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SIMULATION-BASED DECISION SUPPORT FOR ACQUISITION POLICY AND PROCESS DESIGN: THE EFFECT OF SYSTEM AND ENTERPRISE CHARACTERISTICS ON ACQUISITION OUTCOMES

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Doug Bodner, Rob Smith and Bill Rouse

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Simulation-based Decision Support for Acquisition Policy and Process Design: The Effect of System and Enterprise Characteristics on Acquisition Outcomes

Presenter: Presenter: Doug Bodner is a senior research engineer in the Tennenbaum Institute at Georgia Tech. His research focuses on computational analysis and decision support for design, operation and transformation of organizational systems. His work has spanned a number of industries, including automotive, electronics, energy, health care, military acquisition, paper, semiconductors and telecommunications. Bodner is a member of the Institute of Electrical and Electronics Engineers (IEEE), the Institute of Industrial Engineers (IIE) and the Institute for Operations Research and Management Science (INFORMS), and he is a registered professional engineer (PE).

Douglas A. Bodner, PhD, PE
Senior Research Engineer
Tennenbaum Institute
760 Spring Street, NW
Atlanta, GA 30332-0210
E-mail: doug.bodner@gatech.edu

Authors:

Rob Smith is currently pursuing an MS in Industrial Design, with an emphasis on information and interaction, in the College of Architecture at the Georgia Institute of Technology. He received a BS in Systems Engineering with a focus on psychology and human systems from the University of Virginia. In between completing his Bachelor's degree and returning to school for his Master's degree, Smith helped manage several large scale construction projects and served as a Systems Engineer for a major defense contractor.

Robert J. Smith
Research Fellow
Tennenbaum Institute
760 Spring Street, NW
Atlanta, GA 30332-0210
E-mail: robertjsmith@gmail.com

Bill Rouse is the Executive Director of the Tennenbaum Institute at the Georgia Institute of Technology. He is also a professor in the College of Computing and School of Industrial and Systems Engineering. Rouse has written hundreds of articles and book chapters, and has authored many books, including most recently *People and Organizations: Explorations of Human-Centered Design* (Wiley, 2007), *Essential Challenges of Strategic Management* (Wiley, 2001) and the award-winning *Don't Jump to Solutions* (Jossey-Bass, 1998). He is editor of *Enterprise Transformation: Understanding and Enabling Fundamental Change* (Wiley, 2006), co-editor of *Organizational Simulation: From Modeling & Simulation to Games & Entertainment* (Wiley, 2005), co-editor of the best-selling *Handbook of Systems Engineering and Management* (Wiley, 1999), and editor of the eight-volume series *Human/Technology Interaction in Complex Systems* (Elsevier). Among many advisory roles, he has served as Chair of the Committee on Human Factors of the National Research Council, a member of the US Air Force Scientific Advisory Board, and a member of the DoD Senior Advisory Group on Modeling and Simulation. Rouse is a member of the National Academy of Engineering, as well as a fellow of four professional societies—Institute of Electrical and Electronics Engineers (IEEE), the International Council on Systems Engineering (INCOSE), the Institute for Operations Research and Management Science, and the Human Factors and Ergonomics Society.

William B. Rouse, PhD
Executive Director and Professor
Tennenbaum Institute
760 Spring Street, NW
Atlanta, GA 30332-0210
Phone: 404-894-2331
E-mail: bill.rouse@ti.gatech.edu

Abstract

Effective acquisition programs, in terms of cost and capability outcomes, are increasingly important in today's cost-constrained environments. Thus, it is important to have effective decision support for acquisition policy and process design. This paper discusses a simulation-based approach for decision support that facilitates analysis of the effect of system and acquisition enterprise characteristics on acquisition outcomes for different policy and process alternatives (e.g., traditional vs. evolutionary). The particular characteristics studied are system modularity and production quantity, plus enterprise architecture and risk characteristics (i.e., mission risk). The modeling approach and results to date are presented.

1. Introduction

With the continued advent of new threats on the one hand, and likely constraints on the ability of the government to fund new systems on the other, effective military acquisition programs are increasingly important. New threats currently derive from asymmetric and regional sources such as terrorism, insurgencies and cyber-warfare. These new threats call for new types of systems. However, the defense acquisition enterprise operates in an increasingly cost-constrained environment. In recent years, acquisition cost overruns have been highlighted by the GAO and have provoked concern from government funding sources. In addition, short-term war expenditures have used, and continue to use, funds that otherwise might have been used for the acquisition of new systems, and long-term government entitlement commitments may constrain future funding for new systems. Finally, sustainment cost is becoming an increasingly significant area of concern.

This, of course, is not a new observation since the past forty years have seen numerous attempts at reforming the acquisition enterprise. One of the most important reforms is the concept of evolutionary acquisition, in which systems are acquired in smaller increments of capability and then evolved after initial deployment with capability upgrades. The theory is that evolutionary acquisition enables shorter cycles for acquisition, allowing new capabilities to be deployed more quickly to warfighters in the field at less cost, as opposed to traditional acquisition approaches that rely on long development cycles (Johnson & Johnson, 2002).

