



**NAVAL
POSTGRADUATE
SCHOOL**

MONTEREY, CALIFORNIA

**Modern Military Evolutionary Acquisition and the
Ramifications of “RAMS”**

by

Donald P. Gaver
Patricia A. Jacobs
Ernest A. Seglie

June 2005

Approved for public release; distribution is unlimited.

Prepared for: Director, Operational Test and Evaluation
The Pentagon, Room 3E318
Washington, DC 20301-1700

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CA 93943-5001

RDML Patrick W. Dunne, USN
President

Richard Elster
Provost

This report was prepared for and funded by the Director, Operational Test and Evaluation, The Pentagon, Room 3E318, Washington, DC 20301-1700.

Reproduction of all or part of this report is authorized.

This report was prepared by:

DONALD P. GAVER
Distinguished Professor of
Operations Research

PATRICIA A. JACOBS
Professor of Operations Research

ERNEST A. SEGLIE
Science Advisor, Director,
Operational Test and Evaluation

Reviewed by:

LYN R. WHITAKER
Associate Chairman for Research
Department of Operations Research

Released by:

JAMES N. EAGLE
Chairman
Department of Operations Research

LEONARD A. FERRARI, Ph.D.
Associate Provost and Dean of Research

REPORT DOCUMENTATION PAGE			<i>Form Approved OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 2005	3. REPORT TYPE AND DATES COVERED Technical Report		
4. TITLE AND SUBTITLE: Modern Military Evolutionary Acquisition and the Ramifications of "RAMS"			5. FUNDING NUMBERS ROR28	
6. AUTHOR(S) Donald P. Gaver, Patricia A. Jacobs, and Ernest A. Seglie				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER NPS-OR-05-006	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (maximum 200 words) This paper describes the administrative philosophy that currently guides the (evolutionary) acquisition of U.S. military systems. It then sketches a preliminary mathematical model that allows study of the effect of various ways to spend a fixed budget for Block b+1 upgrade so as to obtain a maximum expected number of fielded system upgrades that is effective in the field. This includes the option of simply fielding more of the previous, Block b, design units. Effectiveness/"capability" growth is the design objective, but testing and fault removal provides for reliability growth. The model accounts for various levels of developmental and testing effort at various rates, and for obsolescence of the previous (Block b) and forthcoming (Block b+1) system versions.				
14. SUBJECT TERMS evolutionary acquisition; operational testing; reliability growth			15. NUMBER OF PAGES 20	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

MODERN MILITARY EVOLUTIONARY ACQUISITION AND THE RAMIFICATIONS OF “RAMS”

Donald P. Gaver and Patricia A. Jacobs
Operations Research Department, Naval Postgraduate School
1411 Cunningham Rd., Rm. 239, Naval Postgraduate School
Monterey, CA 93943

Ernest A. Seglie
Science Advisor, Director, Operational Test and Evaluation
The Pentagon, Rm. 3E318
Washington, DC 20301-1700

Abstract

This paper describes the administrative philosophy that currently guides the (evolutionary) acquisition of U.S. military systems. It then sketches a preliminary mathematical model that allows study of the effect of various ways to spend a fixed budget for Block $b+1$ upgrade so as to obtain a maximum expected number of fielded system upgrades that is effective in the field. This includes the option of simply fielding more of the previous, Block b , design units. Effectiveness/“capability” growth is the design objective, but testing and fault removal provides for reliability growth. The model accounts for various levels of developmental and testing effort at various rates, and for obsolescence of the previous (Block b) and forthcoming (Block $b+1$) system versions.

Keywords: evolutionary acquisition; operational testing; reliability growth

1 The Current (2004-05) Acquisition System

Modern (circa ‘04-‘05) U.S. military acquisition follows a top-down policy pattern, governed by a Joint Capabilities Integration and Development System (JCIDS). This informs and supports decisions by the Joint Chiefs of Staff (JCS) and the Joint Requirements Oversight Council, which identifies, assesses, and prioritizes joint military capability needs. JCIDS is concerned with methodology to identify and describe so-called *capability gaps*, review capability improvement proposals and improve capability integration, define non-materiel (e.g., Concept of Operations (CONOPS)) aspects of materiel solutions, improve interdepartmental (Joint) coordination, improve requirement generation, adaptation and revision, and documentation, all in a timely manner; timeliness is intended to be enhanced by *spiral development and evolutionary acquisition*. Program progress occurs according to milestones: a new mission requirement (e.g., induced by changed threat assessment) is described in an Initial Capability Document (ICD) prior to

Milestone (MS) A, at which time T&E strategy (a new name for what was formerly called a first version of the Test and Evaluation Master Plan, or TEMP), is defined, and must be approved at Department of Defense (DoD) level. Then a Capability Development Document (CDD) is due by MS B, and a Capability Production Document (CPD) at MS C. For major programs, the program manager (PM) submits a TEMP that must be approved by Director, Operational Test and Evaluation (DOT&E) officials for MSs B and C, and to lead to Full Rate Production (FRP), and to fielding.

