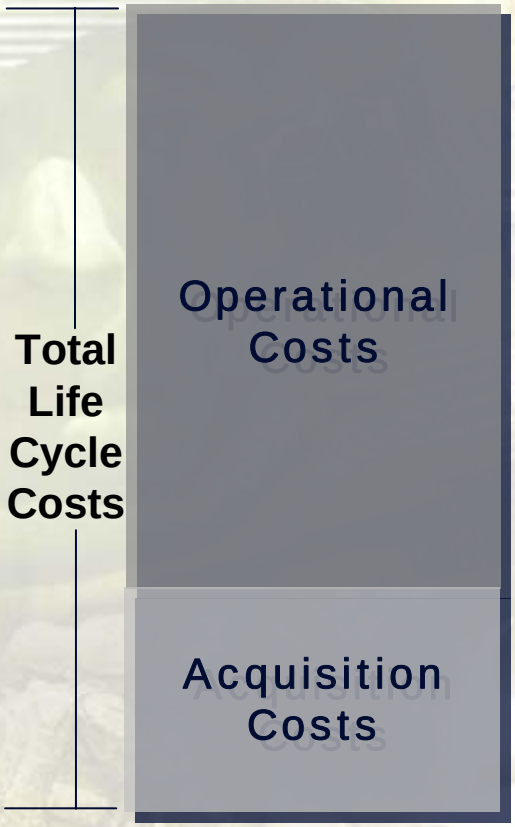
Source: K.C. Kapur and L.R. Lamberson *"Reliability in Engineering Design"*

Sandia National Laboratories

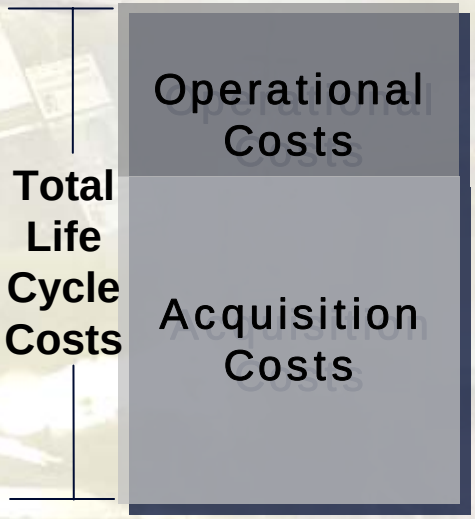
Design for Reliability
Customer Cost Implications

System Sustainment & Readiness Programs

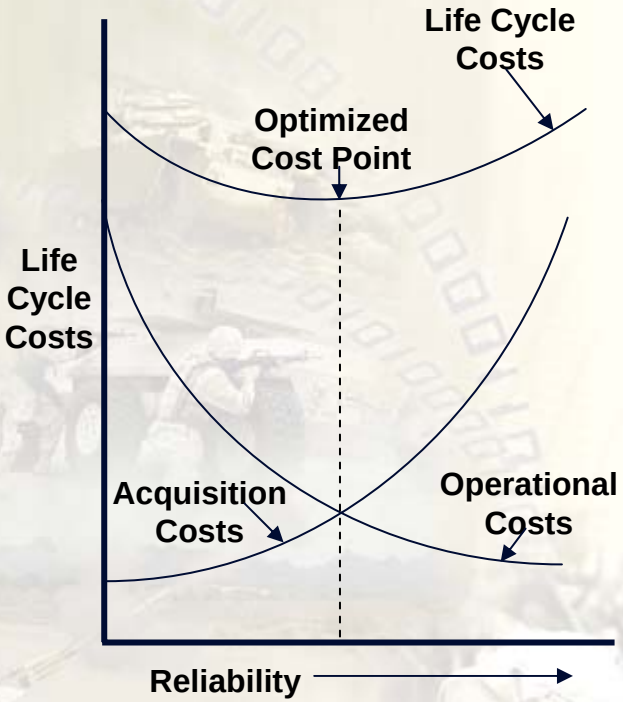
Notional Impact of Design for Reliability on Life Cycle Costs