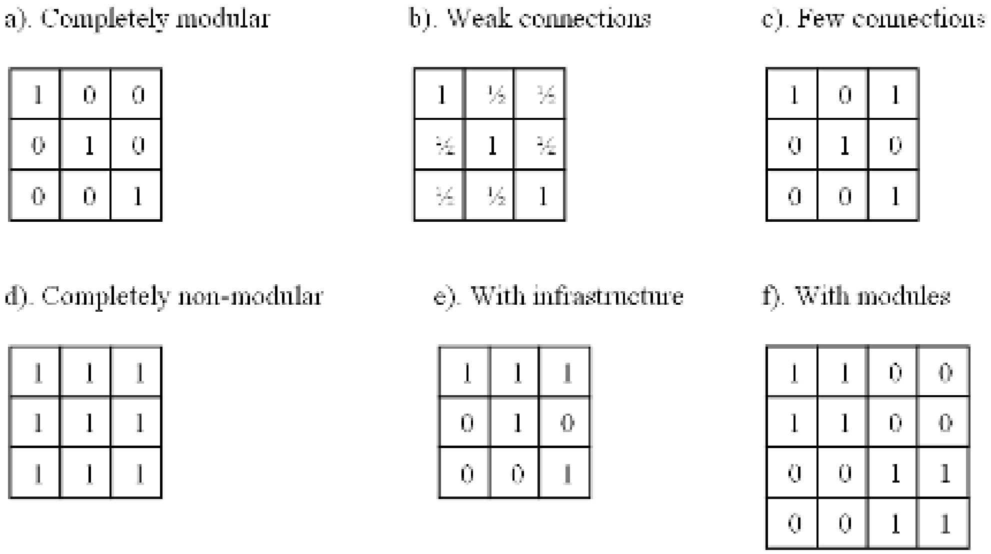
Despite evolutionary acquisition's status as official policy, though, the Department of Defense seems to have had limited success in its implementation (Lorell, Lorrell, & Younossi, 2006). Our previous work has demonstrated that evolutionary acquisition can, in fact, result in quicker deployment of increased capability but that more frequent cycles incur additional overhead that may increase overall costs (Pennock & Rouse, 2008). By expanding on these results, this paper seeks to study the effect of system and enterprise features on the performance of acquisition policies. In particular, the immediate focus is on the effect of system modularity on acquisition lifecycle performance, where performance is considered as (i) the time taken to deploy new capabilities in the field, (ii) the availability of systems in the field once deployed, (iii) and the lifecycle cost associated with acquisition and sustainment. The notion of modularity has potential synergy with evolutionary acquisition—in terms of enabling capability upgrades to be integrated into existing platforms—due to the presence of a modular system architecture.

This paper discusses a simulation-based approach that provides decision support for the design of acquisition policies and processes over the acquisition lifecycle so that issues such as the effect of system modularity can be addressed. The remainder of the paper is organized as follows. Section 2 reviews the literature on system modularity in product design and acquisition processes. Section 3 describes the simulation model used in this research. Sections 4 and 5 discuss an initial experiment and its results, demonstrating the effect of modularity on costs and availability. Then, Section 6 concludes with a description of future research intentions.

2. Literature Review

Modularity is typically conceptualized as a matrix of relationships between different system modules or components, where the relationship may mean that two modules or components are connected or that changes to one impact the other. Here, we adopt the latter as the meaning. For instance, a laptop computer is typically considered less modular than a desktop since many components of a desktop are designed to be assembled and replaced by the user without changes to other components (Hölttä-Otto & de Weck, 2007). The modular architecture of a system often is considered to consist of a set of modules or components and an infrastructure, which connects components or otherwise provides a platform for the system. Here, we adopt the terminology that a simple system is composed of components and that a complex system is composed of modules, which are, in turn, composed of components. In this type of complex system, a module typically has strong relationships among its constituent components.

Assume that a value of 1 means that two components are strongly related, that a value of 0 means that they are not related, and that a value in between represents the probability that they are related over a set of circumstances. Figure 1, then, illustrates the concept of modularity for small systems represented by matrices. It should be noted in the figure that the matrix entry m_{ij} represents the degree to which a change in component i affects component j. Also, the matrix representation is not standardized in the literature. For instance, other efforts reverse the role of the rows and columns (e.g., Baldwin & Clark, 2000). It is assumed that entries along the diagonal are all 1; however, they are not relevant to the model. In Figure 1e, then, component 1 is the infrastructure, and the example shows that a change to it impacts all components. In Figure 1f, there are two modules, each composed of two components.



a). Completely modular

1	0	0
0	1	0
0	0	1

b). Weak connections

1	½	½
½	1	½
½	½	1

c). Few connections

1	0	1
0	1	0
0	0	1

d). Completely non-modular

1	1	1
1	1	1
1	1	1

e). With infrastructure

1	1	1
0	1	0
0	0	1

f). With modules

1	1	0	0
1	1	0	0
0	0	1	1
0	0	1	1

Figure 1. Modularity Representations

The concept of modularity in system design has been researched fairly extensively over the last twenty years. Much of this literature applies to commercial product design rather than military system design. In this discussion, the terms *system* and *product* will be used interchangeably. Ulrich and Tung (1991) offer one of the first definitions of modularity, focusing on (i) similarity between the physical and functional architectures of a product or system and (ii) minimization of interactions between physical components. While function is one focus of modularity research, another focus is on the system lifecycle—for instance, modularity to facilitate component disassembly, recycling or reuse (Gershenson, Prasad & Allamneni, 1999). The lifecycle focus provides a framework for discussing how modularity affects cost during the different phases of acquisition.

In design, there is considerable literature on how to format for modularity. The research literature, for the most part, does not concentrate directly on cost, though. Baldwin and Clark (2000) discuss three stages of cost with respect to designing for modularity: (i) establishing design rules, (ii) establishing design parameters, and (iii) testing and fixes. Design rules provide constraints within which modules (or components) must operate. As the number of modules increases, the cost of establishing design rules also increases, although no specific relationship is identified (Baldwin & Clark, 2000). Establishing design rules is considered a one-time expenditure, since they are believed to remain in effect for a long time. Design parameters must be established each time a module is designed. The cost increases with product complexity and is applied for each redesign. Costs for testing and fixes start high but decrease over time as personnel gain expertise with the particular product or system.