1.1 The TEMP

A vital element of the above process is the creation, updating, and evolution of the TEMP. This paper will discuss issues that should be addressed by the TEMP as it guides a presently more dynamic process than has been in place in the past. To quote a recent instruction (DoDI 5000.2 (2003) E5.4.1): “The Test and Evaluation Master Plan shall describe planned developmental, operational, and live fire testing including measures to evaluate the performance of the system during these test periods; an integrated test schedule; and the resource requirements to accomplish the planned testing.” No specific guidance is given on how to plan testing or how to integrate the testing into a schedule for spiral development or evolutionary acquisition. This present paper elucidates features of a useful and successful dynamic TEMP, emphasizing the use of models (and simulation as required) and data acquisition and analysis in that process. Special emphasis is given here to the use of testing to enhance various Suitability issues; these include obtaining a system that can be placed satisfactorily in field use, with special attention to Reliability, Availability, Maintainability, and Safety, (RAMS). Also included are transportability, interoperability and manpower and logistic supportability, robustness to environment, (e.g. weather and terrain) and training requirements. However, testing is first and foremost invoked to demonstrate improved and required Operational Effectiveness, meaning the degree of improved mission performance over a current system version (Block, or baseline), where the focus is effectiveness against changing threats, meaning relative invulnerability against weapons and countermeasures while accomplishing its mission(s). Mission accomplishment is fundamental, and quantitative measures of effectiveness and suitability should be correctly defined and constantly updated. For this, testers must rely on earlier data, e.g., from developmental Testing (DT)/subsystem/component testing, which, in turn, will be guided by preliminary modeling (and simulation). It should be demonstrated early on that the entire system can be manufactured and integrated, and that it is transportable and sustainable. Useful and cost-effective Initial Operational Test and Evaluation (IOT&E) must depend on information from earlier development and from experience with other systems, and the application of scientific knowledge and insight. Testing must be designed and adequate to cope with defined (presently understood) missions having a quantified need, definitions and measures of mission accomplishment, realistic conditions for testing, and capability to interact with other systems. Robustness and work-arounds when unexpected events (system failures or threat modification) occur are highly valuable, and should be effectively tested. Adaptability is an essential *system-wide* feature.

1.2 Testing and the Design Modification Process: Fault Removal, Block-Block Transition/Up-Grading

The environment for testing under the present more static acquisition philosophy has changed to recognize system design evolution; c.f. DoDD 5000.1 (2003), Daly *et al.* (2003), Seglie (2002). If a system has evolved to Block b , then changes (improvements!) leading to Block $b+1$ are in principle being studied and tested at the prototype “brass board” level; at some point Block $b+1$ is operationally tested using Block b as baseline, and will be accepted when Block $b+1$ is “measurably better” than the baseline. Fault (resulting from inadequate design, manufacturing, transportability, maintainability) removal can occur both within Block b (even after fielding, but at higher cost). A “real option” is to examine several alternative technologies and CONOPS, and select the “measurably best,” considering end-to-end cost-effectiveness and including estimates of the timing of technological and operational obsolescence, likely caused by development of countermeasures by the enemy. Perhaps several alternative versions of Block $b+1$ can be acquired and fielded for different mission types, and to forestall countermeasures. The process of balancing the development process: the Test, Analyze, Fix, Test (TAFT) action sequence, followed by field Operational Test and Evaluation (OT&E) is designed to yield useful and trustworthy improvement in timely fashion (e.g., before Block b penalizing attrition or obsolescence). A central problem is to address both the “effectiveness, or capability gap closure” problem, and, importantly, also to address the “reliability growth” problem realistically and recognizing end-to-end system requirements, important elements being that the new (sub)system version interoperates effectively with other system elements under the entire range of mission alternatives envisioned.

1.3 Models and Analysis to Expedite Cost-Effective Transition Between Blocks (and Within Blocks)

We outline and propose rational attacks on the basic decision problem: when and how to allocate resources (basically, funding, but also previous experience) to Block b to $b+1$ transition. The particular models described in this paper are simple and preliminary, serving to illustrate the basic issues encountered when a sequence of block upgrades is the evolutionary acquisition strategy. More details are given elsewhere. Of course, each system requires its individual understanding and characterization—one that captures essential physical/operational features, but does not dwell on minutia.

At any time point/date there will be a certain number, $B(b; t)$, of surviving and useable copies of Block b . One option is to continue with that number, recognizing that attrition and obsolescence will reduce that Block b 's mission effectiveness, even if the Block b stock (e.g., number of current design copies) is increased over time. The cost of this option will likely grow due to probable increased need for field repairs, and consequent minor modifications and force enhancements. Also, effectiveness and reliability (actually RAMS) may well diminish. We propose to construct and analyze stochastic models for this option. An alternative option is to introduce Block $b+1$ to field use, after the entire TAFT ($b+1$) process, conducted in both Developmental Testing (DT) and Operational Testing (OT) phases. We propose (further) development of models to guide timing of such a transition, taking explicit account of costs of design, DT and Operational (field) Testing. An initial simplified version of

