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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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.
Committed and Planned Spending on 2008 Portfolio of 96 Programs

Billions of FY 2009 dollars

Spent $

Commitments outstanding-$786 Billion

(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

Material Solution Analysis

Technology Development

Prototype

PDR

CDD

Post-PDR

CDR

 Increased Emphasis on Milestone A
• Mandatory for MDAPs with Technology Development Programs
• Likely for Most Programs

Engineering & Manufacturing Development

Mandatory System/Critical Subsystem Competitive Prototyping

Mandatory Preliminary Design Review (PDR) before Milestone B

Production & Deployment

Operation & Support

MDA Certification – MS A

MDA Certification – MS B

MDA Certification – MS C

CPD

PDR

CDD

Post-PDR

CDR

Increased 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

<table>
<thead>
<tr>
<th>Portfolio status</th>
<th>Fiscal year 2003</th>
<th>Fiscal year 2007</th>
<th>Fiscal year 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of programs</td>
<td>77</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>Total planned commitments</td>
<td>$1.2 trillion</td>
<td>$1.6 trillion</td>
<td>$1.6 trillion</td>
</tr>
<tr>
<td>Commitments outstanding</td>
<td>$724 billion</td>
<td>$875 billion</td>
<td>$786 billion</td>
</tr>
<tr>
<td>Change to total RDT&amp;E costs from first estimate</td>
<td>37 percent</td>
<td>40 percent</td>
<td>42 percent</td>
</tr>
<tr>
<td>Change in total acquisition cost from first estimate</td>
<td>19 percent</td>
<td>26 percent</td>
<td>25 percent</td>
</tr>
<tr>
<td>Estimated total acquisition cost growth</td>
<td>$183 billion</td>
<td>$301 billion</td>
<td>$296 billion</td>
</tr>
<tr>
<td>Share of programs with 25 percent or more increase in program acquisition unit cost</td>
<td>41 percent</td>
<td>44 percent</td>
<td>42 percent</td>
</tr>
<tr>
<td>Average delay in delivering initial capabilities</td>
<td>18 months</td>
<td>21 months</td>
<td>22 months</td>
</tr>
</tbody>
</table>
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
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.
Technology maturity has been linked to cost and schedule, however little empirical studies have been conducted to evaluate the degree of its correlation to the quality of DoD products and weapon systems.
To what degree do acquisition programs implement TRAs and enabling engineering activities?

To what degree do acquisition programs achieve system quality objectives?

To what degree do acquisition programs achieve program performance objectives?

What is the strength of correlation between TRAs and interrelated tenets, system quality, and program performance?

Elicit Responses

Develop Close-Ended Survey Instrument

Subject Matter Expert (SME) Discussions

Develop Open-Ended Questionnaire

11 In-Person Interviews

Conceptual Framework

Research Conclusions
Key Engineering Activities

- MDD
- Material Solution Analysis
- Technology Development
- Engineering & Manufacturing

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

ISO/IEC 9126-1

Functionality
- Suitability
- Accuracy
- Interoperability
- Security

Reliability
- Maturity

Usability
- Learnability
- Understandability
- Operability
- Attractiveness

Portability
- Adaptability
- Installability
- Co-Existence
- Replaceability

Maintainability
- Analyzability
- Changeability
- Stability
- Testability

Efficiency
- Time Behavior
- Resource Utilization

Quality-In-Use
- Effectiveness
- Productivity
- Safety
- Satisfaction
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**

<table>
<thead>
<tr>
<th>JOB FUNCTION</th>
<th>Freq</th>
<th>%</th>
<th>ACQUISITION PHASE</th>
<th>Freq</th>
<th>%</th>
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<tbody>
<tr>
<td>Executive</td>
<td>20</td>
<td>9%</td>
<td>Material Solution Analysis</td>
<td>11</td>
<td>6%</td>
</tr>
<tr>
<td>Chief Engineer</td>
<td>19</td>
<td>9%</td>
<td>Technology Development</td>
<td>48</td>
<td>24%</td>
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</tbody>
</table>
| Director              | 12   | 5% | Engineering & Manufacturing Developm | 61   | 31%
| Program Manager       | 50   | 23%| Production & Deployment              | 52   | 26%|
| Systems Engineer      | 100  | 45%| Operation and Support                | 26   | 13%|
| Hardware Engineer     | 8    | 4% | Cancellation                          | 2    | 1% |
| Software Engineer     | 13   | 6% |                                      |      |    |

