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**Lessons from Army System Developments**

**by**

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# Lessons from Army System Developments

**Presenter: William (Bill) A. Lucas** is Executive Director of the Cambridge-MIT Institute (CMI)—a partnership between MIT and Cambridge University funded by the UK government—where he holds an appointment as Principal Research Scientist. He began as Executive Director of the International Center for Research on the Management of Technology, Sloan School of Management in 1996, and then joined CMI in 2000, serving initially as its Deputy Director with particular responsibility for program delivery and assessment. He was concurrently Co-Director of the Centre for Competitiveness and Innovation in the Judge Business School at Cambridge University. His career includes university teaching and research at State University of New York at Buffalo and a year as Visiting Professor of Public Administration at the George Washington University, six years as a Senior Social Scientist at The Rand Corporation, and government service as Associate Administrator of the US National Telecommunications and Information Administration. His research includes the study of knowledge exchange in cross-functional development teams in industry and in university-industry collaborations, and investigation into the development of young professionals who will become leaders of innovation either in the firm or in start-up companies. He teaches innovation processes and methods of applied social research.

**Presenter: Richard (Dick) G. Rhoades** is Director of the University of Alabama in Huntsville's (UAH) Research Institute and Professor of Engineering Management. He has ongoing research activities funded by a variety of organizations, including the Army Space and Missile Defense Command, the Army Aviation and Missile Command, the Army Aviation and Missile Research Development and Engineering Center, Aerojet General Corporation, Colsa Corporation, and L3-SY Coleman. His work focuses on weapon system technical risk assessment and avoidance, propulsion system design analysis, strategic planning and organizational design. He serves on a number of weapon systems independent assessment ("Graybeard") panels and provides a continuing assessment of technical and programmatic risk, together with recommended mitigation approaches, to the Directors of these programs. Prior to joining UAH, Dr. Rhoades held numerous positions in the Missile Research, Development and Engineering Center at Redstone Arsenal, including three Senior Executive Service positions: Director for Propulsion, Associate Director for Technology, and the Associate Director for Systems.

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## Abstract

This paper documents the results of a multi-year Army Materiel Command-sponsored research project which employed a structured case study approach to examine the history and processes that had resulted in the introduction of a number of technology-based Army systems in time to make a positive contribution to the outcome of Desert Storm. In addition to the fifteen case studies documenting these programs, a common set of data was obtained for each system studied. These data were analyzed to identify factors contributing to successful systems development; this paper contains the results of this analysis.

Several of the statistically significant relationships found involve factors that are related to the stability of the program. When key members of the project team left the program too early, project outcome suffered. Further, both project funding cutbacks and project team turn-over negatively correlated with the quality of the testing program and the timeliness of key test events. These two attributes of the testing program also had the strongest correlation with project outcomes. In addition, changes in systems requirements during development correlated with poor project cost performance. Finally, turn-over in key user-representative personnel correlated negatively with system performance in the field. A central conclusion from this study is that shorter development cycle-times favorably correlate with key project outcome variables, largely by minimizing the exposure of the project to destabilizing influences which were also shown to correlate negatively with these same outcome variables.

**Keywords:** technology-based Army systems, project outcome, system requirements, development cycle-time

## Introduction

This paper documents the results of a research project of several years' duration which employed a structured case study approach to examine the history and processes that had resulted in the introduction of a number of technology-based Army systems in time to make a positive contribution to the outcome of Desert Storm. The 15 case studies that resulted were developed on systems ranging from the M829A1 "silver bullet" to the GUARDRAIL Common Sensor and the APACHE attack helicopter.

### Research Project Information

- Principal Sponsor: Army Material Command
- Principal Investigators: Bill Lucas (MIT) and Dick Rhoades (UAH)
- Research Period: September 1999 to May 2004 (data analysis and report preparation continued into 2005)
- Funding: ~$200,000
- Research Purpose: Examine the history and processes used in the development of a number of Army systems which made a positive contribution on the battlefield during Desert Storm
  --determine factors which influence success
  --prepare case studies

