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**System-of-Systems Acquisition: Alignment and Collaboration**

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# Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
- Program Executive Officer SHIPS
- Commander, Naval Sea Systems Command
- Army Contracting Command, U.S. Army Materiel Command
- Program Manager, Airborne, Maritime and Fixed Station Joint Tactical Radio System

- Program Executive Officer Integrated Warfare Systems
- Office of the Assistant Secretary of the Air Force (Acquisition)
- Office of the Assistant Secretary of the Army (Acquisition, Logistics, & Technology)
- Deputy Assistant Secretary of the Navy (Acquisition & Logistics Management)
- Director, Strategic Systems Programs Office
- Deputy Director, Acquisition Career Management, US Army
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- Office of Procurement and Assistance Management Headquarters, Department of Energy

We also thank the Naval Postgraduate School Foundation and acknowledge its generous contributions in support of this Symposium.

James B. Greene, Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

# Panel 19 – System-of-Systems Acquisition: Concepts and Tools

| **Thursday, May 12, 2011** | |
|---|---|
| **11:15 a.m. – 12:45 p.m.** | **Chair: Rear Admiral David H. Lewis,** USN, Program Executive Officer, Ships<br><br>***Capability and Development Time Trade-off Analysis in Systems-of-Systems***<br>Muharrem Mane and Daniel DeLaurentis, Purdue University<br><br>***System-of-Systems Acquisition: Alignment and Collaboration***<br>Thomas Huynh, John Osmundson, and Rene Rendon, NPS<br><br>***Using Architecture Tools to Reduce the Risk in SoS Integration***<br>Chris Piaszczyk, Northrop Grumman |

**Rear Admiral David H. Lewis—**Program Executive Officer Ships. Rear Admiral Lewis is responsible for Navy shipbuilding for surface combatants, amphibious ships, logistics support ships, support craft, and related foreign military sales.

Born at Misawa Air Force Base, Japan, Lewis was commissioned in 1979 through the Navy ROTC Program at the University of Nebraska–Lincoln with a Bachelor of Science degree in Computer Science.

At sea, Lewis served aboard USS *Spruance* (DD 963) as communications officer, where he earned his Surface Warfare qualification; USS *Biddle* (CG 34) as fire control officer and missile battery officer; and USS *Ticonderoga* (CG 47) as combat systems officer. His major command assignment was Aegis Shipbuilding program manager in the Program Executive Office Ships, where he helped deliver seven DDG 51 class ships and procured another 10 ships.

Lewis' shore assignments include executive assistant to the assistant secretary of the Navy (Research, Development and Acquisition), assistant chief of staff for Maintenance and Engineering, commander, Naval Surface Forces, where he also served as a charter member of the Surface Warfare Enterprise. Other ship maintenance and acquisition assignments ashore include the Navy Secretariat staff; commander, Naval Sea Systems Command staff; Aegis Shipbuilding Program Office; supervisor of Shipbuilding, Bath; and Readiness Support Group, San Diego. Upon selection to flag rank, Lewis served as vice commander, Naval Sea Systems Command. Lewis earned a Master of Science degree in Computer Science from the Naval Postgraduate School. He completed the Seminar Course at the Naval War College Command and Staff School, and received his Joint Professional Military Education certification. He is a member of the Acquisition Professional Community with Level III certifications in Program Management and Production Quality Management, and has completed his civilian Project Management Professional certification.

Lewis' personal awards include the Legion of Merit, Meritorious Service Medal, Navy and Marine Corps Commendation, Navy and Marine Corps Achievement Medal, and various service and unit awards.

