A Model for Measuring the Correlation Between TRA and Enabling Engineering Activities, Cost, schedule, and System Quality for U.S. DoD Acquisition Programs

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U.S. DoD Acquisition Challenges

Among other challenges, DoD has been facing problems in the area of acquisition

"First, this department must consistently demonstrate the commitment and leadership to stop programs that significantly exceed their budget or which spend limited tax dollars to buy more capability than the nation needs…

Second, we must ensure that requirements are reasonable and technology is adequately mature to allow the department to successfully execute the programs…

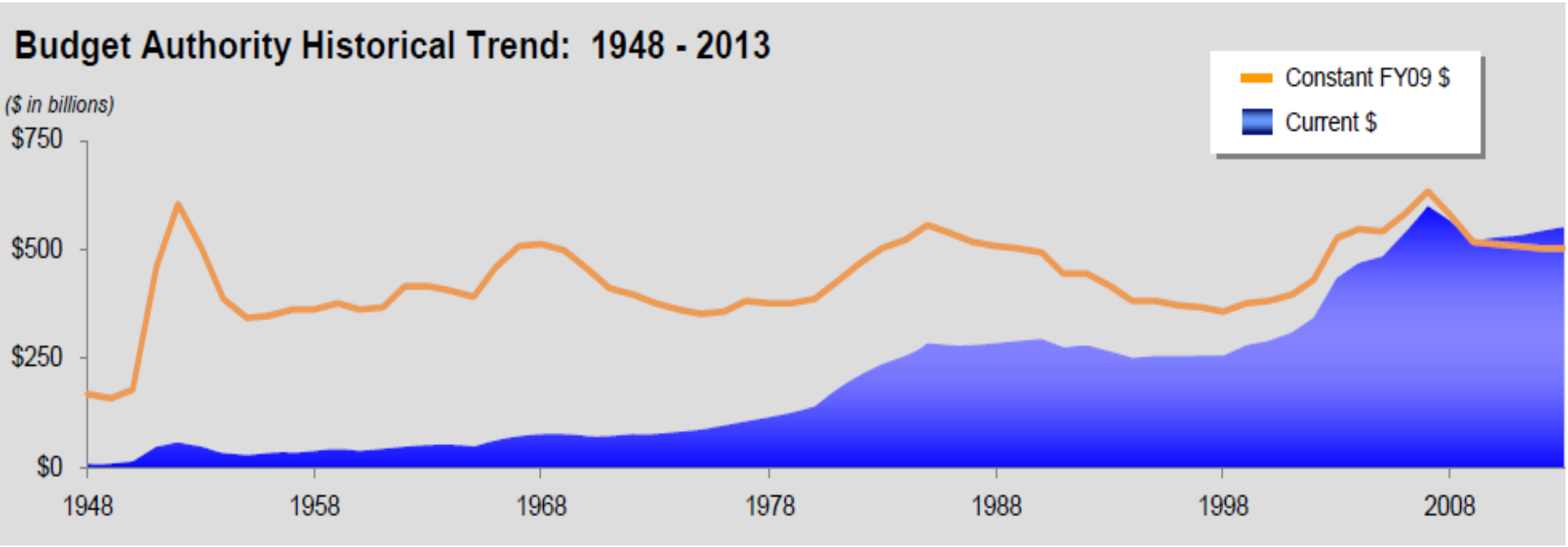
Third, realistically estimate program costs, provide budget stability for the programs we initiate, adequately staff the government acquisition team, and provide disciplined and constant oversight.

We must constantly guard against so-called "requirements creep," validate the maturity of technology at milestones, fund programs to independent cost estimates, and demand stricter contract terms and conditions."

Secretary of Defense Robert M. Gates

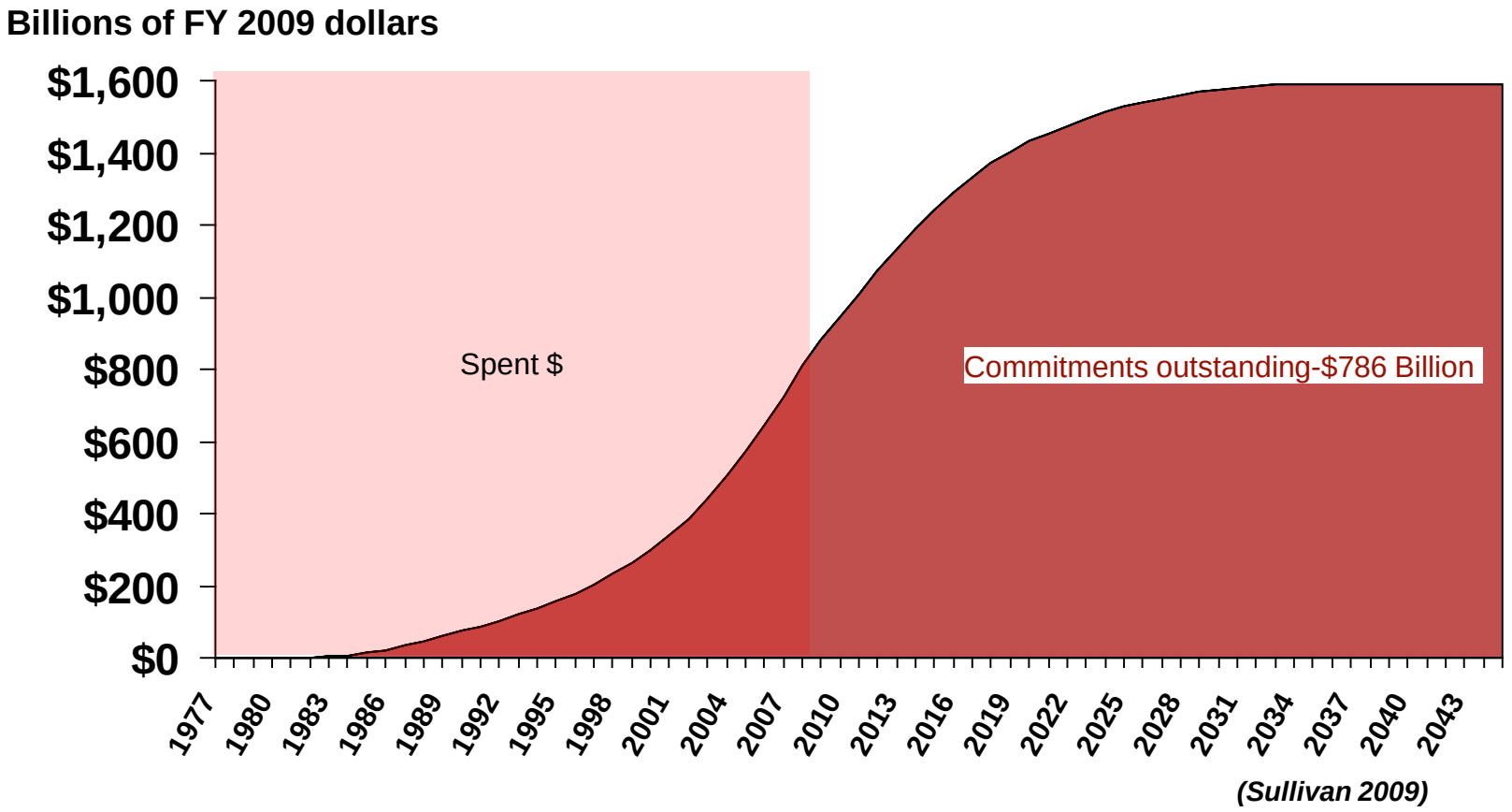
Background

Investment dollars increase, yet U.S. DoD acquisition programs continue to be susceptible to risk in the form of schedule slips, cost overrun, cancellations, and failure to meet performance objectives