**Figure 1. Project Overview**

## Systems Studied

| System | Researcher | Commodity category |
|---|---|---|
| APACHE attack helicopter | Ference | Aviation |
| TADS/PNVS (target acquisition and designation/pilot's night vision systems) | Oelrich | Aviation |
| MLRS rocket system | Sherman | Missiles |
| ATACMS missile system | Romanczuk | Missiles |
| M40 chemical protective mask | Ruocco | Soldier support |
| Dismounted microclimate cooler **Note: Did not enter production** | Ruocco | Soldier support |
| Mounted microclimate cooler | Ruocco | Soldier support |
| M829-A1 armor–piercing kinetic energy tank ammunition | Mitchell | Ammunition |
| FOG-M (fiber optic guided missile) **Note: Did not enter production** | Sherman | Missiles |
| TOW-2A (Tube-launched missile) | Vessels | Missiles |
| AN/TAS 4 infrared night sight | Granone | Target acquisition |
| Joint Stars Ground Station | Sherman | Intelligence |
| Guardrail common sensor | Sherman | Intelligence |
| PAC-2 (PATRIOT anti-missile system) | Sherman | Missiles |
| HELLFIRE missile system | Johansen | Missiles |

**Figure 2. Systems Studied**

The case studies were developed through the use of structured interviews with key participants from the government/contractor team that developed each system. In addition to the case studies, this process resulted in collection of a common set of data for the systems studied which could then be analyzed to identify factors contributing to successful system development. The results of this analysis are contained in this paper. Two of the 15 case studies examined systems which might have been useful on the battlefield (based on the views of Army technical leaders), but that failed to successfully complete development. The intent of including failures in the research was to provide a basis for distinguishing factors which contributed to both successful and unsuccessful system developments.  While they are useful for the qualitative lessons they offer, two cases are inadequate for quantitative analysis; most analysis focuses on the 13 successful cases.  The study is, therefore, primarily an assessment of contributors to the relative degree of success.[1]

[1] The LeanTEC project was a four-year study of the development and transition of technology-dependent systems in the aerospace industry, supported by a cooperative research agreement between the US Air Force Manufacturing Technology Office and The Boeing Company.

## Research Methodology

- Army RDEC and PM leadership nominated systems which either did or could have impacted Desert Storm
- Researchers (intended to be "free" Army student labor) selected a system from list of candidates
- "Structured thesis" approach used to gather comparable data on each system studied, but allow researcher to document areas of particular interest in each case study
- Modified version of questionnaire used on LeanTEC* was administered to Army and contractor development team members; researcher integrated responses
  ---produced composite "best answer" questionnaire
  ---produced case study on system development

15 systems, 13 produced dictated a focus on relative success factors

**Figure 3. Methodology Employed**

The heart of any systematic study is the definition of a common outcome measure that allows comparison. The obvious path was to compare the projects and systems based on their performance relative to their agreed-upon goals and requirements. Each project had a budget, a systems procurement cost goal, a set of technical requirements, and completion dates. In addition, three questions of performance are immediately observable and easily remembered by project managers: Did the system go into production? Once production was started, were problems found that required that further engineering changes be made? And did the system perform well in its use in Desert Storm? Structured questions were used to ask the key government and industry interviewees about how well their projects performed in these areas, with a range of answers that characterized how badly the projects had missed meeting their objectives if they had not been completely successful. Each of these outcomes is shown graphically in the histograms which follow.