the advisability and timing of such a transition appears in Gaver *et al.* (2004). A more comprehensive model is under construction that recognizes that many to most systems function roughly sequentially, activating in succession various sub(sub)system functional stages (consider a missile that must first experience launch, then initial, midcourse, and final stage propulsion and guidance, and final activation of the warhead). Clearly end-to-end testing must assure that all such stages are activated so that design faults can be revealed—and “Fixed”; the latter process is error-prone, so more testing is required; indications of “how much (more) is enough” can be assessed by realistic models, but the crucial ultimate test is experimental/operational. Gaver *et al.* (2003) has discussed the properties of such reliability growth models that explicitly recognize stage-wise system architecture and more detailed and sequential (current-experience-based) test-stopping rules. These will be adapted to evaluate the cost-effective policy for Block-to-Block transition—i.e., rationalize the pace of evolutionary acquisition.

2 A Simplified Formal Model for Performance

The probability of mission success for Block $b+1$ after development and testing depends on the funding allocated to development and its rate of expenditure. The development process should not only increase the effectiveness of Block $b+1$, but also tends to introduce design defects (DDs) that testing can remove. We consider a system that can be used once, such as a missile. This model was introduced in Gaver *et al.* (2004).

Let $T_d(b+1)$ be the total (calendar) time to develop, test, and manufacture Block $b+1$; here $T_d(b+1)$ is a fixed “spiral time,” which is only one alternative. $M(T_d(b+1))$ represents the total funds allocated to Develop Block $b+1$; $m(T_d(b+1)) = M(T_d(b+1))/T_d(b+1)$ is the *average rate of that expenditure* (ignoring feedback adjustments to intermediate events—successes and failures). A plausible, if speculative, model for the performance (Effectiveness) of Block $b+1$ is the fraction of an objective mission success measure (“requirement”) after expenditures of $M(T_d(b+1))$ at rate $m(T_d(b+1))$, given that any remaining DDs, new or old, do not activate during a mission, will be written in the general form:

$$p_d(b+1; T_d(b+1); M(T_d(b+1))) = p^*(b+1) G_d(b+1; M(T_d(b+1)); m(T_d(b+1))); \quad (1)$$

where (a) $p^*(b+1)$ is a goal level (“requirement”) for mission success of Block $b+1$ (realistically this could be the maximum of various minimum acceptable measures of mission success, related to a Pareto optimum); while (b) $G_d(b+1; M(T_d(b+1)); m(T_d(b+1)))$ is the fraction of the maximum, (a), achieved by the development process, when development budget is allocated to be $M(T_d(b+1))$ expended at basic average rate $m(T_d(b+1))$ over time period $T_d(b+1)$.

We provide specific parametric illustrations in Appendix 1. It is anticipated that $G_d(\bullet)$ should increase at a decreasing rate with $M_d(\bullet)$, but that an inordinately high

rate of redesign and system modification (large $m(\bullet)$) will have a detrimental effect on the Block improvement. Note that an optimum rate is impossible to determine for a new/revised system, but studies of the effects of successive development (“spiral”) times, T_d , can guide the choice of budgets and rates of expenditure.

Let the number of DDs introduced during initial development have a Poisson distribution with conditional expected value $E[\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1)) | \mathbf{K}_0]$. \mathbf{K}_0 is introduced to represent a combined deterministic and random component of between-copy variability in Block $b+1$. The Poisson is an acceptable distribution.

DT and OT are pooled in this model. Each remaining DD is activated during a test with probability $1 - \theta = \bar{\theta}$. Several DDs may be activated during a test. Any DDs activated during a test are presumed to be removed (an optimistic simplifying assumption).

The testing policy is to allocate $\tau T_d(b+1)$ DT/OT tests: The parameter τ is an average number of DT/OT tests conducted per spiral time unit. Each test uses one copy of Block $b+1$. The conditional distribution of the number of DDs remaining after development and testing, given \mathbf{K}_0 , has a distribution with mean $E[\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau) | \mathbf{K}_0]$.

DDs remaining in Block $b+1$ after fielding have the potential of causing mission failure if activated during a mission. Let θ_F be the probability with which a DD remaining in Block $b+1$ after fielding does not activate during a mission. The conditional probability of mission success for Block $b+1$, given completion of development and testing, and given the number of remaining DDs, is

$$\begin{aligned} p_F(b+1 | \mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau)) \\ = p_d(b+1; T_d(b+1); M(T_d(b+1))) \theta_F^{\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau)} \end{aligned} \quad (2)$$

All fielded copies of Block $b+1$ have the same remaining DDs since all are constructed by the currently evolved design. This is a oversimplification that can be relaxed.