U.S. Defense Historical Budget Trends From 1948 – 2013 (OM&B 2009)

Committed and Planned Spending on 2008 Portfolio of 96 Programs

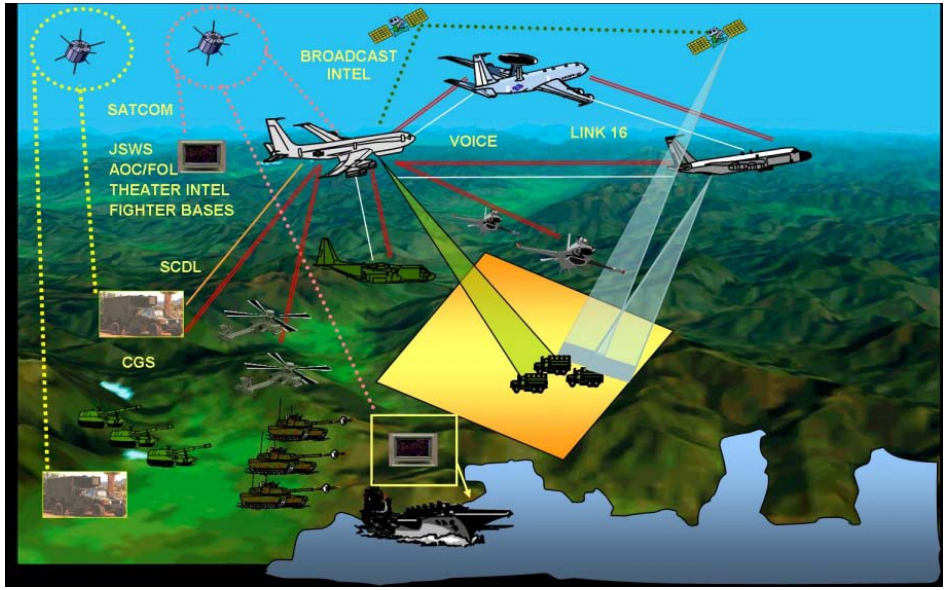


(Sullivan 2009)

Root Causes of Risk

- ✓ Unrealistic performance expectations
- ✓ Unrealistic baseline estimates for cost or schedule
- ✓ **Immature technologies or excessive manufacturing or integration risk**
- ✓ Unanticipated design, engineering, manufacturing, or technology integration issues arising during program performance
- ✓ Changes in procurement quantities
- ✓ Inadequate program funding or funding instability
- ✓ Poor performance by government or contractor personnel responsible for program management
- ✓ lack of mature manufacturing processes

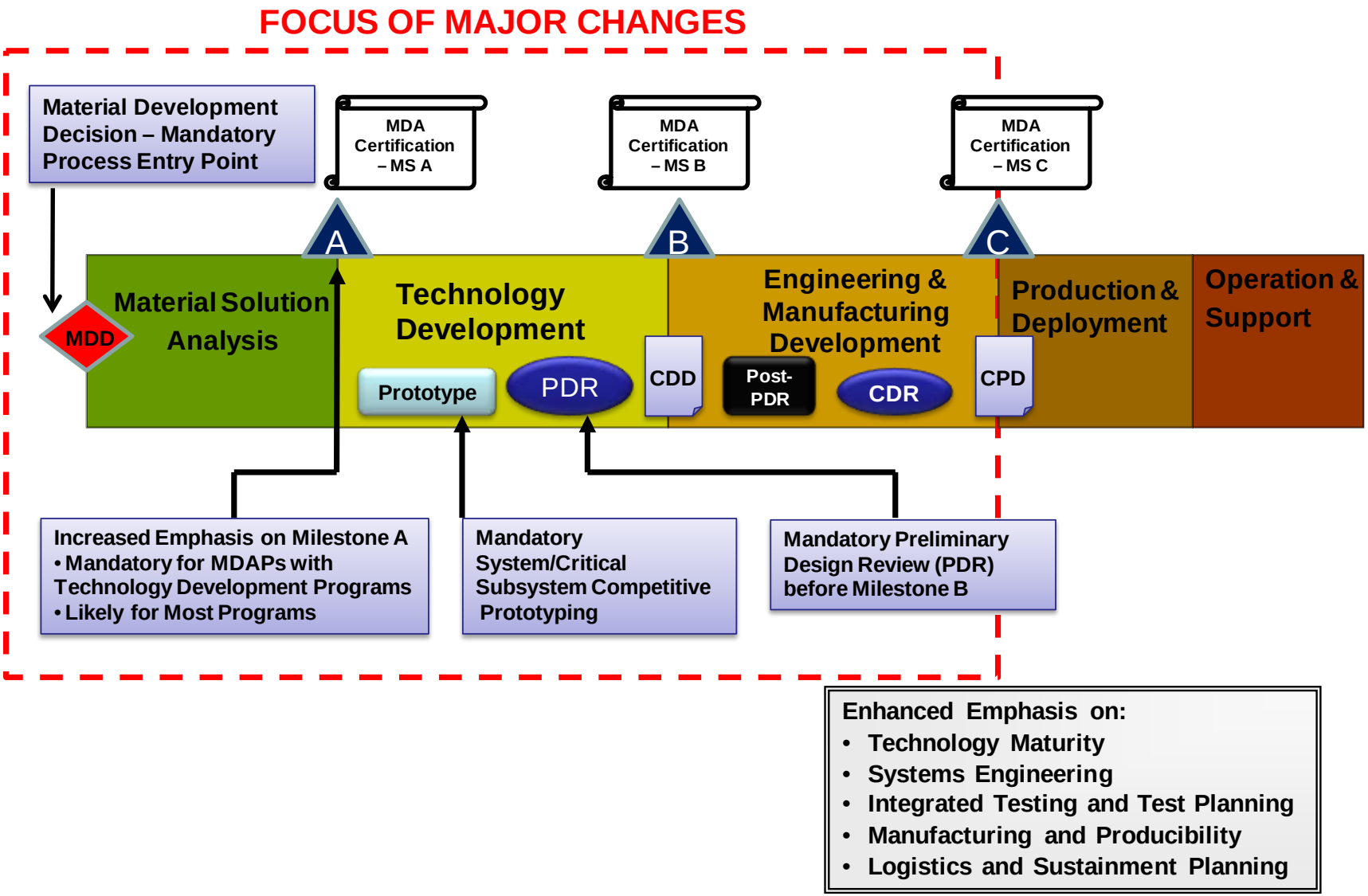
- ✓ Increasingly complex Systems
- ✓ Increased data demand requirements
- ✓ Operating in a net-centric environment
- ✓ System-of-System centric
- ✓ Rapid development cycle
- ✓ Rapid technology obsolescence
- ✓ Evolving requirements