# System-of-Systems Acquisition: Alignment and Collaboration

**Thomas Huynh—**Associate Professor of Systems Engineering, NPS. Dr. Huynh obtained simultaneously a BS (Hons) in chemical engineering and a BA in applied mathematics from UC Berkeley and an MS and PhD in physics from UCLA. His research interests include uncertainty management in systems engineering, complex systems and complexity theory, system scaling, system-of-systems engineering and architecting, and system-of-systems acquisition. Prior to joining the Naval Postgraduate School in 2003, he spent 25 years in the aerospace industry and was a Fellow at the Lockheed Martin Advanced Technology Center in Palo Alto and Sunnyvale, CA, where he engaged in research in computer network performance, computer timing control, bandwidth allocation, heuristic algorithms, nonlinear estimation, perturbation theory, differential equations, and optimization. During his 23 years at Lockheed Martin, he was also teaching part-time in the departments of Physics and Mathematics at San Jose State University. Dr. Huynh is a member of INCOSE.

**John S. Osmundson—**Associate Research Professor, Systems Engineering and Information Sciences Departments (joint appointment), NPS. Dr. Osmundson received a BS in physics from Stanford University and a PhD in physics from the University of Maryland. His research interest is applying systems engineering and computer modeling and simulation methodologies to the development of systems of systems architectures, performance models, and system trades of time-critical information systems. Prior to joining the Naval Postgraduate School in 1995, Dr. Osmundson worked for 23 years at Lockheed Missiles and Space Company (now Lockheed Martin Space Division) in Sunnyvale and Palo Alto, CA, as a systems engineer, systems engineering manager, and manager of advanced studies. Dr. Osmundson is a member of INCOSE.

**Rene G. Rendon—**Associate Professor, NPS. Dr. Rendon teaches defense acquisition courses. He served for over 20 years as a contracting officer in the USAF, retiring at the rank of lieutenant colonel. His career included assignments as a contracting officer for the Peacekeeper ICBM, Maverick Missile, and the F-22 Raptor. He was also the director of contracting for the Space Based Infrared satellite program and the Evolved Expendable Launch Vehicle rocket program. Rendon has published in the *Journal of Public Procurement*, the *Journal of Contract Management*, and the *Project Management Journal*.

## Abstract

System-of-systems (SoS) acquisition research has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. This paper captures the exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a SoS. A collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs. The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system. This work forms a basis for building a web-based SoS collaborative system to support Department of Defense SoS acquisition programs.

## Introduction

The most common type Department of Defense (DoD) systems of systems (SoS) development is one in which a SoS is to be created by integrating separately developed systems—legacy systems, developmental systems, or some combination of both. Research in SoS acquisition has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. By lack of alignment it is meant a system is not ready for its integration into a SoS, or, because of the lack of the front-end SoS systems engineering (SE), the SoS integration discovers that the system does not meet the performance requirements or the interface requirements. By lack of collaboration it is meant the individual system programs fail to work with each other to achieve the goals of the SoS program.

SoS acquisition requires the availability of surrogates of component systems and later the "as built" component systems in a timely manner in order to support SoS integration testing. However, the acquisition schedules for the component systems are typically developed independently of the SoS development schedule. There is thus no assurance that the SoS integration testing can be completed as planned, resulting in the SoS schedule slip and associated cost overrun. Even when the schedules are aligned, but because of the lack of the front-end SoS SE, a system, during the SoS integration, may not meet the performance requirements or the interface requirements or there may be misalignment of resources to support SoS integration testing, such as, for example, the absence of component system experts to support SoS integration testing.

The lack of alignment is related not only to the front-end SoS SE in the SoS acquisition, but also to the lack of collaboration. Collaboration in the development of a SoS is multi-dimensional—between DoD system program offices, between contractors, and between DoD program offices and contractors. "Inter-organizational collaboration has been cited as a critical requirement for successful outcomes; and for those agencies struggling to achieve their goals, lack of inter-organizational collaboration has been cited as a factor accounting for failure (Kirschman & LaPorte, 2008). Inter-organizational collaboration requires collaborative capacity. Mirroring the definition of collaborative capacity by Hocevar et al. (2007), collaborative capacity in SoS acquisition is defined as the ability of individual system programs to enter into, develop, and sustain inter-system programs in the pursuit of SoS collective outcomes. Such collaborative capacity is needed, in addition to contracting structure and organizational structures (Rendon, Huynh, & Osmundson., 2010; Huynh, Rendon, & Osmundson, 2010), to effect resolution of the SoS acquisition issues raised in (Osmundson et al., 2007). These issues are initial agreement, SoS control, organizing, staffing, team building, and training data requirements, interfaces, risk management at the SoS level, SoS testing, measures of effectiveness, emergent behavior.