2.1 Parametric Examples

a) Let $\mathbf{K}_0 = k$, a constant and the conditional distribution of DDs introduced during development is Poisson. Then the probability that, after fielding, no remaining DDs activate during a mission is

$$\begin{aligned} E \left[\theta_F^{\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau)} \right] \\ = \exp \left\{ -kf \left[m(T_d(b+1)) \right] \theta^{\tau T_d(b+1)} (1 - \theta_F) \right\} \end{aligned} \quad (3)$$

where $f[\square]$ is an (ultimately) increasing function of $m(\square)$.

b) Assume \mathbf{K}_0 is random with gamma distribution of scale $\nu > 0$ and shape parameter $0 < \beta$, and Laplace transform $E[e^{-s\mathbf{K}_0}] = \left[\frac{\nu}{\nu + s} \right]^\beta$. This classical modification of the Poisson leads to the Negative Binomial. The expression for the probability of no DDs activating during a field mission (field mission survival):

$$E \left[\theta_F^{\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau)} \right] = \left[\frac{\nu}{\nu + f[m(\square)] \theta^{\tau T_d(b+1)} (1 - \theta_F)} \right]^\beta. \quad (4)$$

Further randomization is possible and tractable (e.g., randomization of β in the above exponent). Such a step can be interpreted in a Bayes manner or as a sensitivity test.

c) Let $\tilde{\mathbf{K}}_0$ be random obeying a positive stable law with scale $\nu > 0$ and order $0 < \beta < 1$ and Laplace transform $E[e^{-s\tilde{\mathbf{K}}_0}] = \exp\{-(\nu s)^\beta\}$; see Feller II (1966). Assume \mathbf{K}_0 is the minimum of the stable random variable and a truncating exponential random variable having mean $1/\kappa$; in this case the Laplace transform of \mathbf{K}_0 is $E[e^{-s\mathbf{K}_0}] = \frac{\kappa}{\kappa + s} + \frac{s}{\kappa + s} \exp\{-(\nu(s + \kappa))^\beta\}$ and $E[\mathbf{K}_0] = \frac{1}{\kappa} \left[1 - e^{-(\nu\kappa)^\beta} \right]$. The probability that no remaining DDs activate during a mission (field mission survival) is given explicitly; see Gaver *et al.* (2004). Auxiliary randomization as in (b) and (c) (dubbed “double stochasticity,” c.f. D. R. Cox (1955), M. S. Bartlett (1955), M. S. Bartlett (1967), and D. R. Cox *et al.* (1980)) can represent environmental variation during a mission and/or manufacturing or configuration variability between manufactured copies. Appropriate parametric statistical estimation to evaluate such expressions is an important problem not yet addressed by the authors.

Note: We present three alternative explicit mathematical formulas for probability of field mission survival by Block $b+1$. These are all directly numerically evaluated on a personal computer, or even a handheld calculator, and are useful for checking far more elaborate simulations.

2.2 Acquisition of Block $b+1$

Let $B(b+1)$ be the total budget to develop, test, and procure Block $b+1$. Table 1 details (average) cost and operational parameters required at this stage.

Table 1: Parameters

Total budget	$B(b+1)$	2,000
Development budget	M	variable
Development (spiral) time	$T_d(b+1)$	variable
Rate of development expenditure	$m = M/T_d(b+1)$	variable
Mean number of tests per unit time	τ	variable
Cost Block b /copy/unit	$c_m(b)$	1
Cost Block $b+1$ /copy/unit	$c_m(b+1)$	1.2
Cost of a test	c_t	1
Cost removing each DD found during test	c_r	3
Mean mission arrival rate	λ	100
Probability mission success Block b	$p(b)$	0.4
Utopian requirement: probability mission success Block $b+1$	$p^*(b+1)$	0.85
Parameters of effectiveness growth	a_1	0.5
	α_1	2
	a_2	0.002
	α_2	0.8
Parameter for introduction of DD	α_3	2
Rate of obsolescence Block b	$\omega(b)$	0.33
Rate of obsolescence Block $b+1$	$\omega(b+1)$	0.2
Probability DD survives test	θ	0.85
Probability DD survives mission	θ_F	0.8
Parameters of gamma: scale, shape	ν	2,000
	β	0.4

Here is a breakdown of Block $b+1$ budget allocation:

$$B^\#(b+1) = B(b+1) - M(T_d(b+1)) - [c_m(b+1) + c_t] \tau T_d(b+1) - c_r E[\mathbf{D}_R(b+1; T_d(b+1); \tau)] \quad (5)$$

where $\mathbf{D}_R(b+1; T_d(b+1); \tau)$ is the number of DDs removed by testing. After development and testing, the mean number of copies Block $b+1$ fielded is $N_F(b+1) = \frac{B^\#(b+1)}{c_m(b+1)}$. Each of these copies has the same remaining DDs in this initial model, and hence has the same probability of field reliability/suitability.