DoD Initiatives

- **Nunn-McCurdy Act 1982** -cancellation of weapons programs that experience a cost overrun of more than 25% above the original estimation
- **Packard Commission Act 1986** -streamlining of the acquisition process, increasing test and prototyping, changing the organizational culture, improve planning, and model the DOD after a competitive firm
- **Defense Acquisition Workforce Improvement Act (DAWIA) 1990** - encouraged training and education for DOD and civilian workforce
- **Federal Acquisition Streamline Act (FASA) 1994**--encouraged the adoption of commercial best practices, which was a significant movement away from Federal acquisition laws and regulations
- **Clinger-Cohen Act 1996** – built upon FASA , simplified acquisition of commercial items; placed high emphasis on accountability, performance, and result-based IT management
- **Weapon System Acquisition Reform Act (WSARA) 2009**

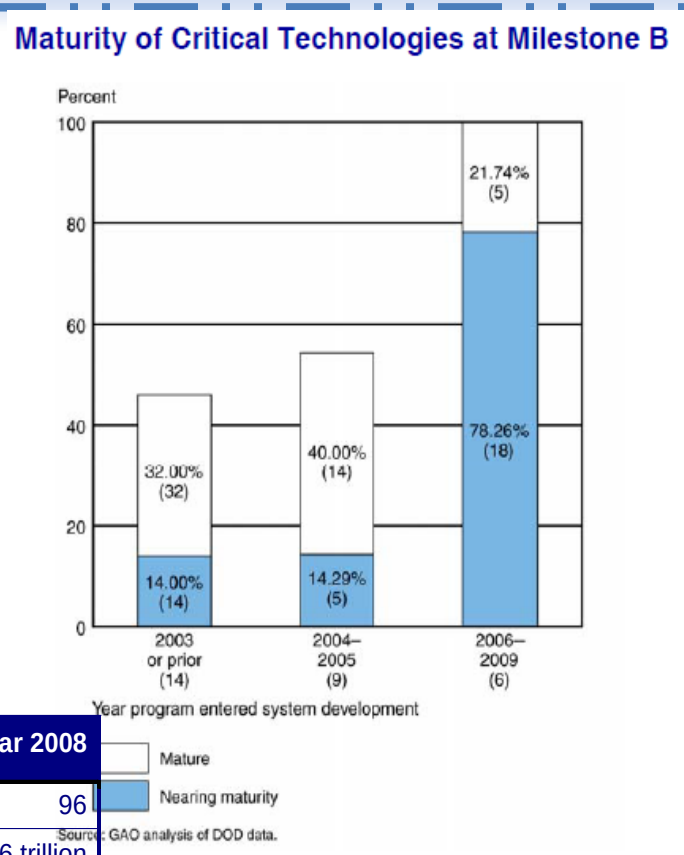
WSARA 2009


FOCUS OF MAJOR CHANGES
Material Development Decision – Mandatory Process Entry Point
MDA Certification – MS A
MDA Certification – MS B
MDA Certification – MS C
A
B
C
MDD
Material Solution Analysis
Technology Development
Prototype
PDR
CDD
Engineering & Manufacturing Development
Post-PDR
CDR
CPD
Production & Deployment
Operation & Support
Increased Emphasis on Milestone A
• Mandatory for MDAPs with Technology Development Programs
• Likely for Most Programs
Mandatory System/Critical Subsystem Competitive Prototyping
Mandatory Preliminary Design Review (PDR) before Milestone B
Enhanced Emphasis on:
• Technology Maturity
• Systems Engineering
• Integrated Testing and Test Planning
• Manufacturing and Producibility
• Logistics and Sustainment Planning

Acquisition Outcomes Per GAO

weapon system programs are initiated without:

1. Sufficiently mature technologies
2. Stable designs
3. Sufficiently mature manufacturing processes



Portfolio status	Fiscal year 2003	Fiscal year 2007	Fiscal year 2008
Number of programs	77	95	96
Total planned commitments	$1.2 trillion	$1.6 trillion	$1.6 trillion
Commitments outstanding	$724 billion	$875 billion	$786 billion
Change to total RDT&E costs from first estimate	37 percent	40 percent	42 percent
Change in total acquisition cost from first estimate	19 percent	26 percent	25 percent
Estimated total acquisition cost growth	$183 billion	$301 billion	$296 billion
Share of programs with 25 percent or more increase in program acquisition unit cost	41 percent	44 percent	42 percent
Average delay in delivering initial capabilities	18 months	21 months	22 months