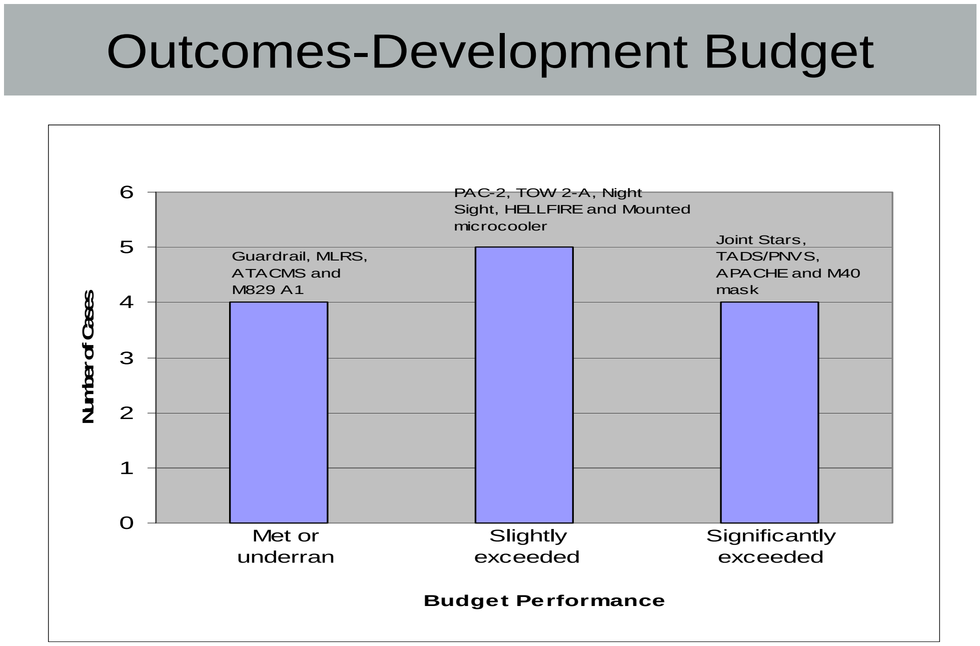


**Figure 4. Development Budget**

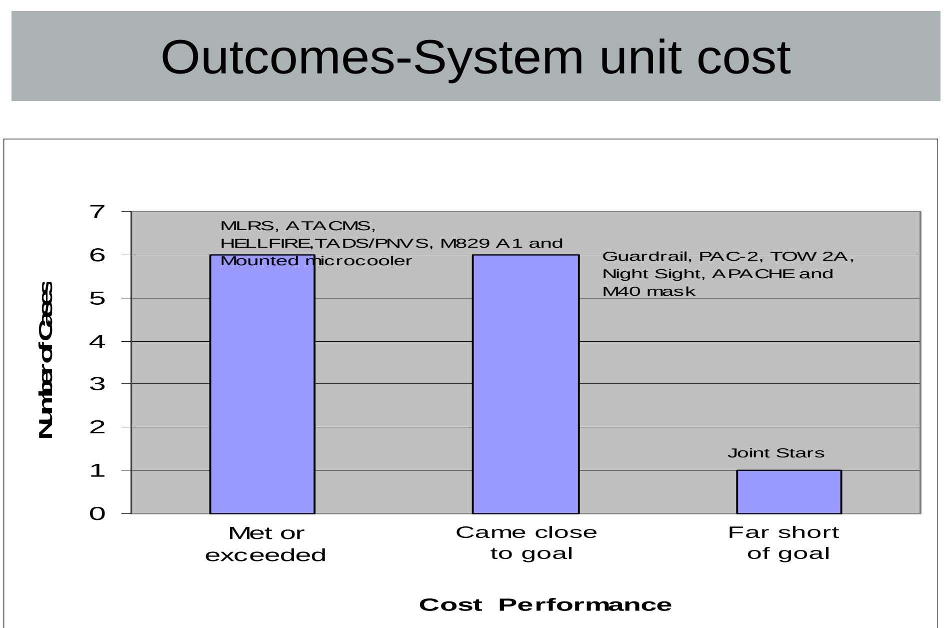


**Figure 5. System Unit Cost**

## Outcomes-Technical performance

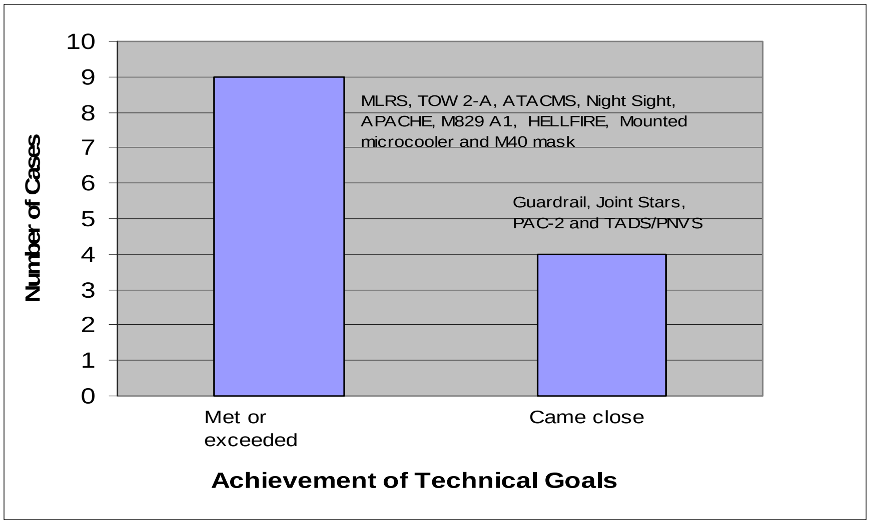


**Figure 6. Technical Performance**

## Outcomes-Delay in transitioning to production

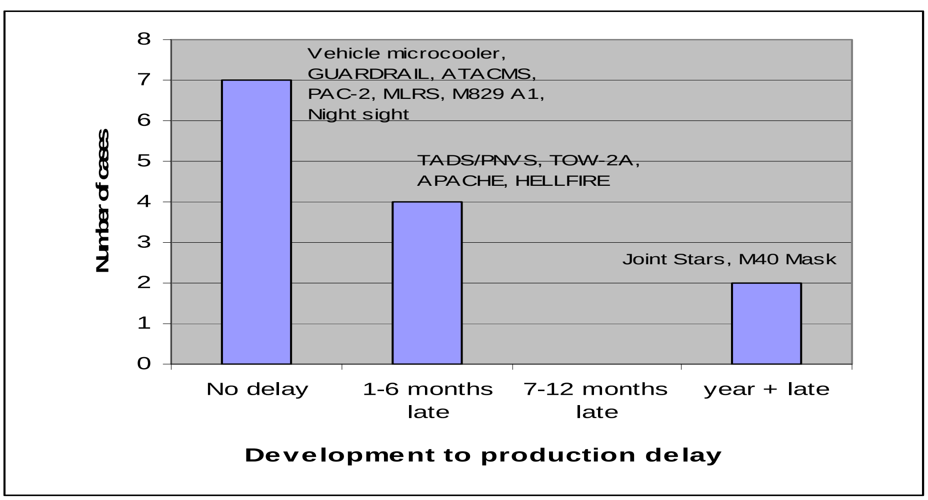


**Figure 7. Delay in Transitioning to Production**

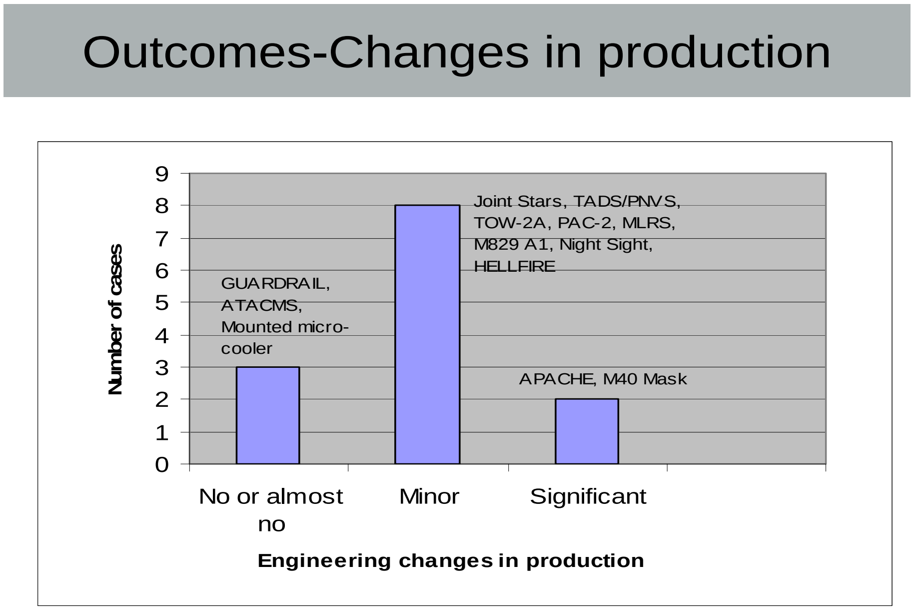


**Figure 8. Changes in Production**

Six of the outcome measures mentioned above were used to create a scale that scores the (system) projects from zero to six according to the number of key outcomes a project achieved. If a project was (1) transitioned to production on time, (2) developed within budget, (3) had no late engineering changes, met both (4) the goals for system unit costs and (5) its technical requirements, and encountered (6) no difficulties when it was deployed in the field, it was awarded (the maximum) six points.