Without Design for Reliability



With Design for Reliability



Optimizing Life Cycle Costs

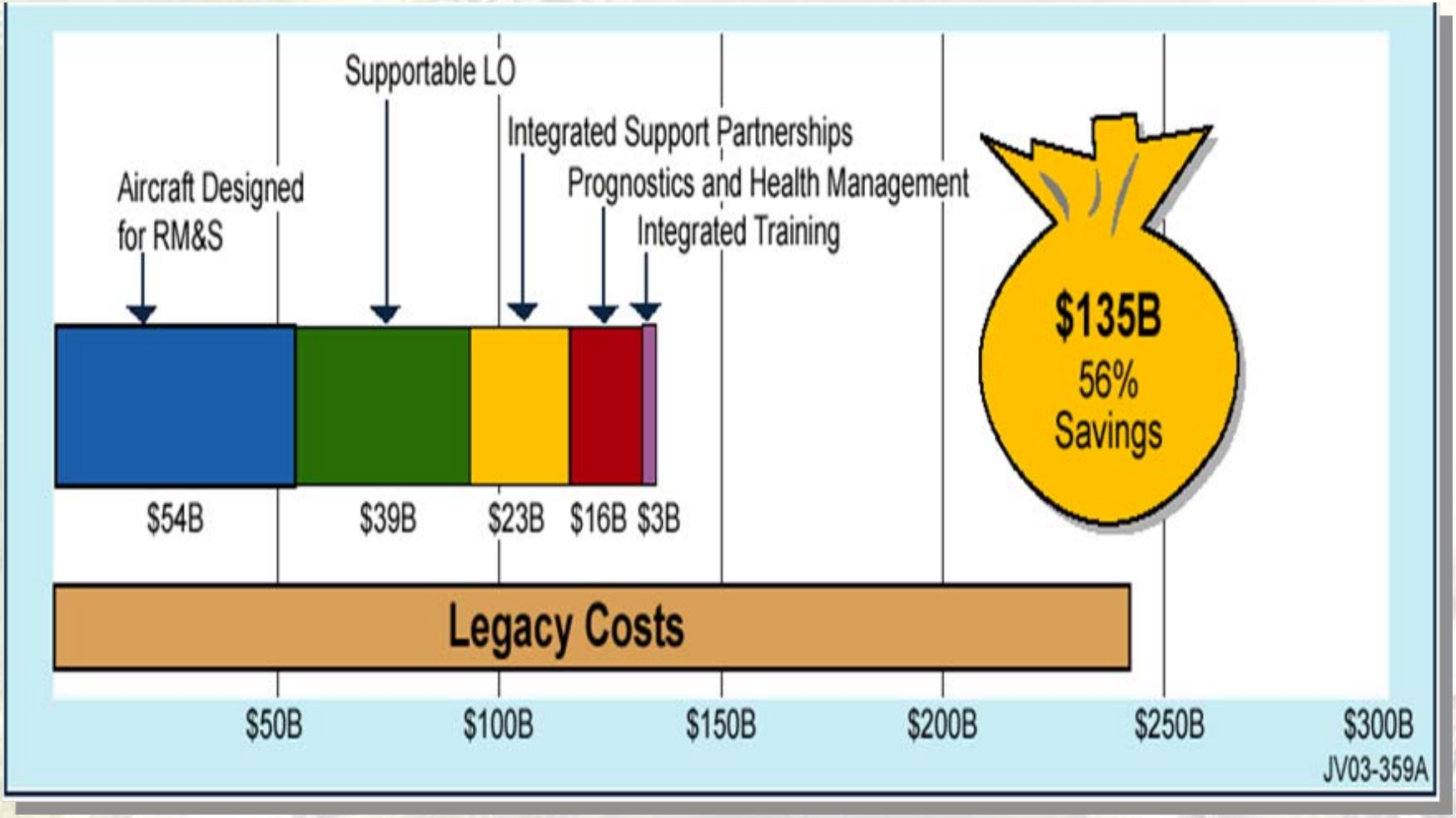
It is important to make Equipment Purchase Decisions Based on Total Life Cycle Costs

Sandia National Laboratories

Impact of Design for Reliability on LCC

System Sustainment & Readiness Programs

Planned Impact of DFR on Total LLC



Sandia National Laboratories

Design for Reliability

System Sustainment & Readiness Programs

- **Why not more widely used?**
  - Reliability is an afterthought - Designs are committed to before reliability is considered
  - Preoccupation with short-term profits
  - Felt to be more costely
  - Not supported by top management
- **Successful Practices**
  - Formalized Reliability Program (that is used throughout the life cycle)
  - Good organized data collection program (e.g., failure recording & corrective action system) that accounts for uncertainty
  - Careful thought given to Reliability metrics
  - Use of predictive modeling & simulation
  - Use of optimization techniques
  - Emphasis on a *system-level* approach to design for reliability

"Prediction* is *part of the process of 'designing the future'."