Hölttä and Otto (2005) support the general relationship described for Baldwin and Clark's "design parameter" costs, but add two boundary cases of significance. First, minor changes often do not require a reworking of the module parameters, largely owing to the allowances of play existing within the system. Second, major changes usually require a much more costly reworking of the module concept itself. Although they do not use the same terminology as Baldwin and Clark, the implication is that these large changes could challenge even the initial design rules. Between those two extremes, however, Hölttä and Otto observe a roughly linear relationship between the degree of change requested and the difficulty—and, by inference, the cost—of enacting that change.

In terms of production, Fixson (2007), in his review of research into modularity and commonality, finds that most studies of modularity have identified economies of scale as a significant cost benefit. Garud and Kumaraswamy (1995) describe the effect as an economy of substitution. The ability to manufacture components separately from the products they comprise permits these component designs to outlive individual product lines. Thus, modularity extends the size of the production runs across both products and through time. This reuse of a design lowers costs by reducing retooling requirements. The relationship is not entirely linear. There is an optimal number of modules where increasing assembly costs balance out the decreasing fabrication costs (Fixson, 2007).

The scale of the product itself may also be significant in whether these cost benefits can be realized. Zhang and Gershenson (2003), investigating a collection of fourteen small-consumer products, “found no general relationships between relative modularity and cost, or between change in modularity and change in cost.”

In sales and demand for commercial products, Desai, Kekre, Radhakrishnan, and Srinivasan (2001) find that increasing commonality between products can hurt demand. Shared components reduce the perceived value of high-value products and increase the component costs for low value products, thus eating into profits from both ends. The F-35 Joint Strike Fighter offers an interesting case of commonality across systems in a military context. Its three variants are designed for three different service applications (a traditional fighter for the Air Force, a vertical/short take-off and landing vehicle for the Marines, and a carrier-based fighter for the Navy). If successful, this approach demonstrates a way whereby commonality increases demand via appealing to different classes of customers.

In sustainment, modularity can help reduce inventory cost by pooling demands, an extension of the economies of scale that benefit the production stage. These early findings have seen much elaboration and investigation, leaving the inventory phase one of the most researched phases in the lifecycle of modular architecture. Fixson (2007) offers a thorough account of the various exceptions and extensions of the inventory research, including the roles of demand distributions, correlated demands, component cost structures, inventory time horizon, process and supply networks, and other constraints and considerations.

Aside from inventory, the sustainment phase of the product lifecycle is one of the least researched aspects of modularity. Gershenson et al. (1999) speculate that maintenance costs should diminish with increased modularity, but their focus is elsewhere, and they do not back this speculation with data. Newcomb, Bras, and Rosen (1998) demonstrate that it is possible to modularize a product with respect to lifecycle, i.e. maintenance and disposal. Tsai, Wang, and Lo (2003) offer a similar demonstration. Both papers indicate that modularity can reduce costs of ownership but only if applied properly. Gershenson, Prasad & Zhang (2003) speculate that any modularity is good for maintenance costs; however, this hypothesis does not yet appear to have been tested in the research literature.

Modularity is related to the notion of open systems, which have been adopted as an initiative in the DoD acquisition. An open-systems approach seeks to enable the integration of current and future capabilities into a system via standards. Ford and Dillard (2008) study the interaction between evolutionary acquisition and open systems and find that the use of the two together may improve schedule and cost performance but may also increase cost in sustainment due to a trade-off between increased integration risks (due to evolving standards) and reduced design risks (due to use of currently stable standards).

There are several hypotheses that are of interest when considering modularity. These include, along with supporting evidence from the literature:

1. Increasing modularity decreases the cost of implementing technology upgrades for deployed systems (Fleming & Sorenson, 2001; Garud & Kumaraswamy, 1995; Gershenson et al., 2003; Huang & Kusiak, 1998; Ulrich & Tung, 1991; Ulrich, 1995);
2. Increasing modularity decreases the mean time to repair a system that has failed (Cheung & Hausman, 1995; Gershenson et al., 2003; Tsai et al., 2003);
3. Increasing modularity increases the upfront engineering design hours required for a system (Ulrich, 1995);
4. Increasing modularity increases the cost of changes to infrastructure (Ethiraj & Levinthal, 2004; Fleming & Sorenson, 2001; Garud & Kumaraswamy, 1995; Ulrich & Tung, 1991; Ulrich, 1995).

It should be noted that Fleming and Sorenson (2001) offer mixed support for hypothesis 1 since they find that small technology upgrades are handled easily with a modular architecture but that major upgrades may pose challenges since they may require changes to the modular architecture itself. In addition, Garud and Kumaraswamy (1995) assert that technology upgrade costs decrease only at the expense of an initial infrastructure cost. This paper primarily addresses the first two hypotheses.

As the number of components in a system increases, it is a complex task to compare different modularity matrices and quantitatively determine differences in modularity. Thus, there has been interest in establishing a modularity index to provide a standardized measurement of modularity. Two such indices are given by Guo and Gershenson (2004) and Hölttä-Otto and de Weck (2007). Effective modularity indices remain an area of research.

3. Model Description

This research uses a simulation-based decision support to determine the effectiveness of different acquisition policies and processes. Simulation has traditionally been used in process-based domains such as manufacturing (Law & Kelton, 2000). Increasingly, it is being used to study acquisition. Ford and Dillard (2008) use a system dynamics approach, which models the delayed effects and feedback flows associated with the acquisition enterprise. Discrete-event simulation is used in our previous work (Pennock & Rouse, 2008) and by Olson and Sage (2003). Discrete-event simulation tends to offer better representational support for organizational decision-making processes.