The issues addressed in this research are not just the ability of individual system programs to "enter into, develop, and sustain inter-systems programs," but also the approach to and mechanism of inducing or motivating the individual system programs to develop and maintain such an ability. The mechanism is intended to remove barriers against and implement factors favorable to the realization of collaborations among the individual system programs. The approach proposed in this work to bring about collaboration among the individual system programs is to combine this mechanism and the implementation of a front-end SoS SE in the SoS acquisition. As the lack of alignment is tied to both the lack of the front-end SoS SE in the SoS acquisition and the lack of collaboration, the collaboration brought about by this approach in turn aids in improving the alignment of the individual system programs.

As constrained by the scope of this paper, the front-end SoS SE in the SoS acquisition is not discussed here. Its discussion can be found in Huynh et al. (2010). A quantitative analysis of the benefits of having the front-end SoS SE in the SoS acquisition in SoS acquisition is currently conducted as part of a master's thesis (Heng, 2011). This paper is focused only on collaboration among the individual system programs as it is related to the misalignment issue.

Enhancement of program collaborations might include re-organization of program structures, creating new program structures, and use of incentives. These techniques, however, are not necessarily the only means to effect enhancement of program collaborations. In this work, the key idea underlying the approach proposed here is the collaborative behavior observed on some existing web-based systems. That is, we extend what has been done with web-based collaborative systems to a system to facilitate the development of a SoS through collaborative behavior from the individual system programs. The web-based system concept inspires the mechanism proposed in this research for inter-program collaboration. To quantify the performance of the inter-program collaboration, modeling and simulation (M&S) is employed, incorporating factors that directly contribute to and barriers that prevent the enhancement and sustainment of collaboration among inter-system programs.

System-of-systems (SoS) modeling and simulation has recently been applied to the problem of engineering SoSs in order to prevent undesired emergent behavior (Osmundson, 2009a). Example SoSs that have been studied are the collateralized debt obligation market (Osmundson et al., 2009b) and the North American electric power grid (Osmundson et al., 2008). Theoretical studies of these SoSs have also been carried out to validate the results from the modeling and simulation work (Huynh & Osmundson, 2008; Huynh & Osmundson, 2009). The results of these studies indicate that SoS modeling and simulation can be used, at least in some cases, to predict undesired emergent behavior in SoSs that consist of engineered systems and non-engineered systems, including people, and to identify ways to prevent or mitigate undesired behavior.

Essentially, to deal with the lack of alignment and collaboration in SoS acquisition, we recommend that a SoS acquisition program institute an overarching front-end SoS SE in the SoS acquisition program and to implement an approach to achieving collaboration among the individual system programs.

In this paper, a collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs. The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system.

Our goals in this paper are as follows:

- Discuss in some detail some existing web-based collaborative systems;

- Explain our exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a system of systems; and
- Elucidate the approach proposed in this research for achieving collaboration among the individual system programs.

The rest of the paper is organized as follows: We first describe and explain the web-based collaborative systems; then we discuss modeling and simulation of the web-based collaborative systems; next we continue with a discussion of the SoS inter-program collaboration approach; and finally we end with some remarks.

## Web-Based Collaborative Systems

### *The Underlying Idea of Web-Based Collaborative Systems*

Many web-based systems are based on what is known as network effect:

> [A] network effect (also called network externality or demand-side economies of scale) is the effect that one user of a good or service has on the value of that product to other people. When network effect is present, the value of a product or service increases as more people use it. ("Welcome to Wikipedia," n.d.)

When the network effect is present, the value of the system to customers or collaborators is thus dependent on the number of customers or collaborators already using the system.