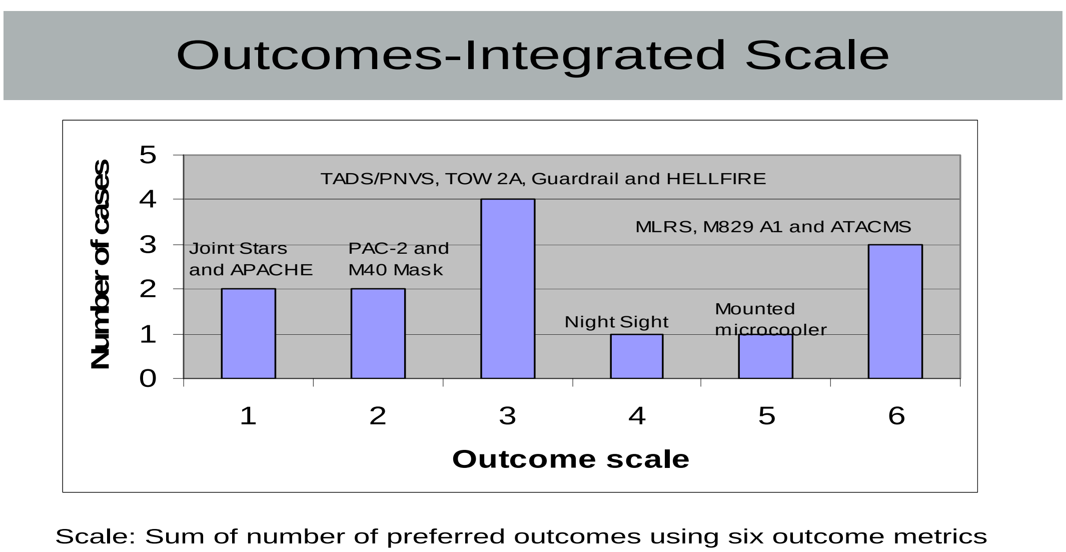


**Figure 9. Integrated Scale**

Table 1 (next page) contains summary information on the 15 systems studied. For each system, this table also contains information on the duration of the development phase of the program and a summary of the project manager's description of the most difficult problem encountered. It is interesting to note that lack of sustained user support for the requirement the system was intended to satisfy was mentioned as the most difficult problem for the two failures, but user-related issues were not identified for any of the successful development cases.

| System/case | Development duration (months) | PM's most difficult problem | Key outcomes achieved (0-6) |
|---|---|---|---|
| APACHE attack helicopter | 108 | Control of production costs; influenced by integration plant location choices | 1 |
| TADS/PNVS (target acquisition and designation/pilot's night vision systems) | ~36 | Cost growth in development | 3 |
| MLRS rocket system | 33 | Establishing and managing four-nation cooperative development program | 6 |
| ATACMS missile system | 37 | Key vendor went out of business | 6 |
| M40 chemical protective mask | ~48 | Immaturity of critical technologies | 2 |
| Dismounted microclimate cooler<br>**Note: Did not enter full development** | Not applicable | Lack of stable user requirements due to immaturity of technology | Not applicable |
| Mounted microclimate cooler | ~24 | Key vendor failed to support integration schedule | 5 |
| M829-A1 armor–piercing kinetic-energy tank ammunition | ~36 | Achieving needed innovation in system design | 6 |
| FOG-M (fiber-optic guided missile)<br>**Note: Did not complete development** | Not applicable; | Lack of sustained user support | Not applicable |
| TOW-2A (Tube-launched missile) | 48 | Stability of threat armor requirements | 3 |
| AN/TAS 4 infrared night sight | ~24 | Selection of unqualified vendor and split management responsibility | 4 |

| | | | |
|---|---|---|---|
| Joint Stars Ground Station | 105 | Cost and schedule growth/delivering complex software | 1 |
| Guardrail common sensor | ~24 | Complexity of integration of mission equipment | 3 |
| PAC-2 (PATRIOT anti-missile system) | ~52 | Early fielding to meet SCUD missile threat | 2 |
| HELLFIRE missile system | ~84 | Adversarial relationship between key vendor and prime | 3 |

**Table 1. Summary Case Information**

Standard statistical analysis procedures appropriate for this number of cases and type of data were used to identify and evaluate correlations between the factors studied and the several outcome variables, and, in some cases, among the factors. The results of these analyses are summarized in Table 2. The testing/simulation and technological maturity factors were included because of their identification in recent Government Accounting Office studies as key determinants of success.

| Factor | Relationships Found/Comments |
|---|---|
| 1. Project team characteristics and practices: | |
| —leadership | Team leader's perceived ability to obtain resources, his/her breadth of experience and ability to resolve technical issues all are positively related to reduced engineering changes during production and to completing development within budget. |
| —staffing | Low turnover in key project team members relates positively to completing development within budget, to meeting system unit cost targets and to achieving system performance objectives. |
| 2. Role of government S&T organizations | Army labs/centers were typically actively involved in both pre-development and development phases, actively involved in both successes and failures, and actively involved in both short and long developments. |
| 3. Testing and simulation approach | Validating component and system maturity at the right time in the program relates positively to completing development within budget, to meeting system unit cost targets and to successful performance in the field. The quality of the testing and simulation conducted relates positively to reduced engineering changes during production and to meeting system unit cost targets. |
| 4. Importance of stability: | |
| —funding | Funding uncertainty was related to increased turnover in key project team members and the need to deal with changes in testing plans and other project structure issues. |
| —system requirements | Changes in system requirements, particularly during the middle of development, relate to an increase in late engineering changes and negatively to project success in meeting its goals for systems costs. |
| —key user (TRADOC) | Changes in key TRADOC personnel during development |