3.1. Existing Model Summary

Our existing model is implemented using ARENA 10.0, a commercially available, discrete-event simulation package. It consists of three interacting components, which address the traditional acquisition system (Pennock & Rouse, 2008):

- Technical Progress Model. The technical progress model accounts for basic research that occurs exogenous to the defense enterprise. This work may be performed in the commercial sector or via government funding. It feeds raw, new technologies into a technology development process model that reflects the DoD's science and technology (S&T) development enterprise. Technologies are characterized by an application area, a maturity level and a capability level. An example of an application area might be radar. The maturity level reflects the readiness of the technology for usage and is measured using the NASA technological readiness level (TRL) scale, recently adopted by the DoD (DoD, 2006, July). Capability level, on the other hand, represents the technology's capability (once deployed) in relation to previous generations within the same application area. Capability level for each succeeding generation is determined by a combination of a learning effect (from the other DoD applications) and an exogenous progress effect (from commercial and outside technical progress). Technologies are put into the technology development process model at an early TRL (e.g., 1).

- Technology Development Process Model. In this S&T enterprise, new technologies for the DoD systems typically undergo a staged process of development whereby ideas are reduced to working technologies that can be integrated into a system. There is considerable technical risk in the development process, as ideas often do not work in practice, do not scale-up to production, or do not integrate into systems. The staged process mitigates risk by not fully funding a technology's development, allowing it to be culled if it fails or if it is outpaced by competing technologies. It should be noted that the S&T enterprise model consists of a single, unified organization rather than the myriad agencies that comprise the actual DoD S&T enterprise.
- System Acquisition Process Model. The system acquisition model primarily represents the first four phases of a defense acquisition program, as specified in the DoD Defense Acquisition Guidebook (2006). These include concept development, technology development, system development and production & deployment. Operations & support is represented by a simple delay function for the period of sustainment. The system acquisition process model pulls technologies from the technology development process model for use in the system being developed. In the existing model, the TRL at which these technologies are selected is an experimental variable used to assess the effect of traditional acquisition (which selects relatively immature technologies and matures them in the program for significant capability leaps in deployed systems) versus evolutionary acquisition (which selects relatively mature technologies for more frequent, but smaller capability leaps).

The remainder of this section discusses two enhancements to the existing model—the introduction of a representation for system modularity and a model of the sustainment phase of the acquisition lifecycle.

3.2. Modularity Matrix

A system is assumed to have *n* components. These components may or may be related with one another for the purposes of repair/replacement and/or technology upgrades during sustainment. One of these components is designated as the system infrastructure, or the platform that integrates the various components. Modular systems often require such an infrastructure to facilitate modularity. Modularity is then characterized as the degree to which the various components interact or are connected, and it is represented as an *n* x *n* matrix. It should be noted that modularity is assumed to be a function of the system design, as determined in upstream stages of the acquisition process.

Each entry m_{ij} in this modularity matrix **M** represents the probability that a change in component *i* necessitates a change in component *j*. Component failures and component technology upgrade opportunities arrive and involve changes to a component. Due to modularity effects, they may also involve changes to other components through the relations represented by **M**. The modularity values for a particular system may differ for repairs and technology upgrades, resulting in two different matrices, $\mathbf{M}_r$ and $\mathbf{M}_t$. Also, a modularity matrix is not necessarily symmetric. That is, changes to component *i* may affect component *j* in a manner different from that in which changes to *j* affect *i*. A simple example of asymmetry is when replacing *i* requires removing *j*, but replacing *j* does not require removing *i*. Components may be organized into modules in complex systems.

3.3. Sustainment Model

The sustainment model has two primary processes—repairs and technology upgrades. Failures and technology upgrade opportunities arrive as random events to a deployed system, according to a Poisson process with a particular rate. Each failure or technology upgrade opportunity directly affects only one component, except that an infrastructure component, when present, is not affected by failures or technology upgrades and is assumed to be component 1. However, repairs or upgrades may cascade to other components, due to modularity relationships. The following notation is used for the sustainment model.

- f_i is the failure rate associated with component *i*. f_1 is undefined when infrastructure is present (since infrastructure is component 1).
- r_i is the repair rate associated with component *i*. r_1 is undefined when infrastructure is present.
- t_i is the arrival rate of new technology upgrades for component *i*. t_1 is undefined when infrastructure is present.
- u_i is the upgrade rate for component *i*. u_1 is undefined when infrastructure is present.
- p_i is the cost of repairing component *i*. p_1 is undefined when infrastructure is present.
- q_i is the cost associated with a technology upgrade to component *i*. q_1 is undefined when infrastructure is present.
- c_{ij} is the compatibility cost associated with making component *j* technologically compatible with component *i* if *i* is upgraded and if the interaction between *i* and *j* necessitates that *j* be made compatible to the new technology for *i*. c_{i1} is undefined when infrastructure is present.

In general, it is assumed that $f_i > t_i$, $r_i > u_i$, and $p_i < q_i$.

The simulation logic works as follows. When a failure to component *i* arrives to the system, it invokes a repair delay for that component, occurring at rate r_i. All components *j* such that $m_{ij} > 0$ are evaluated probabilistically via a Bernoulli variable, using the probability m_{ij}, to determine whether *j* must also be repaired. Any components *j* requiring a repair are then repaired at rate r_j. This repair requirement can cascade to additional components that are dependent on *j*, and so on. The system experiences a repair downtime equal to the maximum repair time of *i* and that of any other affected components.

Similarly, when a technology upgrade to component i arrives to the system, it invokes an upgrade delay for that component. This delay occurs at rate u_i. All components j such that $m_{ij} > 0$ are evaluated probabilistically via a Bernoulli variable to determine whether j must also be made compatible with the upgrade. Any components j requiring a compatibility operation invoke a delay at rate u_j. Upgrade effects can cascade similarly to repair effects. The system experiences an upgrade downtime equal to the sum upgrade time of i and compatibility time of any affected components. This is in contrast to the downtime due to repairs.

If a failure or technology upgrade for i arrives while the system is in downtime, then that failure or technology upgrade queues until the downtime is resolved. Multiple entities in this queue are processed as first-come-first-served.

Clearly, this is a relatively simple model. It is meant to allow basic analysis of the effects of modularity and to provide a basis for more complex models in the future.