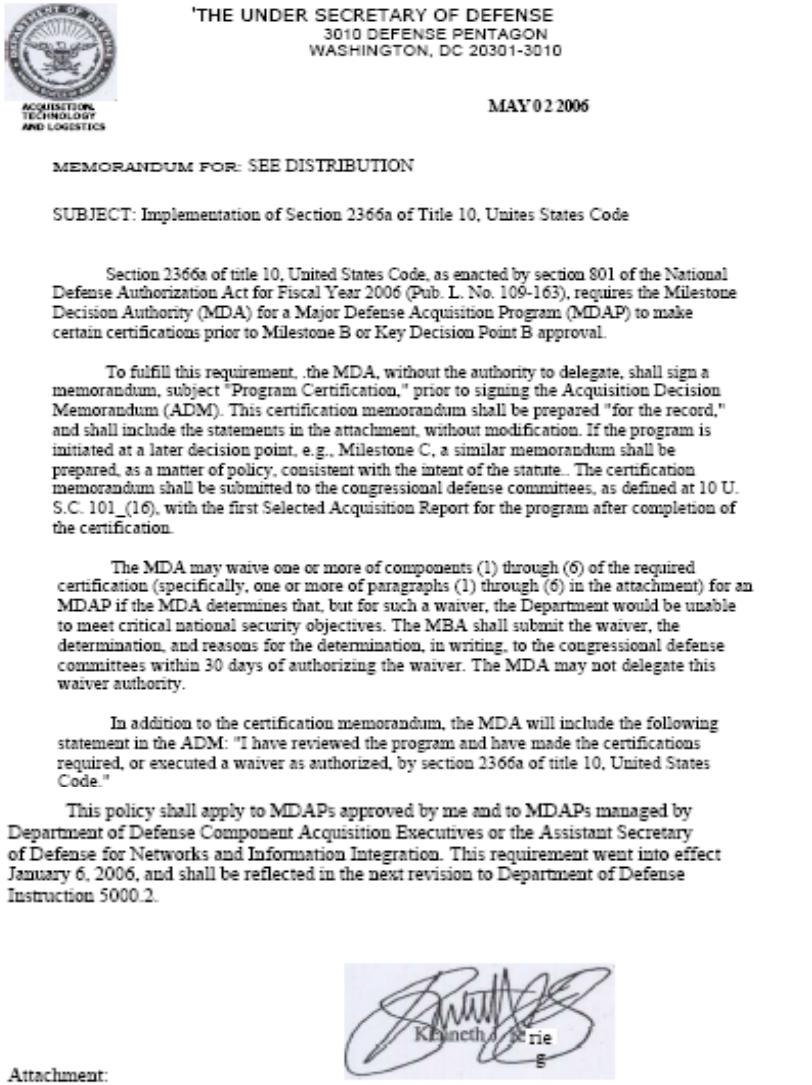
Strategy to Improve Acquisition Outcome

- **1999** - GAO stated in report that

  "Maturing new technology before it is included in a product is perhaps the most determinant of the success of the eventual product or weapon system" GAO/NSIAD-99-162
- **2001**- In a memorandum DUSD(S&T) endorsed assessing technology maturity using the TRL metrics
- **2003** - DoDI 5000.02 (2003), para 3.7.2.2 required the inspection of technology maturity by stating

  "Objective assessment of technology maturity and risk shall be a routine aspect of DoD acquisition."
- **2006** – Congressional legislation (Title 10, section)

  Technology maturity must be assessed and certified to be adequate prior to MS B&C



'THE UNDER SECRETARY OF DEFENSE
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WASHINGTON, DC 20301-3010

ACQUISITION, TECHNOLOGY AND LOGISTICS

MAY 0 2 2006

MEMORANDUM FOR: SEE DISTRIBUTION

SUBJECT: Implementation of Section 2366a of Title 10, Unites States Code

Section 2366a of title 10, United States Code, as enacted by section 801 of the National Defense Authorization Act for Fiscal Year 2006 (Pub. L. No. 109-163), requires the Milestone Decision Authority (MDA) for a Major Defense Acquisition Program (MDAP) to make certain certifications prior to Milestone B or Key Decision Point B approval.

To fulfill this requirement, .the MDA, without the authority to delegate, shall sign a memorandum, subject "Program Certification," prior to signing the Acquisition Decision Memorandum (ADM). This certification memorandum shall be prepared "for the record," and shall include the statements in the attachment, without modification. If the program is initiated at a later decision point, e.g., Milestone C, a similar memorandum shall be prepared, as a matter of policy, consistent with the intent of the statute.. The certification memorandum shall be submitted to the congressional defense committees, as defined at 10 U. S.C. 101_(16), with the first Selected Acquisition Report for the program after completion of the certification.

The MDA may waive one or more of components (1) through (6) of the required certification (specifically, one or more of paragraphs (1) through (6) in the attachment) for an MDAP if the MDA determines that, but for such a waiver, the Department would be unable to meet critical national security objectives. The MBA shall submit the waiver, the determination, and reasons for the determination, in writing, to the congressional defense committees within 30 days of authorizing the waiver. The MDA may not delegate this waiver authority.

In addition to the certification memorandum, the MDA will include the following statement in the ADM: "I have reviewed the program and have made the certifications required, or executed a waiver as authorized, by section 2366a of title 10, United States Code."

This policy shall apply to MDAPs approved by me and to MDAPs managed by Department of Defense Component Acquisition Executives or the Assistant Secretary of Defense for Networks and Information Integration. This requirement went into effect January 6, 2006, and shall be reflected in the next revision to Department of Defense Instruction 5000.2.

Attachment:
As stated

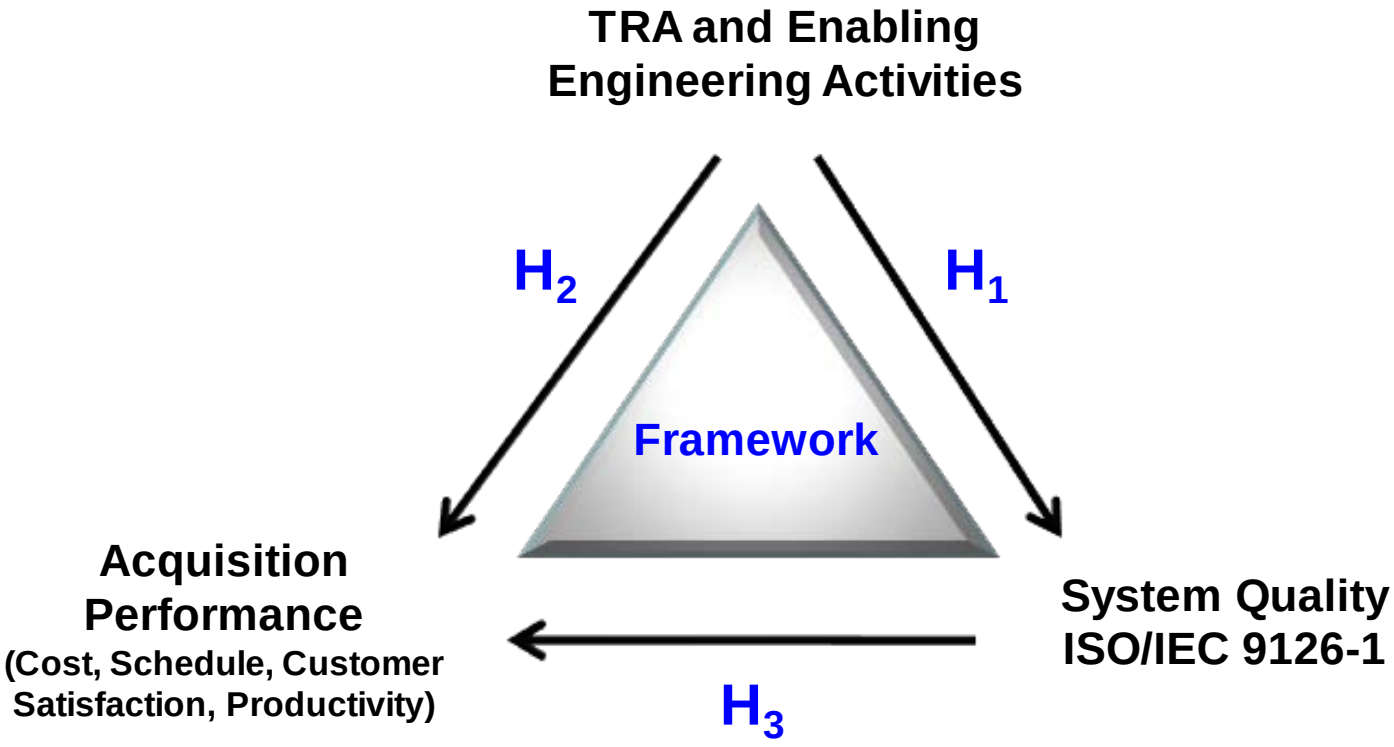
Defining Technology Readiness Assessment (TRA) and Technology Readiness Level (TRL)