MIL-HDBK 217

Sandia National Laboratories

Design for Reliability
Reliability Engineering Cycle

System Sustainment & Readiness Programs

System Design

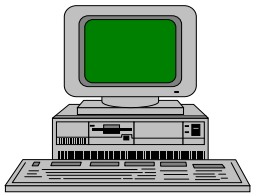
- Architecture
- Component Reliability
- Maintenance Policies

.
.
.

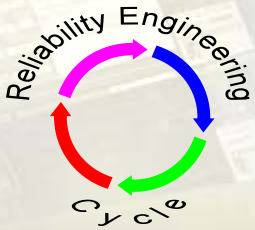
System Models

Step 1:

- Model Development
- Reliability Predictions
- Sensitivity/Uncertainty Analyses



Predicted System Performance



Step 2: Design Meets Reliability Objectives?

No → **Step 3: Reliability Improvement Activities**

Yes →

- Design Trade-off Studies
- Reliability Allocation
- Next Phase

Reliability Engineering Cycle activities are repeated until design meets requirements

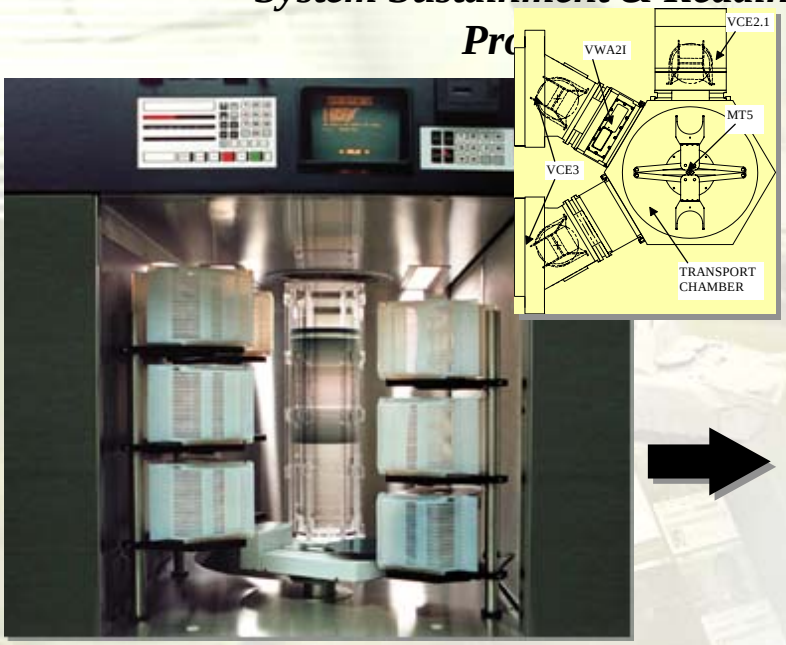
Source: *Reliability by Design*, AT&T

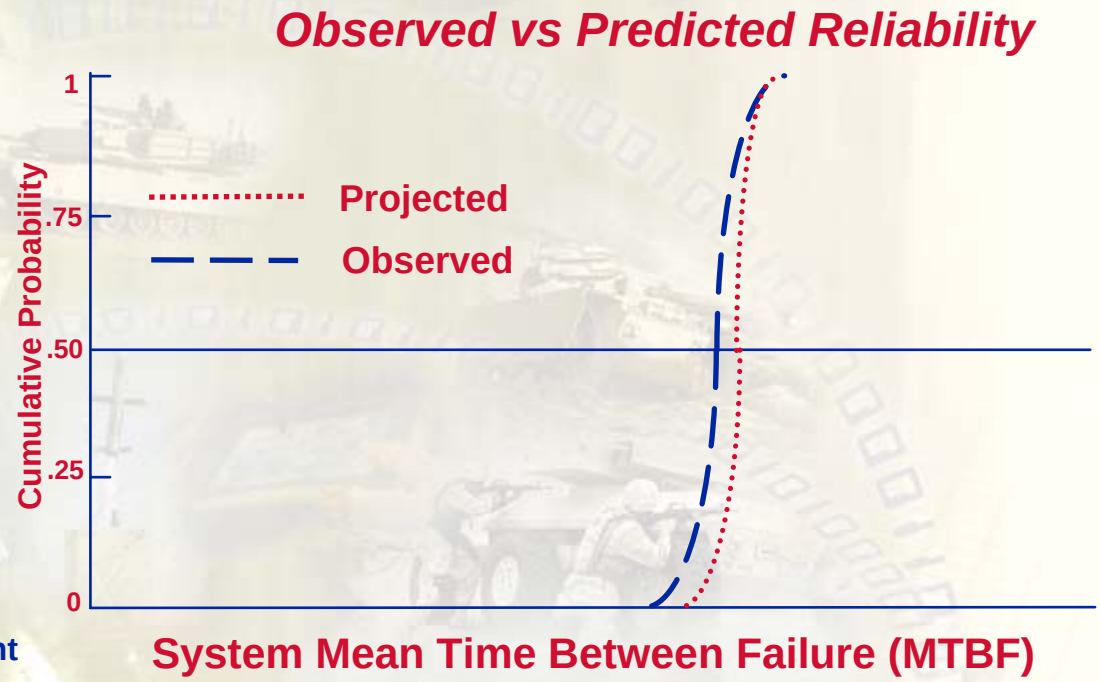
Sandia National Laboratories