4. Experiment

In this section, we detail a simulation experiment to test the effect of different types of modularity matrices on sustainment. The dependent variables are the repair costs, upgrade costs and system availability. Sustainment of a single system is considered in each experimental run. Three classes of modularity are considered:

- Type 1. All non-diagonal entries in the matrix are the same fractional probability value.
- Type 2. All non-diagonal entries in the modularity matrix are either zero or one.
- Type 3. The matrix consists of modules, comprised of components that have strong relationships, but the relationship entries between modules in different components is zero.

4.1. Parameters and Assumptions

The simulation is executed over a period representing ten years of sustainment. The following parameter values are used. These parameter values are selected as notional values for the experimental analysis to illustrate the effects of the modularity.

- f_i = 60 days for all i
- r_i = 1 hour for all i
- t_i = 360 days for all i
- u_i = 6 hours for all i
- p_i = 10 currency units for all i
- q_i = 100 currency units for all i
- c_{ij} = 15 currency units for all i and j

4.2. Experimental Setup

Table 1 shows the variations tested among the different types of modularity matrices. In matrices of types 1 and 2, n equals 10. In matrices of type 3, the size is adjusted to n equals 16 to accommodate modules being the same size (e.g., systems with eight modules, each having two components, or with four modules, each having four components).

Table 1. Modularity Matrix Variations Tested

Matrix Type	Variations
Type 1	Eleven different variations are simulated. Each variation uses a different value for all non-diagonal m_{ij}. The different values used are 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0.
Type 2	Seven different variations are simulated. Each variation has a mix of values (0, 1) for non-diagonal m_{ij}. Each variation uses a different probability to select a specific value for each m_{ij}. These probabilities are 0.0, 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6, and the probability corresponds to m_{ij} equaling one, as opposed to zero. It was determined that probability values above 0.6 had similar behavior; thus, they are not considered here.
Type 3	Five variations are simulated. Each variation has a different size of module. The variations include sixteen modules of size 1, eight modules of size 2, four modules of size 4, two modules of size 8, one module of size 16. Within each module, all m_{ij} equal 1. Relationships between modules have m_{ij} equal 0.

Ten replications of each variation are run for statistical significance.

5. Results and Analysis

5.1. Repair Costs

Figures 2-4 illustrate average repair costs as a function of the level of modularity in a system. The actual average repair cost shown is the average collateral repair cost, or the cost of repairing other components related to a failed component that must be repaired due to a modularity relationship. This shows the variable effect of modularity in terms of average repair cost. The result from each replication across each variation is shown in each figure. The units for cost are in currency units, as specified in the parameters for the model.

According to expectations, as the level of relationship strength (or coupling) increases (i.e., as modularity decreases), the repair cost increases for each type of matrix. The factors of interest include the points at which the costs start to converge to a maximum value and the relative spread of the costs for each level of variation within each type of modularity matrix. In the type 1 matrix, the variance is less than that of the type 2 matrix, suggesting that numerous weak relationships provide a more predictable repair cost for a system than a set of relationships that are either very strong or very weak. Intuitively, this makes sense. It also is reinforced by the outcome from type 3 matrices, in which the repair cost is always the same, since a component failure leads to replacement of the entire module, and each module is the same size and cost. Since module size has a linear relationship with module cost, the cost relationship with modularity is likewise linear.

Since the failure rates are the same across all replications, the patterns for total repair costs of each replication (over the entire ten-year time horizon) are similar to those of average costs (per failure incident). Therefore, only the average costs are shown. However, it should be noted that there would be variance across variations in the type 3 matrix total costs since the number of failures during the time horizon is a random variable.