- A TRA is a systematic, metrics-based process and accompanying report
- The TRA assesses the Maturity of Critical Technology Elements (CTEs)
- Critical Technology Elements (CTEs) are…
  - The system depends on this element to meet operational requirements
  - The element or its application is either new or novel.
  - Element poses major technological risk during detailed design or demonstration

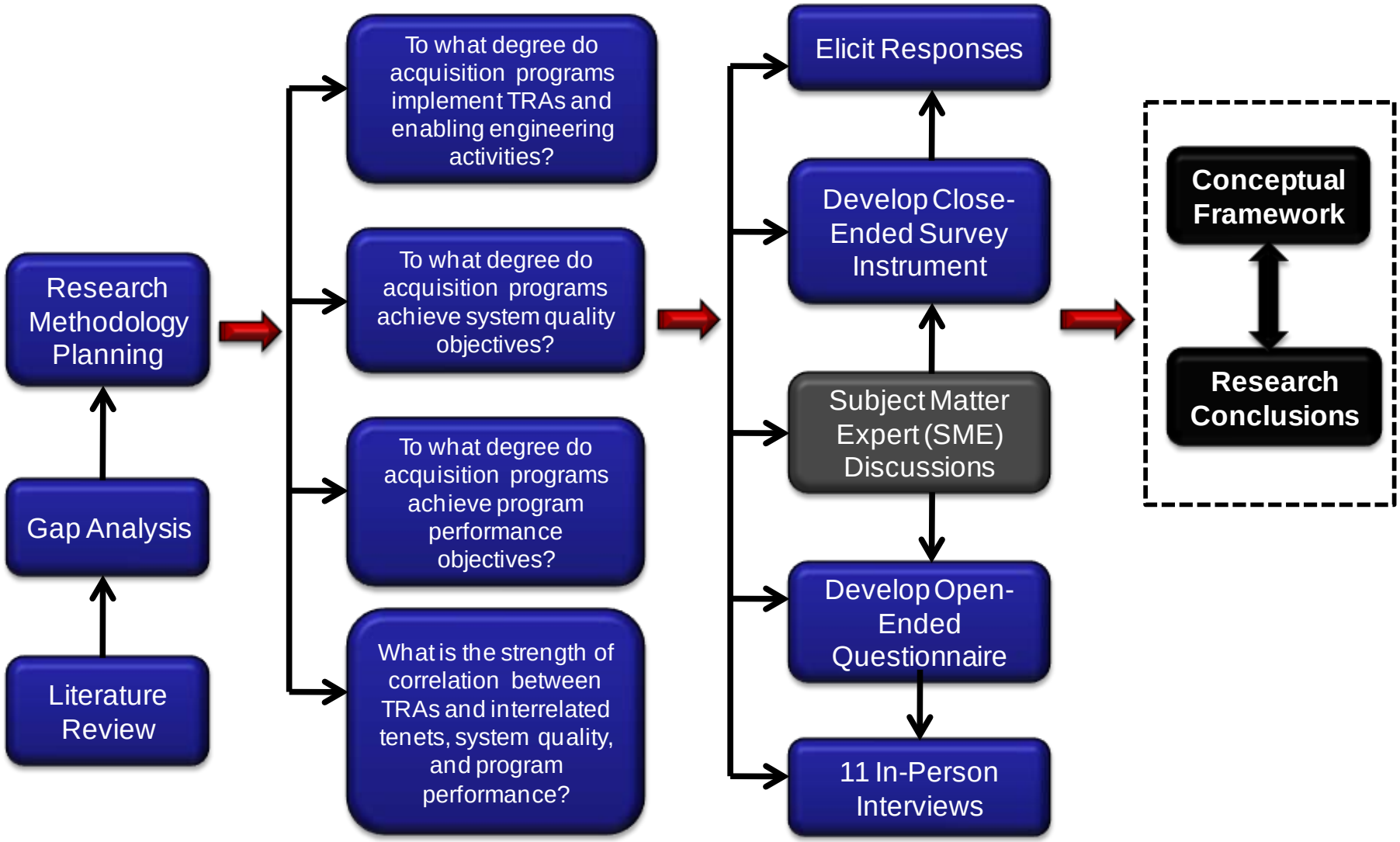
- DoD standard tool for performing TRAs is Technology Readiness Level (TRL) metric
  - Technology Readiness Level (TRL) is a 9 tier metric that systematically assess the maturity of a technology with respect to a particular use

Research Framework

Technology maturity has been linked to cost and schedule, however little emperical studies have been conducted to evaluate the degree of its correlation to the quality of DoD products and weapon systems.



Research Roadmap



Key Engineering Activities

Key Activities Leading to MS A

- White Papers
- Research Papers
- Analytical Studies
- Analysis of Alternatives
- Identification of KPPs
- CTE Identification
- Early CTE Maturity Assessment
- Systems Engineering Plan