2.3 Obsolescence of Block b and Block $b+1$

Operational obsolescence is inevitable, and is a powerful reason for Block upgrading. Assume that Block b will become obsolete after an independent exponential time having mean $1/\omega(b)$. An important problem not addressed yet explicitly is to develop an adaptive inferential policy for one's own force (B) to conclude that the opposing

force (R) has found a countermeasure to B's asset, such could take the form of first occurrence of a "failure run of r (e.g., 5) B mission failures. Such would signal a needed change in B's CONOPS, or a needed block upgrade, or both. After obsolescence, the probability of mission success for Block b is $p_O(b) < p(b)$; $p_O(b)$ may be close to zero. Assume a fielded Block $b+1$ can also become obsolete after an independent exponential time having mean $1/\omega(b+1)$. After obsolescence, the probability of mission success for Block $b+1$ is $p_O(b+1) < p(b+1)$. If Block b becomes obsolete before the completion of development and testing for Block $b+1$, then a decision can be made to continue to field Block b , or to field the current Block $b+1$ prematurely. We defer discussion of this possibility to Gaver *et al.* (2005). In this paper, we will assume that Block b is completely ineffective after obsolescence; that is, $p_O(b)=0$; we also assume that Block $b+1$ is completely ineffective after obsolescence.

2.4 A Basic Decision Problem

Suppose for the present that Block b does not become obsolete before the end of development and testing of Block $b+1$. The decision to be made is whether to use the budget remaining after development and testing of Block $b+1$ to purchase copies of Block $b+1$, or to use it to purchase more copies of Block b . Let each mission use one copy of a Block design. Each unit of a Block can be used once. DDs remaining in Block $b+1$ after fielding can cause mission failure. The decision criterion is to maximize the expected number of successful missions. The decision is to allocate that amount of the budget, $B(b+1)$, to upgrade Block $b+1$ so the expected number of successful missions by the copies of Block $b+1$ procured with the remaining budget is maximized.

Assume missions arrive according to a stationary Poisson process having rate λ . Let $N_F(b)$ be the number of copies of Block b that can be purchased using $B(b+1)$. The expected number of mission successes, S_b , if Block b is purchased exclusively is

$$\begin{aligned}
& E[S_b(N_F(b))] \\
&= \left[\frac{\lambda}{\lambda + \omega(b)} \right]^{N_F(b)} N_F(b) p(b) \\
&+ \frac{\lambda}{\omega(b)} \left[1 - \left[\frac{\lambda}{\lambda + \omega(b)} \right]^{N_F(b)} - N_F(b) \left[\frac{\lambda}{\lambda + \omega(b)} \right]^{N_F(b)-1} \frac{\omega(b)}{\lambda + \omega(b)} \right] p(b)
\end{aligned} \tag{6}$$

A similar expression occurs for the conditional expected number of successful missions given the remaining number of DDs if $N_F(b+1)$ copies of Block $b+1$ are fielded. Let

$$\begin{aligned}
& E \left[S_{b+1} (N_F (b+1)) \mid \mathbf{D} (b+1; M (T_d (b+1)); T_d (b+1); \tau) \right] \\
& = p_F (b+1 \mid \mathbf{D} (b+1; M (T_d (b+1)); T_d (b+1); \tau)) \quad , \quad (7) \\
& \times \left[\sum_{k=0}^{N_F (b+1)-1} \left[\frac{\lambda}{\lambda + \omega (b+1)} \right]^k \left[\frac{\omega (b+1)}{\lambda + \omega (b+1)} \right]^k + \left[\frac{\lambda}{\lambda + \omega (b+1)} \right]^{N_F (b+1)} N_F (b+1) \right]
\end{aligned}$$