<table>
<thead>
<tr>
<th>MARKET DOMAIN</th>
<th>Freq</th>
<th>%</th>
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<tbody>
<tr>
<td>Aircraft</td>
<td>47</td>
<td>21%</td>
</tr>
<tr>
<td>Science and Technology</td>
<td>42</td>
<td>19%</td>
</tr>
<tr>
<td>C4I Systems</td>
<td>52</td>
<td>24%</td>
</tr>
<tr>
<td>Mission Support</td>
<td>8</td>
<td>4%</td>
</tr>
<tr>
<td>Ground Vehicles</td>
<td>6</td>
<td>3%</td>
</tr>
<tr>
<td>Missile Defense</td>
<td>9</td>
<td>4%</td>
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<tr>
<td>Munitions and Missiles</td>
<td>4</td>
<td>2%</td>
</tr>
<tr>
<td>Shipbuilding and Maritime Systems</td>
<td>38</td>
<td>17%</td>
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<tr>
<td>Space Based Systems</td>
<td>14</td>
<td>6%</td>
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Degree of Compliance

MSA

TD

EMD

System Quality

- Functionality
- Reliability
- Usability
- Efficiency
- Maintainability
- Portability
- Quality-In-Use
- SysQual Avg

0% 20% 40% 60% 80% 100%

Strongly Agree Agree Somewhat Agree Neutral Somewhat Disagree Disagree Strongly Disagree

### Pearson Correlation & Cronbach’s Alpha

#### Cronbach’s Alpha Analysis

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<thead>
<tr>
<th></th>
<th>Cronbach’s Alpha</th>
<th>N of Items</th>
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<tbody>
<tr>
<td>Materiel Solution Analysis (MS)</td>
<td>0.862</td>
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<tr>
<td>Technology Development (TD)</td>
<td>0.862</td>
<td>7</td>
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<tr>
<td>Engineering and Manufacturing Development (EMD)</td>
<td>0.891</td>
<td>8</td>
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<tr>
<td>Overall System Quality</td>
<td>0.957</td>
<td>27</td>
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<tr>
<td>Cost</td>
<td>0.782</td>
<td>3</td>
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<tr>
<td>Schedule</td>
<td>0.766</td>
<td>3</td>
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<tr>
<td>Customer Satisfaction</td>
<td>0.749</td>
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#### Pearson Correlation Analysis

<table>
<thead>
<tr>
<th></th>
<th>MSA</th>
<th>TD</th>
<th>EMD</th>
<th>System Quality</th>
<th>Cost</th>
<th>Schedule</th>
<th>Customer Satisfaction</th>
<th>Productivity</th>
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<tr>
<td>MSA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TD</td>
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<tr>
<td>EMD</td>
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<td>.703</td>
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<tr>
<td>System Quality</td>
<td>.625</td>
<td>.610</td>
<td>.570</td>
<td></td>
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<tr>
<td>Cost</td>
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<td>.311</td>
<td>.291</td>
<td>.364</td>
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<td>.389</td>
<td></td>
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<tr>
<td>Schedule</td>
<td>.343</td>
<td>.307</td>
<td>.251</td>
<td>.389</td>
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<tr>
<td>Customer Satisfaction</td>
<td>.426</td>
<td>.397</td>
<td>.345</td>
<td>.500</td>
<td>.515</td>
<td>.550</td>
<td></td>
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<tr>
<td>Productivity</td>
<td>.412</td>
<td>.410</td>
<td>.332</td>
<td>.532</td>
<td>.388</td>
<td>.437</td>
<td>.485</td>
<td>1</td>
</tr>
</tbody>
</table>

*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

ISO/IEC 9126-1

Overall System Quality

- Functionality
- Reliability
- Usability
- Efficiency
- Maintainability
- Portability
- Quality-in-Use

Program Performance

- Cost
- Schedule
- Customer Satisfaction
- Productivity

Cost

$R^2$ (p-value)  $t$ (p-value)
0.884 (0.000)    41.128 (0.000)

Schedule

$R^2$ (p-value)  $t$ (p-value)
0.891(0.000)     42.625 (0.000)

Customer Satisfaction

$R^2$ (p-value)  $t$ (p-value)
0.943 (0.000)    66.795 (0.000)

Productivity

$R^2$ (p-value)  $t$ (p-value)
0.953 (0.000)    60.324 (0.000)
• **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 \( 0.01 \leq \alpha \leq 0.05 \)

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