New Design Reliability Prediction

System Sustainment & Readiness

Pr





- **Equipment manufacturer**
  - Semiconductor manufacturing equipment
  - New "Central Wafer Handling System"
- **Considering new design based on:**
  - New technology
  - Performance improvements
  - Market potential
- **Predict performance of new design**
  - Identify potential problem areas
  - Suggest improvements
  - Predict equipment reliability

Company reporting $M's in design and life cycle cost savings from use of DFR!

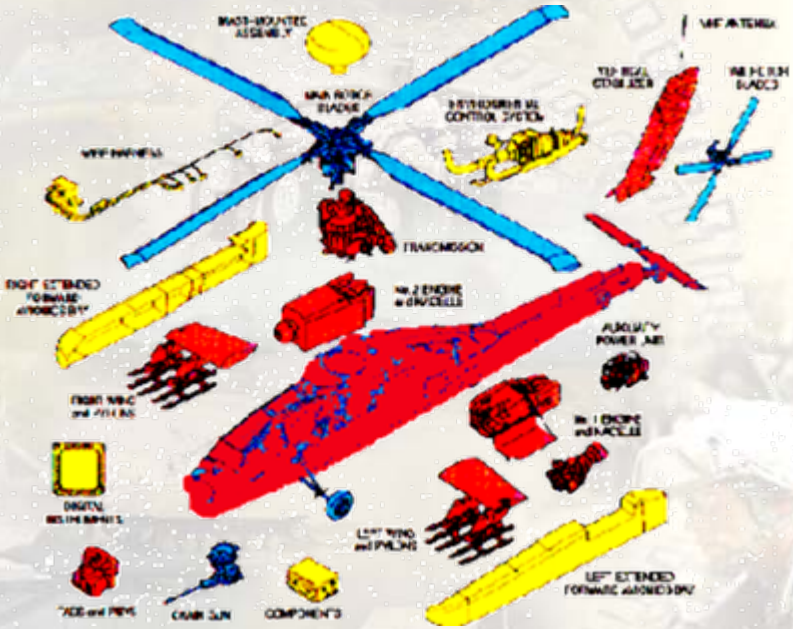
Reliability Allocation

System Sustainment & Readiness Programs

Allocate System Requirements to Subsystems & Components

- Equal Apportionment Technique
- Using Optimization Techniques (such as GA's)
- The ARINC Apportionment Technique
- The AGREE Allocation Method
- Effort Minimization Algorithm
- Using Dynamic Programming