Network effects become significant after a certain number of people have subscribed to the system, called the critical mass. At the critical mass point, the value obtained from the good or service is greater than or equal to the price paid for the good or service. Cost also incurs in using a web-based. Cost could be payment of money for a service or product, time to prepare inputs for the system, time spent using the system before a match is found, or a loss associated with the risk of using the system such as not receiving goods paid for, receiving incorrect goods, or some other loss. There may also be some cost associated with attracting the participants. At the critical mass point, the value obtained from the system is greater than or equal to the cost encountered when obtaining the good or service provided by the system. As the value of the good is determined by the user base, this implies that after a certain number of people have subscribed to the service or purchased the good, additional people, because of the positive value/cost ratio, will subscribe to the service or purchase the good.

Prior to reaching the critical mass, and depending on the system type, the system must attract early adopters by investment capital, incentives, or other means. In the interim, before the critical mass is achieved, some early adopters may drop out of the system because of lack of perceived value, while others join the system. Thus, the success of a web-based system depends on achieving a critical mass of subscribers before the effectiveness of attracting additional subscribers to the system is exhausted.

The system factors that determine the success or failure of a web-based system include the number of subscribers or participants as a function of time; the factors that attract a subscriber; the factors that cause a subscriber to leave the system; the value of the system's services or to the subscriber/participant; and the cost of the system's services or products to the subscriber/participant. The term 'participant' will be used exclusively hereafter, as the individual system programs are 'participants', although in a strict sense the term 'subscriber' more properly refers to someone who pays for a service while a participant refers to a person who invests time and effort to obtain a product or service, but does not pay money for it. It is assumed that a participant wants to find a match in the system—the match may be with another participant, or with a product or service provided by the system that meets the participant's search criteria. Value to the participant is associated with finding a match.

### *Examples of Collaborative Systems*

The type of web-based system of most interest is a collaborative enterprise whose success depends on the number and quality of the participants, but not on how much revenue the system attracts. Examples of this type of system are those that are established to facilitate a process through collaborative behavior such as eBay, Facebook, and the Zerox Eureka system.

eBay is an online auction and shopping website in which individuals and businesses buy and sell a wide variety of products and services. eBay was founded in 1995 and experienced very rapid growth. By the second year of operations eBay hosted 250,000 on-line auctions, and 2 million on-line auctions the following year ("eBay," n.d.). Facebook is a social networking website that began in February 2004 and had more than 500 million participants by July, 2010 ("Statistics," n.d.). Participants maintain personal profiles, can add people as friends, send messages to friends, notify friends about updates to their profile, and access friends' profiles. The Eureka system, developed by Xerox ("The Eureka Project," 2010), allows customer service engineers to share validated tips on problems encountered and solutions on Xerox's family of copier machines. The system is an example of a net-based community of practice within an organization. Customer service engineers browse the Eureka system to see if there is a known solution to a problem that they are encountering. Five years after its introduction, the Eureka system had been widely adopted by Xerox technicians and has resulted in significant savings in time and parts cost (Bobrow & Whalen, 2002).

## Modeling and Simulation of Collaborative Systems

The SoS modeling and simulation approach discussed in the Introduction section is used in this research to model a system of individual system programs collaborating to form a SoS. This M&S approach has been illustrated with eBay, Facebook, and Eureka (Osmundson & Olgerson, 2011). To be self-contained, this paper briefly discusses the M&S approach and results of these collaborative systems.

This M&S approach considers a collaborative system to consist of people, databases and other elements. People interact with one another directly, through databases and/or other elements to achieve outcomes. The collaborative system models are populated with an initial population of users, database items, and other necessary elements. Users are assumed to want to match with other users or database items, and individual user's desire to join the system and remain a part of the system is assumed to depend on their success in finding matches. Further, the probability of finding a match is assumed to depend on user and database item populations, the type of collaborative system, and the number and standard deviations of the parameters that are required to determine a match. People's choices are heavily influenced by other people's choices. Thus, if a SoS reaches some critical threshold in terms of number of users and/or number of successful interactions—hits—one would expect the SoS to be successful. On the other hand, if users are unsuccessful in obtaining useful matches with the system, the assumption is that they will withdraw from the system, thereby reducing the user population and the number of hits. At some point in time the population should keep growing, reach a stable, useful level, or decline to a point where the system is no longer viable.