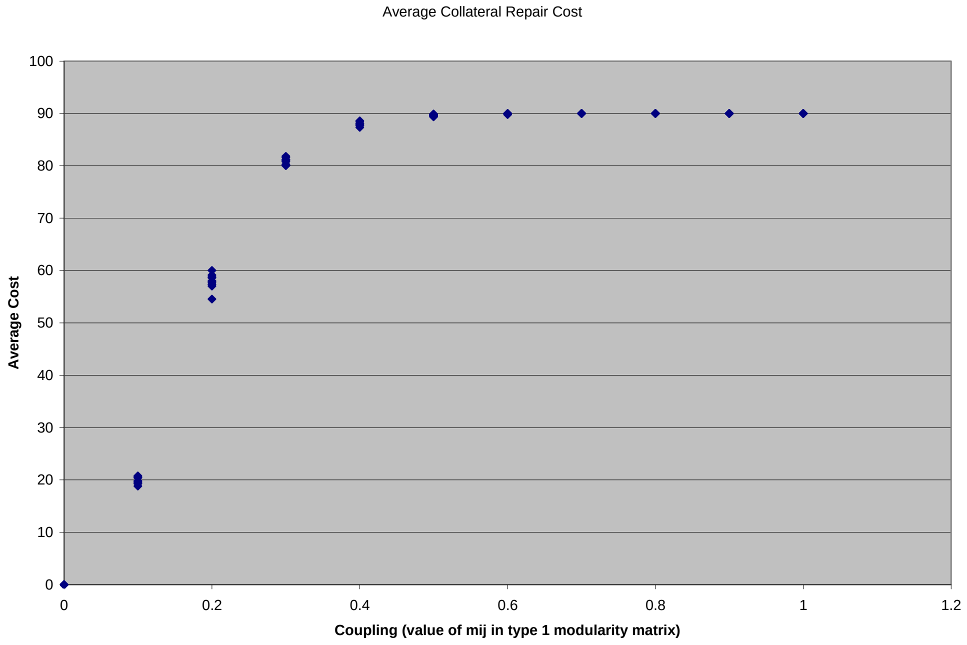


Figure 2. Repair Cost as a Function of Modularity for Type 1 Matrix

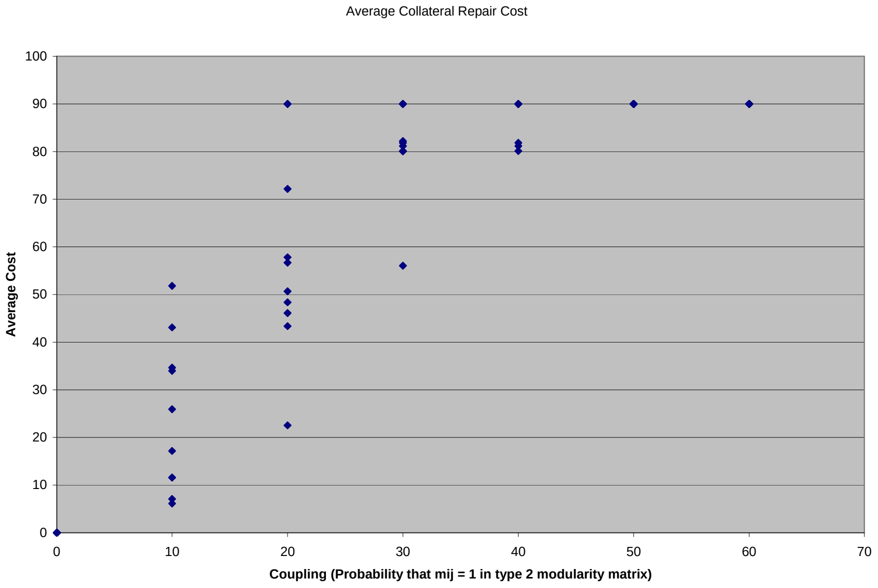


Figure 3. Repair Cost as a Function of Modularity for Type 2 Matrix

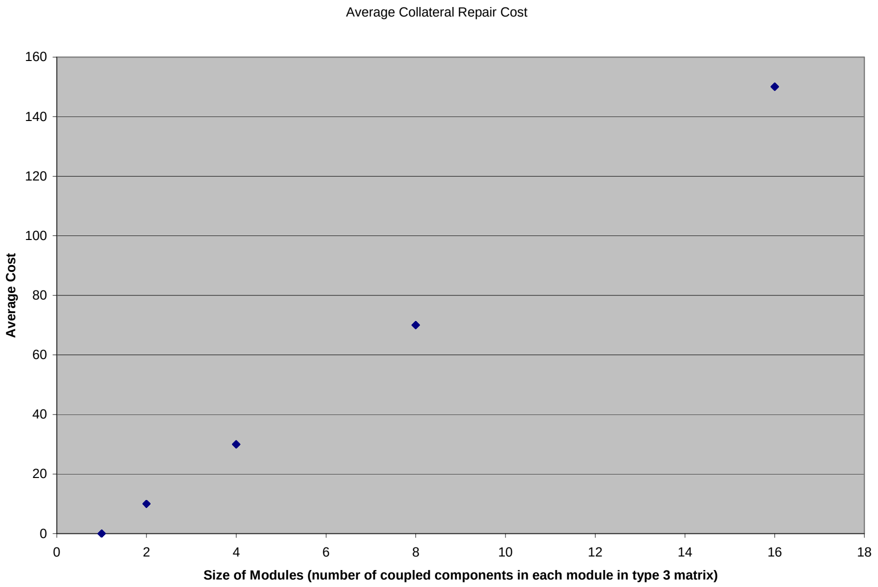


Figure 4. Repair Cost as a Function of Modularity for Type 3 Matrix

5.2. Technology Upgrade Costs

Figures 5-7 illustrate average upgrade costs as a function of the level of modularity in a system. Average upgrade cost addresses the work to make components consistent to upgrades when they are related to the component being upgraded, i.e., the variable portion of cost related to modularity. The result from each replication across each variation is shown in each figure.

The behavior patterns for upgrade costs are comparable to those for repair costs: as the level of relationship strength increases, the upgrade cost increases for each type of matrix. As with repair costs, the pattern for total upgrade cost over the ten-year time horizon is similar to that of the average cost, so only the average costs are shown. The units for cost are in currency units, as specified in the parameters for the model.