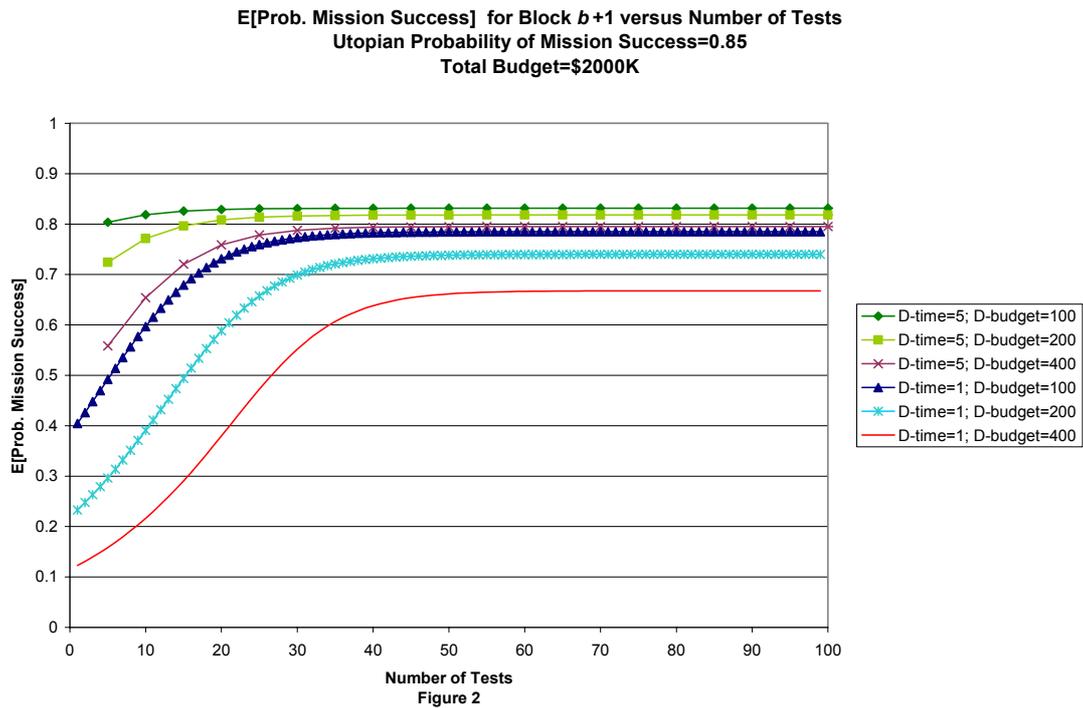
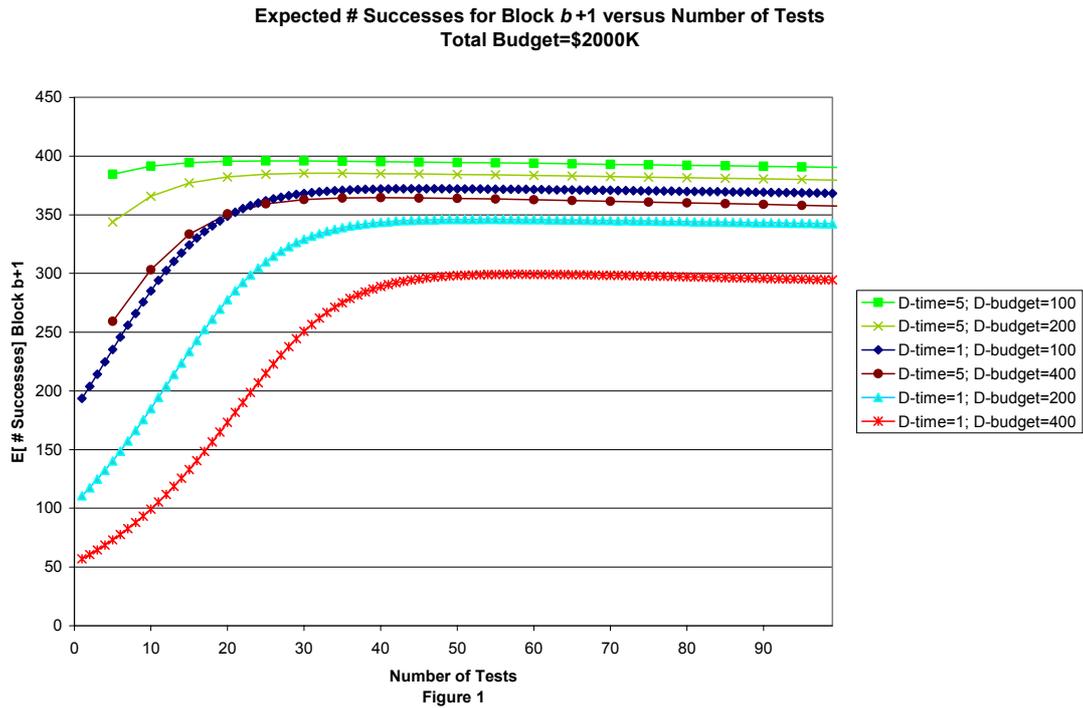
where as before the distribution of $\mathbf{D} (b+1; M (T_d (b+1)); T_d (b+1); \tau)$ can be Poisson ($\mathbf{K}_0 = k$), or Truncated Stable Poisson, or Gamma-Poisson (negative binomial).

2.5 Example

The parameters for the numerical examples appear in Table 1. The total budget for development, testing, and procurement of Block $b+1$ is \$2,000K. Development budgets \$100K, \$200K, and \$400K are considered. Each of these budgets can be spent over an integer time interval length T_d of 1 time period, or 5 time periods. The rate of DT/OT testing ranges in integer values from 1 to 100 tests per time period. The proportionality constant, \mathbf{K}_0 , has a gamma distribution with mean equal to 0.0002 and shape parameter 0.4. Table 2 summarizes the gains made by an appropriate choice of time for development and testing. If Block $b+1$ is not developed and units of Block b are bought with the budget, then the expected number of mission successes is 120 (so developing and buying Block $b+1$ is advantageous).

Table 2: Maximum Expected Number of Successes for Block $b+1$ after Development and Testing; [Maximizing Number of Tests]; Total Budget=\$2,000K.

<i>M/T</i>: rate of expenditure of development budget	20=100/5	40=200/5	80=400/5	100=100/1	200=200/1	400=400/1
<i>M/B</i>: fraction of total budget used for development						
0.2=400/2000			365 [40]			299 [58]
0.1=200/2000		385 [35]			346 [54]	
0.05 =100/2000	396 [25]			372 [46]		



Discussion: If Block $b+1$ is not developed and the development budget is spent to acquire copies of Block b , the expected number of mission successes using Block b is 120. Figure 1 displays the expected number of mission successes for Block $b+1$ as a function of the number of tests for various developmental budgets and developmental times. Figure 2 displays the expected probability of mission success as a function of the number of tests for various development budgets and development times. As Table 2 illustrates, perhaps surprisingly, larger expected number of mission successes

and smaller number of tests needed to achieve the maximum are associated with a smaller development budget and longer development times.