The probability of matches may depend not only on match parameters but also on the manner in which the parameters are retrievable by the users. Each model of a specific type of system has one or more probability models appropriate to the type of system. There can also be competitive behavior. For example, users may want recognition for having the most hits on their blog and therefore may compete with other users in creating content.

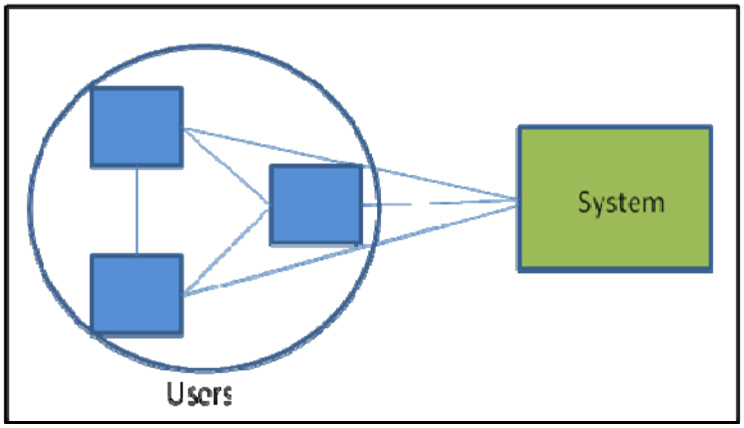


**Figure 1. Abstract Form of Web-Based Systems Model**

Three types of discrete-event models represent eBay, Facebook, and the Xerox Eureka system. Each model assumes a specific type of attraction mechanism, unique to each system, which attracts sufficient users over time, resulting in a successful system whose value exceeds its costs. In Figure 1, the users interact with other users and/or the web-based system. In each case there is a small initial seed population of users. If the users are attracted to one another and/or to the system in sufficient numbers, over time a successful net presence ensues. The key to this type of system is the attractor mechanism, which is the mechanism that provides value to the users while at the same time a cost is imposed on the users. The cost could be a monetary fee and/or—more likely in many cases—the time and effort required to participate in the system and the potential risk in participating in the system. Each of the models of the three types of systems are implemented in Extend,©[1] a discrete-event modeling and simulation tool, and results of each of the three types of models agree closely with real world data.

Cost and value are specific to each example system. As the eBay model represents on-line sellers and buyers of a variety of goods, the value to the seller is low cost of sales and potentially a large number of buyers and the value to the buyer is a wide selection of goods at low prices. These values are functions of the number of users over time; as the number of sellers and buyers increases the value to both parties increases. There are also costs to the seller and buyer. The seller is at risk of not being paid and the buyer is at risk of not getting the goods at all or getting miss-represented goods and/or suffering identify theft. Initially these risks were relatively high, but as improvements to eBay over time, such as introduction of seller ratings and use of Pay Pal, these risks declined. Thus the value-to-

[1] Extend is a product of Imagine That Inc., 6830 Via Del Oro, Suite 230, San Jose, CA, 95119 USA.

cost ratio can be represented by the time-dependent number of eBay users and an S-curve function representing declining risk over time. The rate at which sellers enter the system is dependent on the number of buyers in the system. The buyers' risk factor is given by an S-curve function. A detailed discussion of the simulation results of the Extend eBay model, as well as the Extend Facebook model and the Extend Eureka model, is in Osmundson and Holgerson (2011). In this paper, it suffices to point out the agreement, as shown in Figure 2, between the simulation results and the eBay user growth data.