Allocation of System Requirements



Shows where to optimally spend your dollars

Sandia National Laboratories

Resource Allocation

System Sustainment & Readiness Programs

Standard Approach:

Resources *not* guided by allocation process

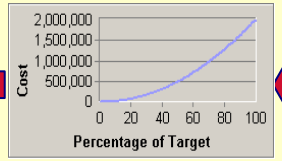
Part	Funding for Redesign
LRU 1	$1.6M
LRU 2	$1.6M
LRU 3	$1.6M
LRU 4	$1.6M

- Does not easily account for differing costs required to upgrade parts
- Difficult to apply for multiple objectives (cost and readiness)
- Does not support iterative process needed to reach optimal allocation

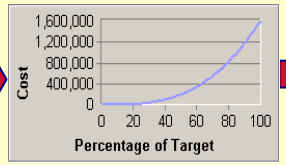
Optimal Approach

Part	Allocated Improvement Level	Effort to Improve
LRU 1	5	Easy
LRU 2	3	Int.
LRU 3	1	Hard
LRU 4	4	Very Hard

Updated



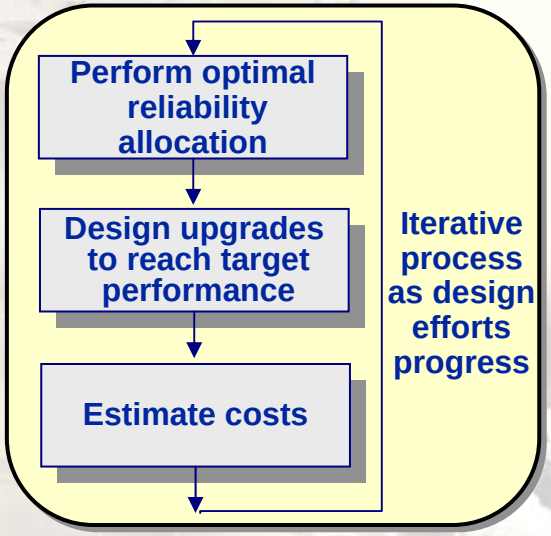
Cost vs. Improvement



Current

Part	Funding for Redesign
LRU 1	$0.5M
LRU 2	$1.6M
LRU 3	$0.2M
LRU 4	$2.7M

Iterative Redesign Evaluation



Allocation process provides efficient targeting of resources

Sandia National Laboratories

Resource Allocation Optimization

System Sustainment & Readiness Programs

- **Objectives:**
  - **Improve system availability 20%**
- **Improvement options: Improve reliability of major subsystems and components**
  - **For example:**
    - **Level 0 = no improvement**
    - **Level 1 = 20% improvement**
    - **Level 2 = 40% improvement**
    - **Level 3 = 60% improvement**
    - **Level 4 = 80% improvement**
    - **Level 5 = 100% improvement**
- **Constraint: Costs to improve failure rates of cost & availability drivers**
- **Find optimal allocation (level of improvement) of each subsystem and component given costs constraints**

Progress: 100.00% | Generation: 200 | Best Fitness: 0.643

Rank: 1 Export...

1 Summary | 2 Details

Option	Level	Cost
PNVS Azimuth Drive Gimbals	4	3.20
PNVS ELECTRONIC UNIT	5	5.00
PNVS TURRET	5	5.00
POWER SUPPLY	1	64,000.00
PROCESSOR,SIGNAL (FAULT FUNC)	1	64,000.00
PUMP, HYDRAULIC RAM (GRND SERV)	0	0.00
PUMP,AXIAL PISTONS, (L&R HYD)	2	256,000.00
PUMP,SUBMERGED, (REFUEL XSFR)	0	0.00
PYLON, AIRCRAFT (4)	2	256,000.00
RADAR ALTIMETER R/T	1	64,000.00
RECEIVER-TRANSMITTER	3	576,000.00
SCISSORS ASSY MAIN ROTOR UPPER CONTROL SECONDARY	1	64,000.00
SERVOCYLINDER (COLL. CONT.) (1 ea)	0	0.00
SERVOCYLINDER (DIR. CONT.) (2 ea)	4	1,024,000.00
SERVOCYLINDER (LAT. CONT.) (1ea)	3	576,000.00
SHAFT ASSY COMM	1	64,000.00
SHOCK STRUT ASSY (MLG) (2 EA)	2	256,000.00
SHOCK STRUT ASSY (TLG) (1 EA)	1	64,000.00
SWASHPLATE,CONTROL (T/R)	1	64,000.00
SWASHPLATE,CONTROL, (M/R)	0	0.00
TADS ELECTRONICS UNIT	5	5.00
TADS POWER SUPPLY	5	5.00
TADS SERVO ELEC/TORQ AMP	5	5.00
TADS TURRET	5	5.00
TAIL ROTOR FORK ASSY	1	64,000.00
TRAIN RATE SENSOR	2	256,000.00