| | |
|---|---|
| personnel | relates to less successful performance in the field. |
| 5. Timely communication of problems | Nearly all cases described timely communication of problems from contractor to government PM and from government PM to Army leadership. |
| 6. Importance of technology maturity (TRLs) | Maturity of critical technologies used in systems studied, as measured by TRLs, was similar to that found in previous LeanTec study of small electronics projects. No positive correlation found between higher TRLs at the start of development and most outcome variables. |

**Table 2. Summary of significant relationships**

Several of the statistically significant relationships involve factors that are related to the stability of the program. When key members of the project team left the program too early, project outcome suffered. Further, both project funding cutbacks and project team turn-over negatively correlated with the quality of the testing program and the timeliness of key test events. These two attributes of the testing program also had the strongest correlation with project outcomes. In addition, changes in systems requirements during development correlated with poor project cost performance. Finally, turn-over in key user-representative personnel correlated negatively with system performance in the field.

Destabilizing Influences

| Variable | Timing Implications |
|---|---|
| 1. Reductions in project funding | Potential for change in administration every 48 months; typical turn-over in key military leaders occurs every 24-36 months. Potential change in key Congress positions every 24 months; likelihood increases with development duration |
| 2. Uncertainty in project funding | Potential for change in administration every 48 months; typical turn-over in key military leaders occurs every 24-36 months. . Potential change in key Congress positions every 24 months; likelihood increases with development duration. |
| 3. Change in system requirements | Changes in the threat environment occur unpredictably, but become more likely with longer development durations. Changes in doctrine and system requirements follow a similar pattern. |
| 4. Change in key user representatives | Typical turn-over in such key military positions occurs every ~36 months |
| 5. Change in key project team members | Typical turn-over in military acquisition positions occurs every ~36 months. Longer development durations present more opportunities for career moves on the part of key civilian team members |

**Figure 10. Destabilizing Influences**

Taken together, these several relationships strongly suggest that stability of program resources and objectives is a very powerful influence on the relative success of the project. In reflecting on this array of instabilities that could impact a system development, it became clear that they had at least one thing in common: The longer a system stayed in development, the greater chance it had to experience one or more of these program destabilizing events. Or, stated another way, shorter system development cycles should result in better project outcomes. When this hypothesis was tested by examining the correlation between the system development durations and the aggregate outcome scale (See the data in Table 1), a strong correlation was found. A central conclusion from this study is, therefore, that shorter development cycle-times favorably correlate with key project outcome variables—largely by minimizing the exposure of the project to destabilizing influences which have also been shown to correlate negatively with these same outcome variables.

## Central Conclusion

Shorter development cycle times favorably correlate with key project outcome variables, largely by minimizing the exposure of the project to destabilizing influences

**Length of Project Development and Project Performance**
(Average number of successful outcomes)

| | Over 3 years | Three years or less | Sig. at |
|---|---|---|---|
| Length of development | 2.00 | 4.71 | .002 |

**Figure 11. Conclusion**

Whether or not a change to selecting projects with shorter development times is made, the Army could do more to stabilize the guidance and resources given to both shorter and longer development projects. Acting alone, the Army could do more to map rotating personnel assignments and other sources of TRADOC change to project development cycles. Since it appears, as is widely believed, that changes in systems requirements made once projects move beyond early development will almost certainly hurt project performance, the Army could eliminate all but the most critically important of such changes. Both through contract language and informal management practices, the Army could work with its contractors to provide better continuity of development project staffing.

The defense acquisition community has long recognized that lengthy systems development times are disadvantageous. Sometimes the associated negatives have been phrased in program instability terms; this study certainly provides strong empirical support for those who hold these beliefs. Over the years, a number of initiatives have been attempted to shorten development cycles, with limited success where complex systems were involved. The current approach is referred to as “spiral development”; its basic concept is to get a useful, if limited, capability in the field quickly and then introduce additional technology-based capabilities through further “spirals” of development. This approach appears to be in keeping with the implications of this study’s central conclusion.

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