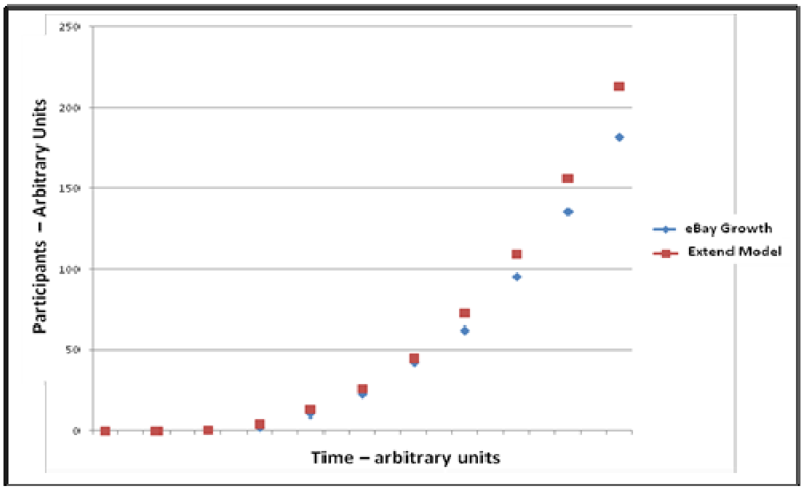


**Figure 2. Results of the Extend eBay Model**
("eBay.com's Site Profile," n.d.)

*Note.* Red markers are model results, and blue markers are eBay actual growth numbers ("eBay.com's Site Profile," n.d.).

The Facebook model represents people who want to form social networks with their friends. The value to each individual is the ability to communicate on a regular basis with a large number of friends by posting text and pictures to their Facebook homepage, which can be viewed by their friends. Value increases with the number of friends added up to a point where the cost of maintaining meaningful connections is outweighed by the incremental value of adding additional friends or becoming a friend on another person's site. There is an initial population of participants and new participants arrive at a rate proportional to the total population. Participants look for a match—that is, a friend, and the probability of finding a friend is proportional to the total population. As shown in Figure 3, the Extend model results fit the actual Facebook population data fairly well through the first 41 months, but beyond that point the model population grows at a rate faster than the actual population. The Extend model is a very simple model and does not include any saturation effects such as might occur if the early adopters of Facebook are more likely to find friends among a given population than are late arrivals, or if the Facebook population begins to approach a limit of all possible networked users.

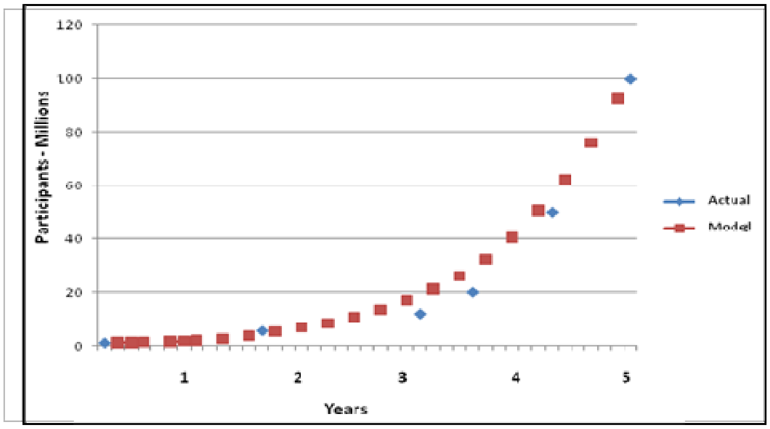


**Figure 3. Results of the Extend Facebook Model**

*Note.* Red markers are model results and blue markers are Facebook actual growth numbers (Statistics, n.d.).

The Eureka model begins with generation of experts who initially are assigned problems randomly; the experts then enter tips for solving each of the problems. This generates an initial set of validated tips. Other technicians are generated next. The experts are randomly assigned new problems, they check the data base for tips and if a tip exists they utilize it and solve the problem quickly. If no tip exists they take a long time to solve the problem and, with some probability, enter either a new tip or not. The probability of entering a new tip is given by an S-curve function that is dependent on the number of times a given person's tips have been utilized. This reflects the fact that technical workers are highly motivated by peer recognition and is consistent with Xerox's experience.