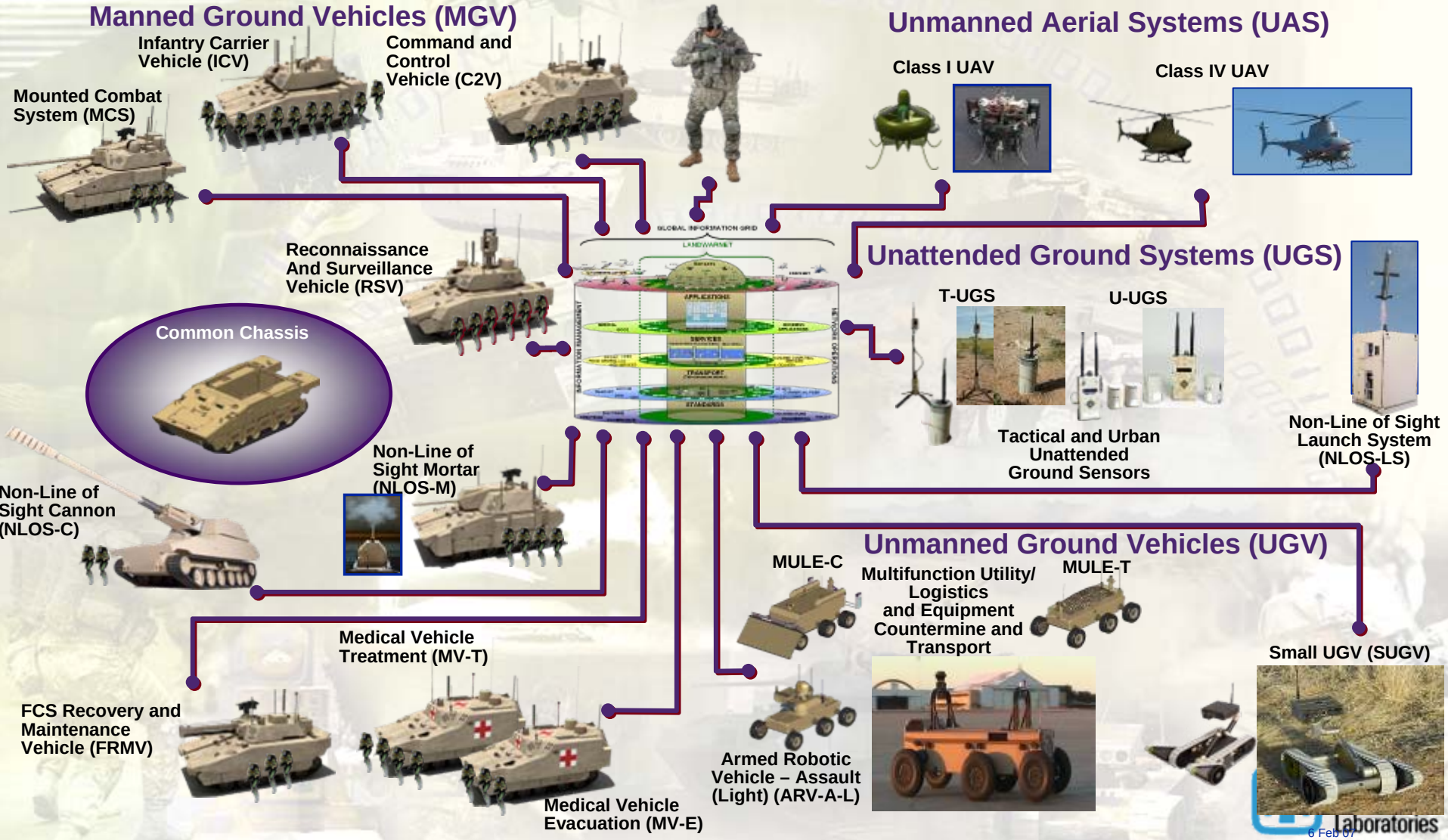
The results show where to optimally spend your dollars