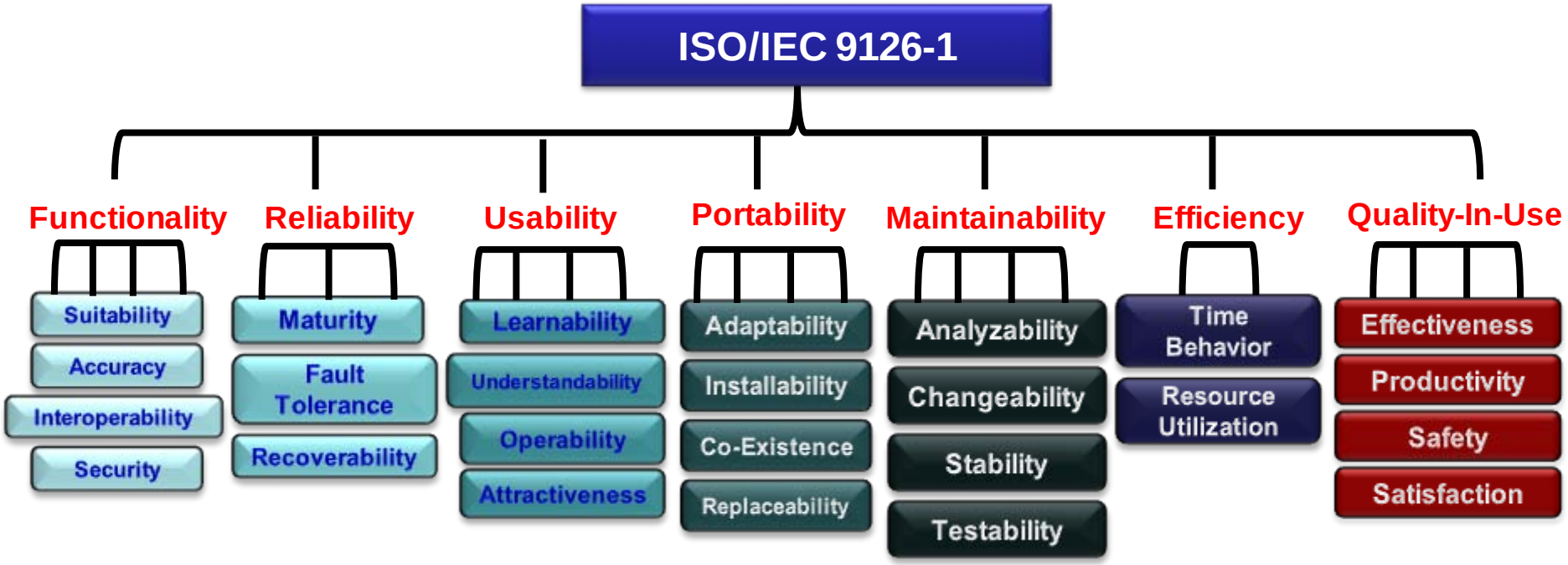
Key Activities Leading to MS B

- Laboratory Environment Evaluation of Components
- Relevant Environment Evaluation of Components
- System/Subsystem Prototyping
- Relevant Environment Evaluation of Prototype
- Milestone B TRA
- Capability Development Document (CDD)
- Test and Evaluation Master Plan (TEMP)

Key Activities Leading to MS C

- Actual System Prototyping
- System Demonstration in Relevant Environment
- System Development Testing
- Operational Testing
- Milestone C TRA
- Certification and Accreditation
- Capability Production Document (CPD)
- Information Support Plan

System Quality- ISO/IEC 9126-1



Hypotheses

H_1 -There is no correlation between TRAs and enabling engineering activities and the quality of military systems as measured by ISO/IEC 9126-1.

H_2 -There is no correlation between TRAs and enabling engineering activities and acquisition performance

- **H_{2a}** -There is no correlation between TRAs and engineering activities and acquisition cost
- **H_{2b}** -There is no correlation between TRAs and enabling engineering activities and acquisition schedule
- **H_{2c}** -There is no correlation between TRAs and enabling engineering activities and customer satisfaction
- **H_{2d}** -There is no correlation between TRAs and enabling systems engineering activities and acquisition productivity

H_3 -There is no correlation between the quality of military systems as measured by ISO/IEC 9126-1 and acquisition performance measured by cost, schedule, customer satisfaction, and productivity