Tables 3 and 4 display the expected probabilities of mission success after development and testing for different distributions of K_0 . The numbers of tests performed for the results in Tables 3 and 4 are the same as those displayed in Table 2; that is, they are the number of tests for K_0 having a gamma distribution with shape parameter 0.4 and mean 0.0002, which maximize the expected number of mission successes for Block $b+1$. In Table 3, the distributions considered are $K_0=0.0002$; K_0 having a gamma distribution with shape parameter =0.4 and mean 0.0002; K_0 having a positive stable law distribution with order equal to the shape parameter of the gamma and scale the same as the gamma; K_0 having a truncated stable law distribution with the same scale and order as the stable and the exponential truncation rate, κ , chosen so that the mean is equal to 0.0002. In Table 4, the distributions of K_0 are the same except the shape of the gamma and the order of the stable law are 0.1.

Table 3: Expected Probability of Mission Success for Block $b+1$ after Development and Testing: Constant $K_0=0.0002$; (gamma K_0 , shape parameter 0.4, and mean 0.0002); {stable K_0 with order (scale) equal to shape (scale) of gamma}; (truncated stable K_0).

M/T: rate of expenditure of development budget	20=100/5	40=200/5	80=400/5	100=100/1	200=200/1	400=400/1
M/B: fraction of total budget used for development						
0.2=400/2000			0.79 [0.79] {0.75} (0.79)			0.67 [0.67] {0.62} (0.67)
0.1=200/2000		0.82 [0.82] {0.78} (0.82)			0.74 [0.74] {0.70} (0.74)	
0.05 =100/2000	0.83 [0.83] {0.79} (0.83)			0.78 [0.78] {0.75} (0.78)		

Table 4: Expected Probability of Mission Success for Block $b+1$ after Development and Testing: Constant $K_0=0.0002$; (gamma K_0 , shape parameter 0.1, and mean 0.0002); {stable K_0 with order (scale) equal to shape (scale) of gamma}; (truncated stable K_0).

M/T: rate of expenditure of development budget	20=100/5	40=200/5	80=400/5	100=100/1	200=200/1	400=400/1
M/B: fraction of total budget used for development						
0.2=400/2000			0.79 [0.79] {0.45} (0.79)			0.67 [0.67] {0.37} (0.67)
0.1=200/2000		0.82 [0.81] {0.48} (0.82)			0.74 [0.73] {0.43} (0.74)	
0.05 =100/2000	0.83 [0.83] {0.48} (0.83)			0.78 [0.78] {0.46} (0.78)		

Discussion: The expected probabilities of mission success are nearly equal for the moment and shape-matched versions of constant, gamma, and truncated stable K_0 , except for the stable with order β small (0.1). This behavior may be due to the much-exaggerated shape of the pure stable law with these shape parameters; there can be many small values versus a few very large. The mean number of DDs introduced when K_0 has a pure (untruncated) positive stable law is infinite and the expected probability of mission success after development and testing is much less than the others; the smallest expected probabilities of mission success occur for the stable law of order 0.1. This suggests the need for a sequential stopping rule, a problem under current investigation.

3 Conclusions and Future Program

The problem discussed is simple and generic, and widely encountered in defense acquisition. In subsequent work we propose to elaborate on the above conditions and issues, and to provide operational tools to guide the timing of evolutionary cycles. We will consider the development and testing of systems consisting of subsystems in series or in a time-dependent, random pattern elsewhere. We will also consider Test-Analyze-Fix-Test (TAFT) testing policies with a sequential stopping rule based on first occurrence of a run of successful (no DDs activating) operational tests. Simulation and more analysis will be designed to assess the procedure's robustness. Application to Interim Armored Vehicle, IAV (STRYKER) acquisition and preview testing is underway.

The preceding initial decision-aiding model illustrates the steps necessary to build a case for a new block, and the timing of its initiation. The decision should depend on the improvement of performance (effectiveness) achieved in the process of TAFT and consequent improvement of reliability (suitability). More elaborate model examples are required to exhibit the system-wide capability goals needed for more complex

externally supported, mobile systems to operate in groups (e.g., brigades) with acceptable mission success probability.