Importance of Simulation in DFR

System Sustainment & Readiness Programs

PROGRAM MANAGER FCS BRIGADE COMBAT TEAM
One Team-The Army/Defense/Industry

FCS System of Systems (SoS) Force Structure

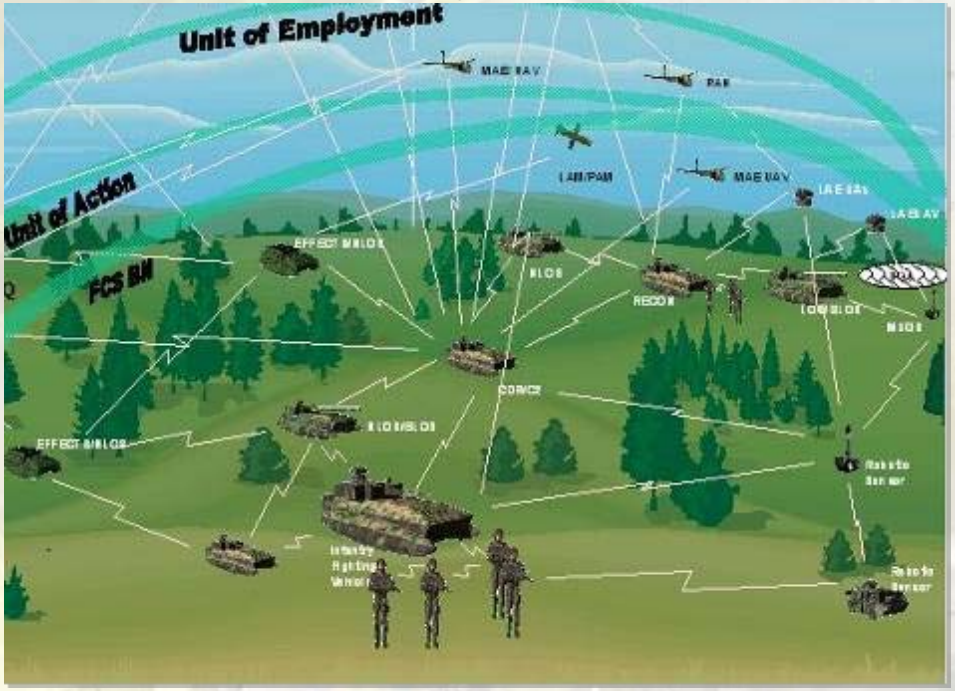


Simulation of FBCT Combat Mission

System Sustainment & Readiness Programs

PROGRAM MANAGER FCS BRIGADE COMBAT TEAM
One Team-The Army/Defense/Industry

SoS Simulated Mission



- **Utilizes:**
  - Unique State Modeling Concepts
  - State-of-Art SoS Simulation Framework
  - Customized Optimization Algorithms
- **Provides Capability for Analyzing:**
  - Systems as well as Systems-of-Systems
  - Warfight capabilities (pre, post, during campaigns)
  - Spiral integration of technologies
- **Flexibility to Include:**
  - Complex supply & communication networks
  - Stochastic treatment of combat damage
  - Human performance (maintainers, warfighters, …)
- **Allows Analyst to Assess Impacts of:**
  - PHM
  - Asset visibility/reduced consumables
  - Parts on board/crew repairable

- *Time-Dependent Operational Status*
- *SoS MOE's/TPM's (e.g., A_0)*
- *Sensitivity Trades*
- *Integrated Logistics Status*
- *Optimization Analyses . . .*

Integrated methodology provides unique capabilities for SoS analysis

Sandia National Laboratories