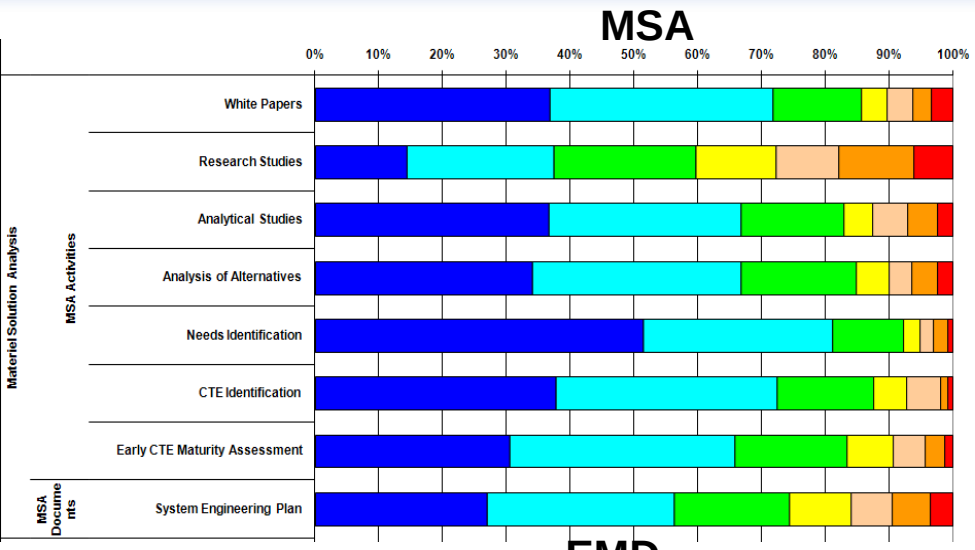
Demographic

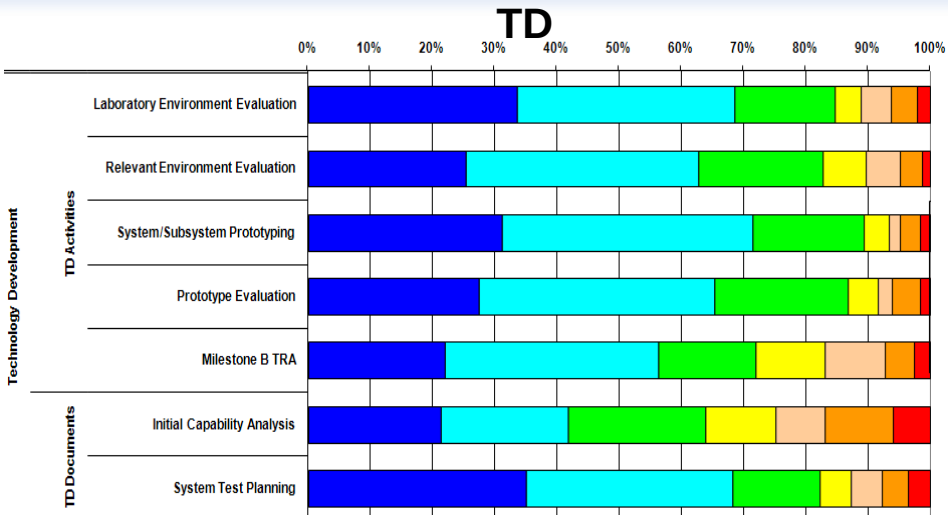
- Sample size n = 223

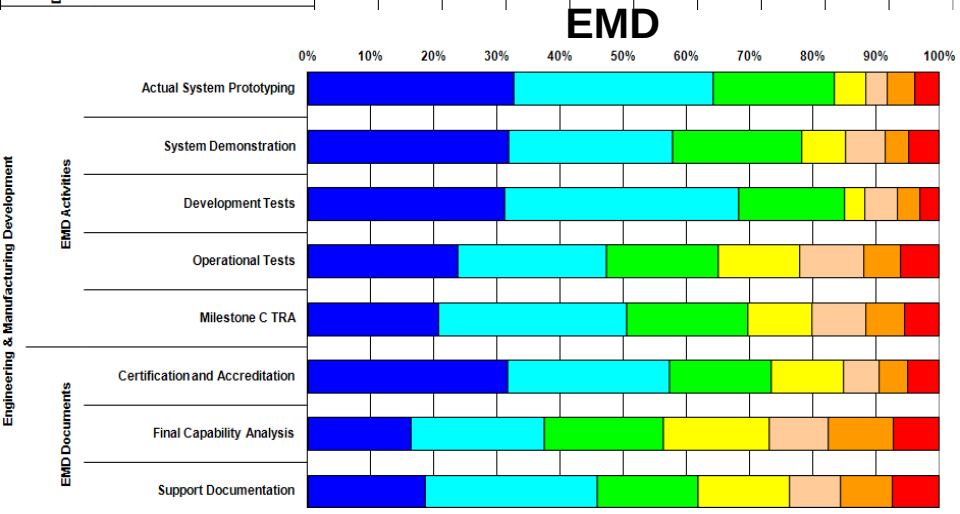
JOB FUNCTION	Freq	%
Executive	20	9%
Chief Engineer	19	9%
Director	12	5%
Program Manager	50	23%
Systems Engineer	100	45%
Hardware Engineer	8	4%
Software Engineer	13	6%
YEARS OF EXPERIENCE	**Freq**	**%**
0-5	21	11%
6-10	17	9%
11-15	18	9%
16-20	36	18%
21-25	28	14%
26-30	56	29%
31-35	20	10%

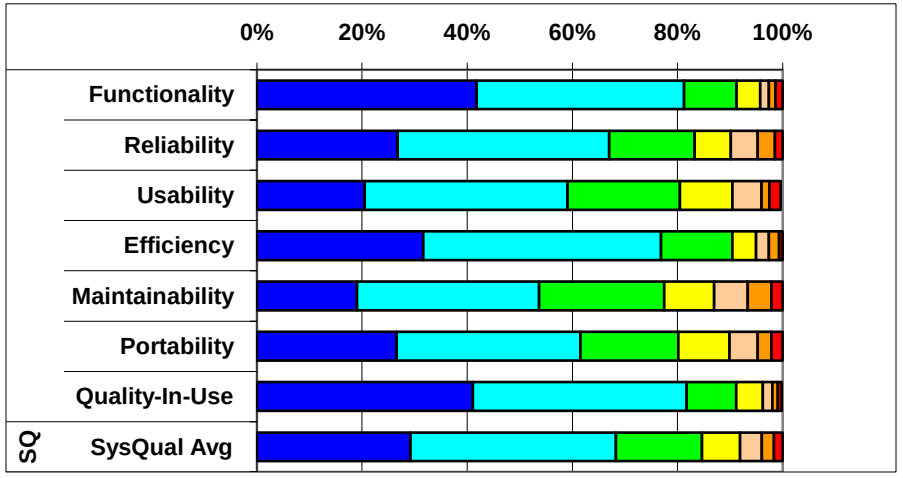
ACQUISITION PHASE	Freq	%
Material Solution Analysis	11	6%
Technology Development	48	24%
Engineering & Manufacturing Develop	61	31%
Production & Deployment	52	26%
Operation and Support	26	13%
Cancellation	2	1%
MARKET DOMAIN	**Freq**	**%**
Aircraft	47	21%
Science and Technology	42	19%
C4I Systems	52	24%
Mission Support	8	4%
Ground Vehicles	6	3%
Missile Defense	9	4%
Munitions and Missiles	4	2%
Shipbuilding and Maritime Systems	38	17%
Space Based Systems	14	6%

Degree of Compliance









Strongly Agree | Agree | Somewhat Agree | Neutral | Somewhat Disagree | Disagree | Strongly Disagree

Pearson Correlation & Cronbach's Alpha

Cronbach's Alpha Analysis

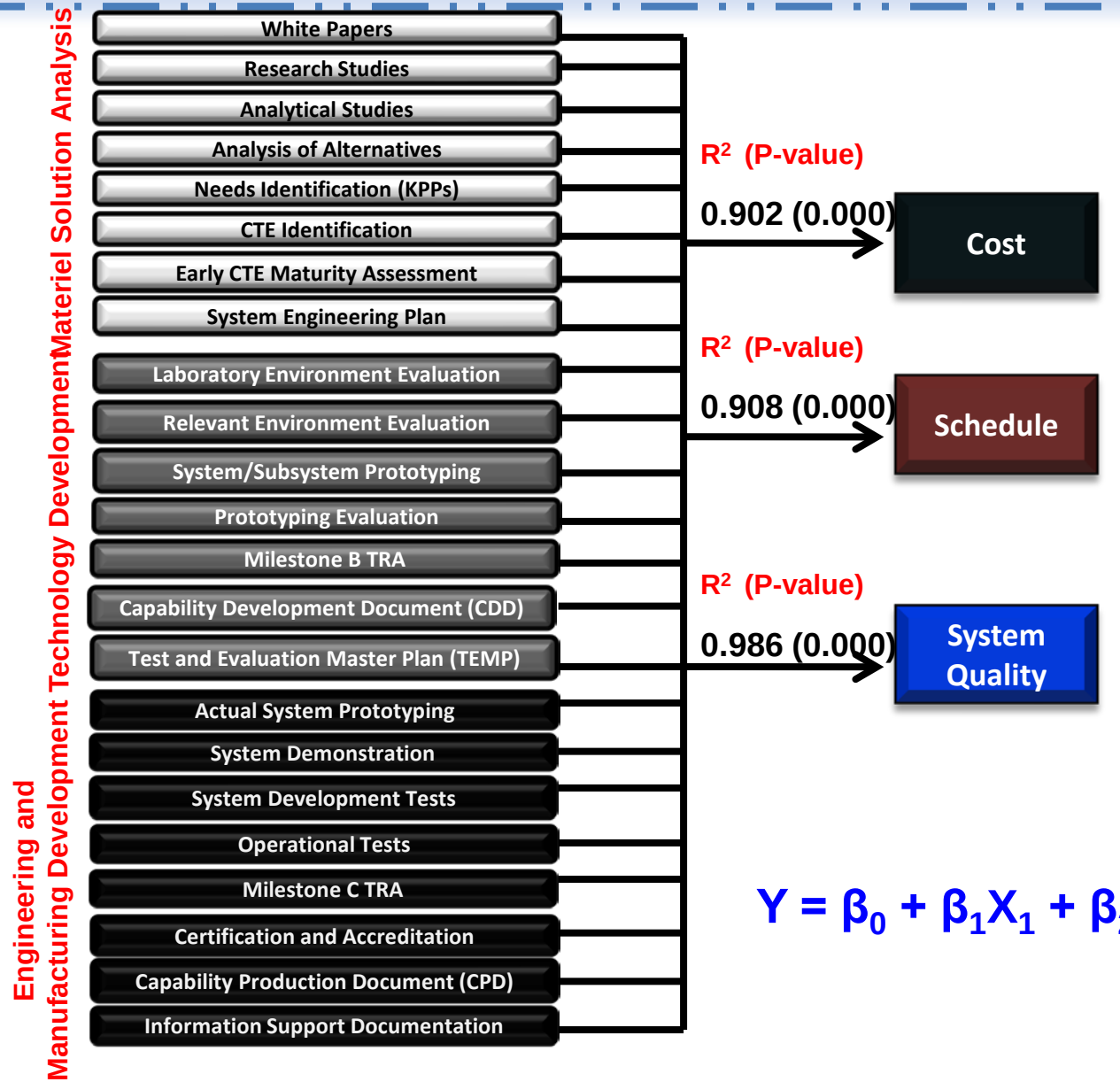
	Cronbach's Alpha	N of Items
Materiel Solution Analysis (MS)	0.862	8
Technology Development (TD)	0.862	7
Engineering and Manufacturing Development (EMD)	0.891	8
Overall System Quality	0.957	27
Cost	0.782	3
Schedule	0.766	3
Customer Satisfaction	0.749	3