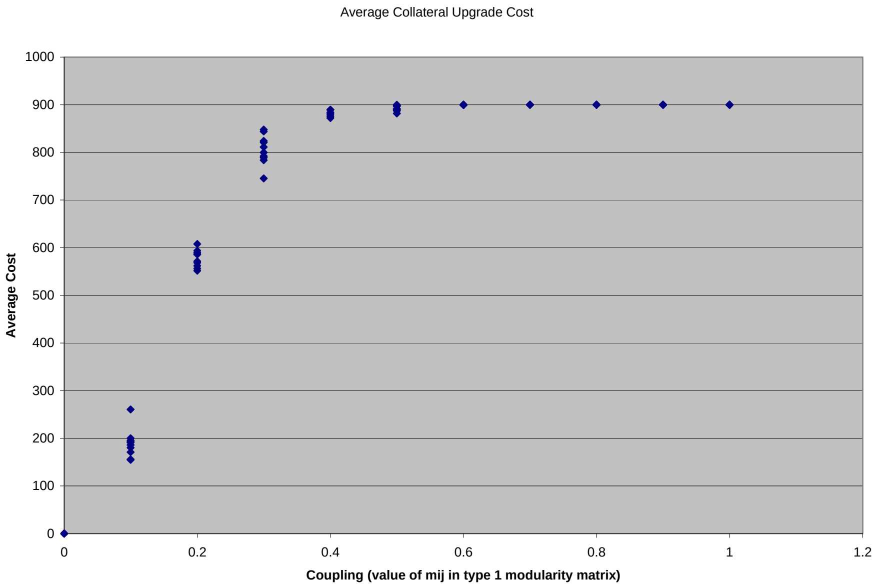


Figure 5. Upgrade Cost as a Function of Modularity for Type 1 Matrix

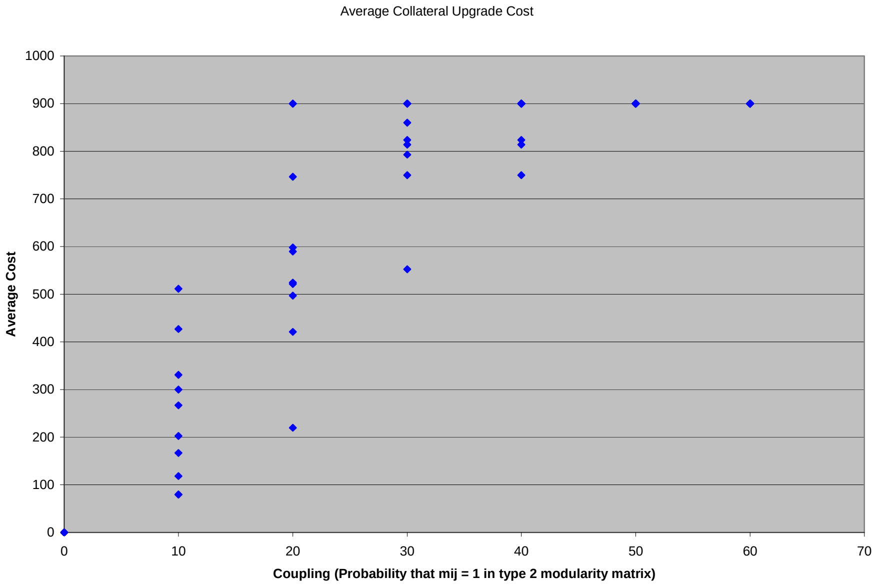


Figure 6. Upgrade Cost as a Function of Modularity for Type 2 Matrix

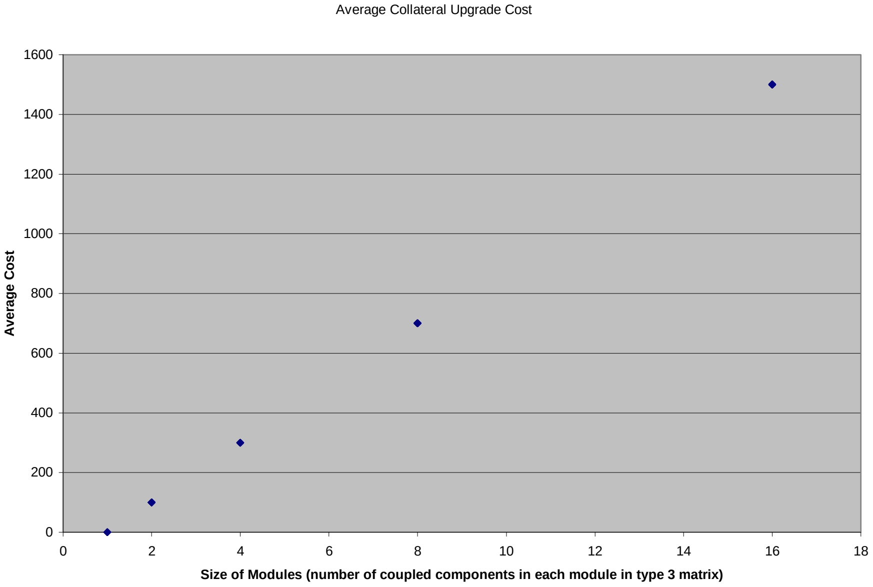


Figure 7. Upgrade Cost as a Function of Modularity for Type 3 Matrix

5.3. System Downtime

Finally, Figures 8-10 illustrate average system downtime during the ten-year time horizon as a function of the level of modularity in a system. Average downtime is a combined effect of failures and technology upgrades. The result from each replication across each variation is shown in each figure.

As the level of relationship strength increases, the average downtime increases for each type of matrix. The behavior patterns are somewhat similar to those for costs. The average downtime values across matrix type 3 variations are not constant, due to the random number of failures and technology upgrades in each replication. The units for downtime are the fraction of time that the system is unavailable.