The Eureka model was initially run and the probability with which technicians checked the database was adjusted until a best fit was obtained with real world data. The best fit occurred when the probability of checking the database at a given time was set to 0.4T/P, where T is the number of tips generated up to a given time and P is the total number of problems that are expected to be encountered. Based on available data on Xerox's Eureka system, the initial number of tips was 100–200 ("The Eureka Project," 2010), the total number of technicians during the first 5 years of use was 19,000, the number of technicians participating in the Eureka system after 5 years was 15,000 and the total number of unique vetted tips after 5 years was 36,000. The total number of problems to be solved was not available; for purposes of calibrating the model the total number of problems was assumed to be 50,000. It was also assumed that it took an average of 1 hour to solve a problem with a tip and an average of 8 hours without a tip and that technicians completed approximately one trouble call per day. Jack Whalen (personal communication, October 14, 2010) estimated that non-routine problems occurred more frequently than once per week, but less frequently than once per day.

The most important measure of effectiveness of this type of system is the participation rate. The participation rate drives the number of new tips generated over time and is the main factor in determining the reduction in time to solve problems. Participation rates at the end of one year and at the end of five years, as a function of initial tips and total expected problems, are shown in Figures 4 and 5, respectively. The results clearly show that the ratio of initial tips to number of expected problems to be encountered is critical to success, particularly in achieving a reasonably high rate of technician participation.

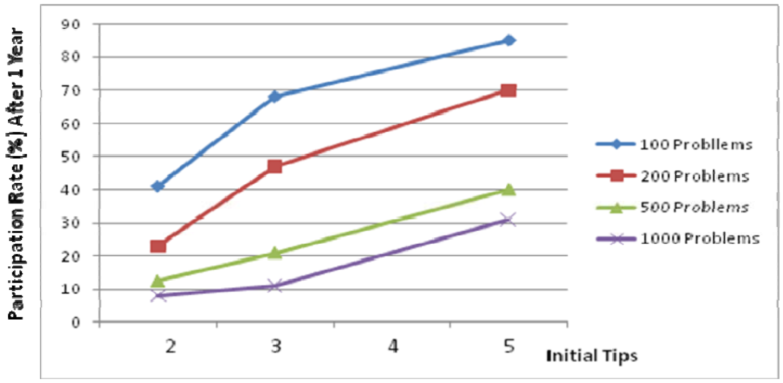


**Figure 4. Participation Rate After One Year as a Function of Initial Tips and Number of Problems to be Encountered**

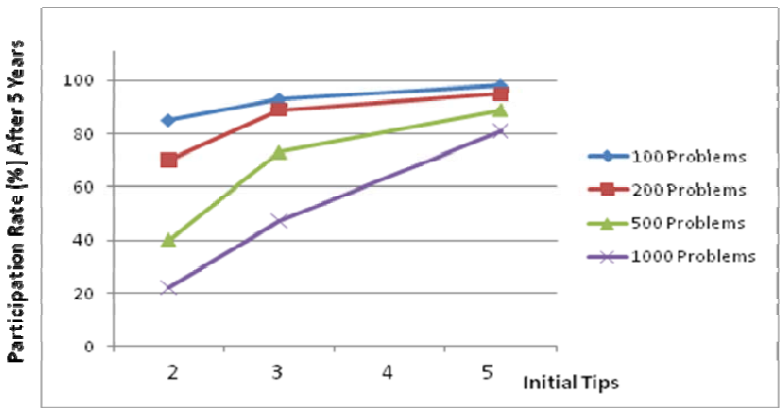


**Figure 5. Participation Rate After Five Years as a Function of Initial Tips and Number of Problems to be Encountered**

## SoS Inter-Program Collaboration Approach

As discussed in the Introduction section, collaboration among the individual system programs participating in a SoS acquisition depends on the presence of mechanisms to induce the willingness on the part of the individual programs to collaborate and to enable their collaboration. Mechanisms can include formalized structures for coordination; formalized processes including meetings, deadlines, etc.; sufficient authority of participants; clarity of roles; and assets such as personnel that are dedicated for collaboration. Lateral mechanisms can include interpersonal networks, effective communication and information exchange, technical interoperability, and training (Hocevar et al., 2006). As discussed in the section on Modeling and Simulation of Collaborative Systems, a web-based service-oriented architecture is an efficient means of providing a mechanism that provides many of the mechanistic requirements for collaboration. However, successful web-based collaboration is highly dependent on the value/cost ratio that applies to a given system.