Pearson Correlation Analysis

	MSA	TD	EMD	System Quality	Cost	Schedule	Customer Satisfaction	Productivity
MSA	1							
TD	.741	1						
EMD	.573	.703	1					
System Quality	.625	.610	.570	1				
Cost	.318	.311	.291	.364	1			
Schedule	.343	.307	.251	.389	.749	1		
Customer Satisfaction	.426	.397	.345	.500	.515	.550	1	
Productivity	.412	.410	.332	.532	.388	.437	.485	1

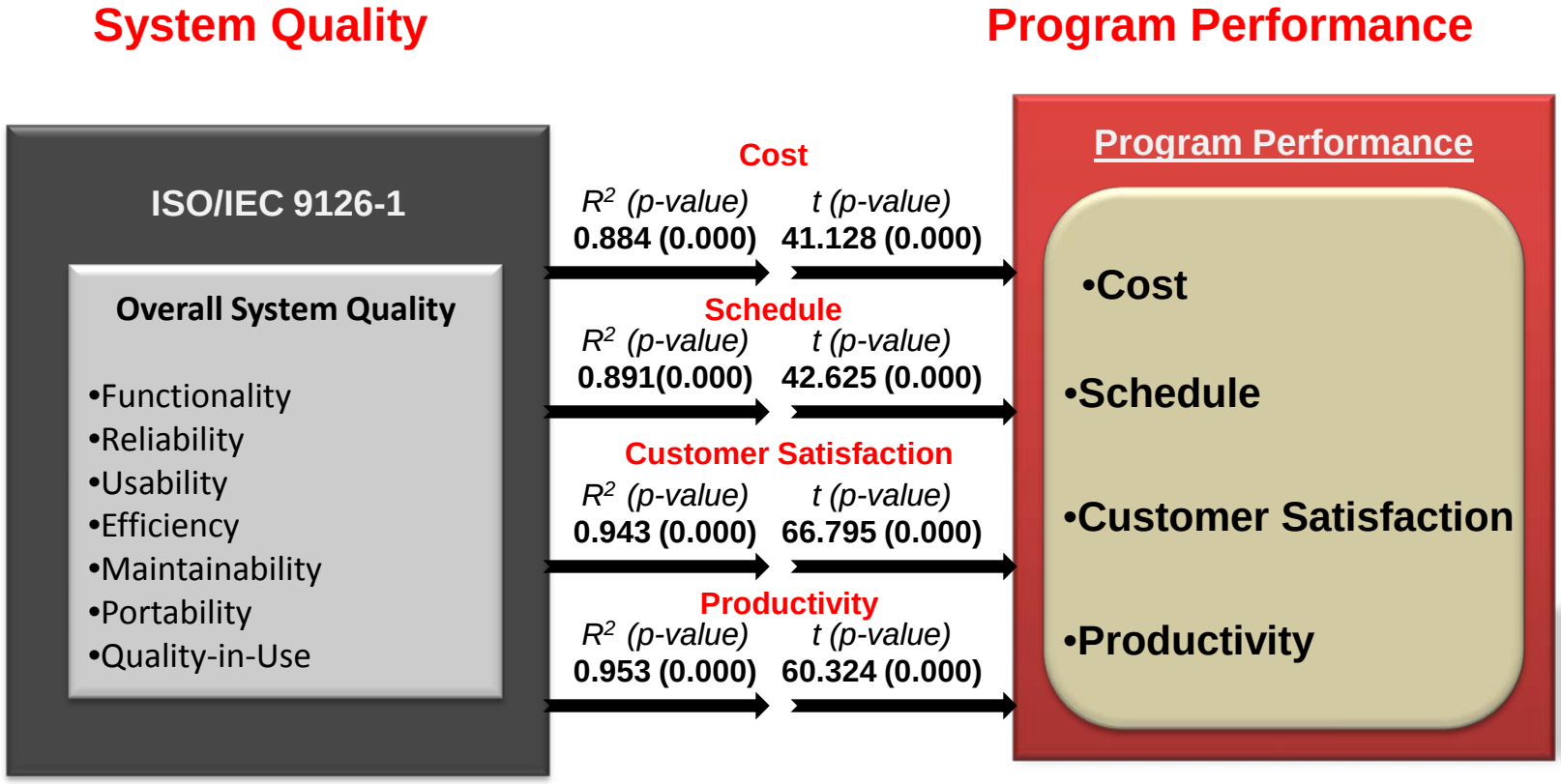
All correlations are significant p < 0.01

Regression Test



$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \ldots + \beta_n X_n + \varepsilon$$

Acquisition Performance as a Function of System Quality



Interview Findings

- ***Finding One***: assessing technology maturity is ineffective if other recommended systems engineering activities are not implemented in parallel (i.e documentation and planning)
- ***Finding Two:*** Most did not use the TRL metric to assess technology maturity - technology readiness and maturity were assessed by test and integration of components to determine the number of requirements and specifications that are met
- ***Finding Three:*** Many acquisition programs did not develop prototypes or perform operational environment testing because they claim that it is impossible to replicate the environments and it costs too much to prototype the actual system
- ***Finding Four:*** It was determined that many acquisition programs do not implement TRA enabling systems engineering activities in the order suggested by DoD 5000. Therefore, they may be advancing through the stages of the acquisition lifecycle with knowledge gaps

Conclusions

- Rejected all null hypotheses at the 0.01 significance level and showed that TRA enabling engineering activities are strongly correlated to system quality and program performance.
  - Although Milestones B and C TRAs did not show significance on system quality, cost, schedule, and productivity, the results showed that numerous enabling systems engineering activities that support the TRA process were significant at ≤ 0.01 $\alpha \leq 0.05$
- Quality of U.S. military systems exhibited strong correlations to cost, schedule, customer satisfaction, and productivity of acquisition
- There is evidence to show that adhering to many of the U.S. DoD engineering activities related to acquisitoin that are called for in a TRA process may have a positive effect on the quality of U.S. DoD systems, as well as the cost and schedule of acquisition programs

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"Executable programs should be the natural outgrowth of a disciplined, knowledge-based process." (GAO 2008)