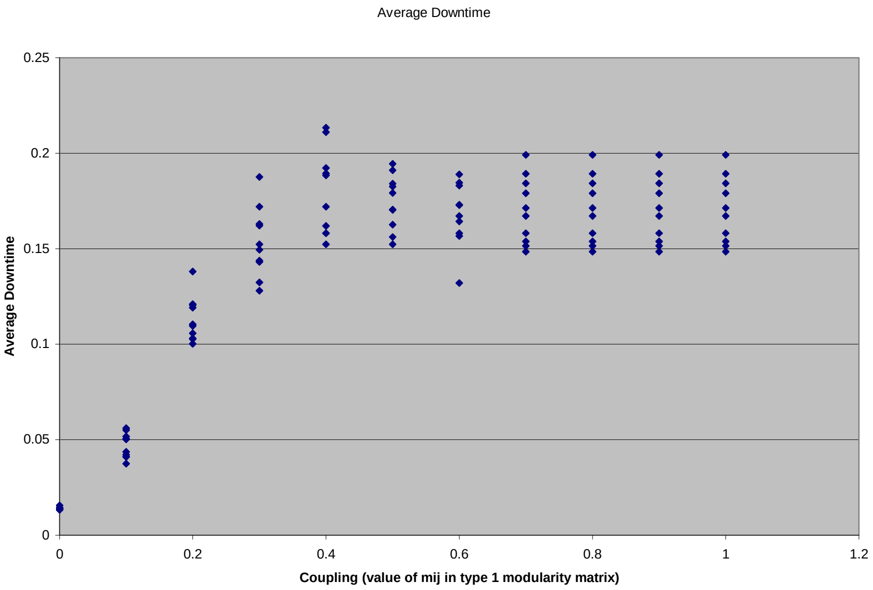


Figure 8. Downtime as a Function of Modularity for Type 1 Matrix

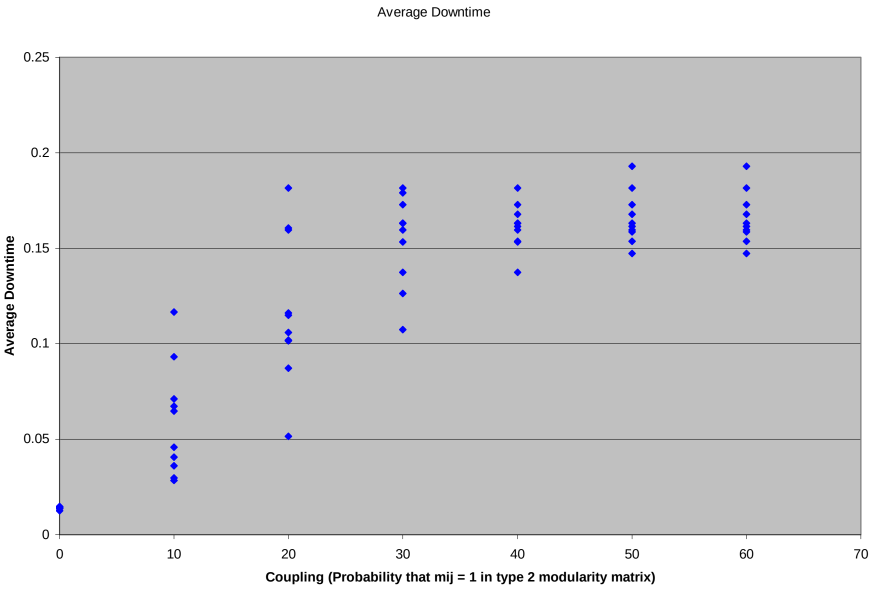


Figure 9. Downtime as a Function of Modularity for Type 2 Matrix

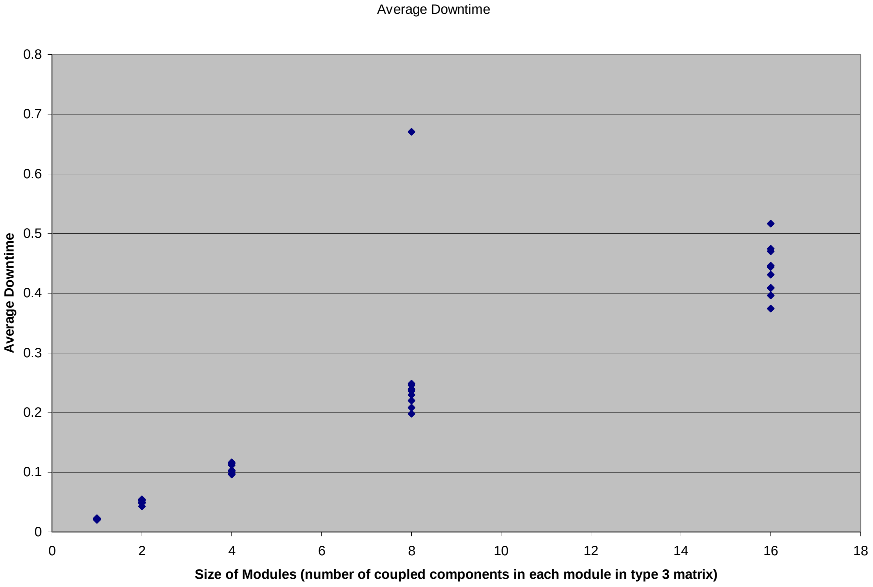


Figure 10. Downtime as a Function of Modularity for Type 3 Matrix

6. Discussion and Future Research

These results provide some insight into the effect of modularity on sustainment costs and system availability. There is some potential for cost savings and improved system availability as modularity is increased. Clearly, the parameter values and complexities of real systems need to be considered, and this will be a focus of future research efforts. Such efforts need to account for the notion of integration risk over the lifecycle, as detailed in Ford & Dillard (2008).

One major goal of this research is to characterize the effect of modularity over the acquisition lifecycle. Thus, current work is focusing on integration of the existing model of acquisition with the new sustainment and modularity models. This involves modeling modularity and its engineering costs in the acquisition model as well as modeling the flow of technology upgrades to the sustainment model from the S&T model. The emphasis on cost modeling will be on parametric models for cost estimation (e.g., Valerdi & Liu, in press). Such models must address not only the initial design of modularity but also adjustments during development such as evolution of design parameters (Baldwin & Clark, 2000). The hypothesis is that modularity tends to increase design and development costs while decreasing production and sustainment costs. The question is to determine what levels of modularity, in combination with other system characteristics, achieve the best results, not only in terms of cost but also in terms of time to deployment and post-deployment availability. One such system characteristic is production level, which has the potential to leverage economies of scale in making modularity more cost effective.

To answer the question about the effectiveness of modularity levels, it is important to be able to characterizer modularity by a standard metric such as a modularity index. This also will be an avenue of future research.

Another goal is to study the effect of enterprise characteristics and their interactions with system characteristics. In particular, we are interested in studying the effects of alignment in the S&T system and the concept of mission risk. The current model assumes a unitary S&T organization rather than the multi-organization S&T enterprise. In terms of cost, schedule and risk, what is the trade-off between the redundancy of a multi-organization S&T enterprise versus the efficiency of a unitary organization? Mission risk is increasingly important, given the evolution of threats that need to be addressed. Does modularity aid in adapting systems in the field to new mission requirements? Finally, we plan to extend previous results by exploring which conditions from the above areas of study make evolutionary acquisition more favorable than traditional approaches.

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