References

- Bartlett, M. S. (1955). Discussion of paper of D. R. Cox. *JRSS B*, Vol. 17, pp. 159-160.
- Bartlett, M. S. (1967). Inference and stochastic processes. *JRSS A*, Vol. 130, pp. 457-477.
- Cox, D. R. (1955). Some statistical methods connected with series of events (with discussion). *JRSS B*, Vol. 17, pp. 129-164.
- Cox, D. R. and Isham, V. (1980). *Point Processes*. Chapman & Hall.
- Daly, S. C., Miller, L. W., Seglie, E. A., and Wauer, G. (2003). The test and evaluation master plan: an operational view. *The ITEA Journal of Test and Evaluation*, Vol. 24.
- Feller, W. (1966). *An Introduction to Probability Theory and Its Applications*. John Wiley & Sons, Inc.
- Gaver, D. P., Jacobs, P. A., Glazebrook, K., and Seglie, E. (2003). Probability models for sequential-stage system reliability growth via failure mode removal. *International Journal of Reliability, Quality and Safety Engineering*, Vol. 10, No. 1, pp. 15-40.
- Gaver, D. P., Jacobs, P. A., and Seglie, E. (2004). Dynamic management of systems undergoing evolutionary acquisition. *Proceedings of the 4th International Conference in Mathematical Methods in Reliability*, Santa Fe, NM, June 21-25, 2004.
- Gaver, D. P., Jacobs, P. A., Glazebrook, K., and Seglie, E. (2005). Reliability growth through block upgrade. *To appear in the Proceedings of the European Safety & Reliability Conference (ESREL) 2005*.
- Seglie, E. A. (2002). The future of test and evaluation. *The ITEA Journal of Test and Evaluation*, Vol. 23.
- U. S. Department of Defense. (2003). *DoD Directive 5000.1 The Defense Acquisition System*. U. S. Department of Defense, Washington, DC.
- U. S. Department of Defense. (2003). *DoD Instruction 5000.2 Operation of the Defense Acquisition System*. U. S. Department of Defense, Washington, DC.

Appendix

The specific parametric example used for illustration is

$$\begin{aligned}
 & G_d \left[b+1; M(T_d(b+1)); m(T_d(b+1)) \right] \\
 &= \left[1 - \exp \left\{ -a_1 M(T_d(b+1))^{\alpha_1} \right\} \right] \exp \left\{ -a_2 \left[m(T_d(b+1))^{\alpha_2} \right] \right\}
 \end{aligned} \tag{8}$$

for $a_i > 0$, $\alpha_i > 0$ for $i=1,2$. Of course, (8) is hypothetical and speculative, and subject to replacement. Note that the overall fraction of possible success G_d achieved decreases as the time-rate of expenditure, m , increases, (the ‘‘haste makes waste’’ effect). The conditional expected number of DDs introduced during development is

$$\begin{aligned}
 & E \left[\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1)) \mid \mathbf{K}_0 \right] \\
 &= \mathbf{K}_0 m (T_d(b+1))^{\alpha_3};
 \end{aligned} \tag{9}$$

the expected number of DDs introduced is an increasing function of the rate of expenditure during development, m . For this parametric form

$$\begin{aligned}
 & E \left[\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau) \mid \mathbf{K}_0 \right] \\
 &= \mathbf{K}_0 m (T_d(b+1))^{\alpha_3} \theta^{\tau T_d(b+1)};
 \end{aligned} \tag{10}$$

for \mathbf{K}_0 having the gamma distribution of (4)

$$\begin{aligned}
 & E \left[\theta_F^{\mathbf{D}(b+1; M(T_d(b+1)); T_d(b+1); \tau)} \right] \\
 &= \left[\frac{\nu}{\nu + m(T_d(b+1))^{\alpha_3} \theta^{\tau T_d(b+1)} (1 - \theta_F)} \right]^{\beta}.
 \end{aligned} \tag{11}$$

INITIAL DISTRIBUTION LIST

1. Research Office (Code 09).....1
Naval Postgraduate School
Monterey, CA 93943-5000
2. Dudley Knox Library (Code 013).....2
Naval Postgraduate School
Monterey, CA 93943-5002
3. Defense Technical Information Center.....2
8725 John J. Kingman Rd., STE 0944
Ft. Belvoir, VA 22060-6218
4. Richard Mastowski (Editorial Assistant).....2
Department of Operations Research
Naval Postgraduate School
Monterey, CA 93943-5219
5. Distinguished Professor Donald P. Gaver4
Department of Operations Research
Naval Postgraduate School
Monterey, CA 93943-5219
6. Professor Patricia A. Jacobs.....3
Department of Operations Research
Naval Postgraduate School
Monterey, CA 93943-5219
7. Dr. Ernest A. Seglie1
Office of the Director, Operational Test and Evaluation
The Pentagon, Room 3E318
Washington, DC 20301-1700
8. Dr. Arthur Fries..... electronic copy
9. Dr. Les Servi..... electronic copy
10. Dr. John Lehoczky electronic copy
11. Dr. Kevin Glazebrook..... electronic copy
12. Professor Min Xie electronic copy
13. Professor Lyn Thomas electronic copy
14. Professor Ramalhoto electronic copy
15. Dr. Chiu..... electronic copy
16. Dr. Alyson Gabbard Wilson electronic copy

17. Professor Tim Bedford..... electronic copy
18. Dr. J. Norstrom electronic copy
19. Dr. Paul Ellner electronic copy
20. Dr. G. Latouche..... electronic copy
21. Dr. G. Fayolle electronic copy
22. Professor Kolowrocki electronic copy
23. Professor M. Nikouline electronic copy