Like eBay, Facebook, and Eureka, the collaborative system envisioned for SoS acquisition needs to have an attraction mechanism—to attract the individual programs to collaborating with the other programs to achieve the objectives of the SoS acquisition program. Such a mechanism, just like those implemented with eBay, Facebook, and

Eureka, should be highly related cost and value of collaboration, as it provides value to the participating programs while at the same time a cost is imposed on them.

Each individual program invariably is burdened with the production of a system with required performance on schedule and within budget. Consequently, the value and cost derived from collaborating with the other programs are related to these parameters—performance, schedule, and budget. There is also, however, another element that can highly motivate participation in a collaborative system—recognition. Value is in terms of recognition. In the Eureka system, if technicians see that another worker has been recognized for providing a tip for solving repair problems, they too will want similar recognition and will be motivated to enter a new tip. If a technician sees that his own tip has been useful to others, he will be motivated to provide additional tips in order to achieve further peer recognition. Thus, in addition to promoting value and compensating for cost, recognition should be instituted for contributing to the development of the SoS acquisition. But, in what form should recognition be realized—money, promotion, reputation, rewards beyond a program manager's tour on the program? And to whom should recognition be attributed—just to the program managers, or to the entire team?

Some contributors to the cost of collaboration, hence the barriers to collaboration, are observed. The cost of dedicating their resources to developing the parts that are required to satisfy the SoS requirements. The cost to program personnel collaborating in this effort is the additional time spent on executing the SoS part of the system. The cost associated with a potential delay in the development of their own systems, caused by their participation in the SoS development. The individual programs that are not compensated for these costs will more than likely decline to participate or pay lip service to collaborating in the SoS acquisition.

Assessing value for collaborating is more problematic. There is high value to the overall SoS through keeping the individual system programs aligned in order to support SoS testing, but there is not necessarily much value to each individual component program. Program managers are typically rewarded for producing the desired system, on time and within budget, but they are not presently rewarded for aligning their programs with other programs. Value to individual program managers and program offices must be provided in order to achieve effective collaboration.

The system factors that determine the success or failure of this collaborative SoS acquisition system include the number of participating programs which depend on the aforementioned incentives, the factors that attract a collaborator, the factors that cause an individual program to continue to buy in collaboration, the values of the SoS to the participating programs, and the cost or risks to their programs. As in the web-based collaborative systems discussed above, it is assumed that a participant wants to find a "match" in the collaborative system. That match need be understood for the collaborative SoS acquisition system. Value to the participant is associated with finding a match.

One mechanism that holds promise for meeting many of the requirements for inter-program collaboration is a web-based service-oriented architecture system on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs:

> Service Oriented Architecture (SOA) is an architectural paradigm and discipline that may be used to build infrastructures enabling those with needs (consumers) and those with capabilities (providers) to interact via services across disparate

domains of technology and ownership. Services act as the core facilitator of electronic data interchanges yet require additional mechanisms in order to function. Several new trends in the computer industry rely upon SOA as the enabling foundation. (www.adobe.com)

As discussed in the Introduction section, to achieve a successful SoS acquisition, we propose a web-based service-oriented architecture on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs.

The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration, typically a joint review. This approach is consistent with knowledge-based acquisition, since the SoS development proceeds only as the required component information is available. In this work we analyze the development of a SoS from a systems engineering perspective, identifying the points in the SoS development where information, surrogates, software and hardware are needed from the component systems. The web-based SoS acquisition system is envisioned to incorporate the knowledge-based acquisition approach.

An Extend model is built to capture this web-based service-oriented architecture. An attraction mechanism is incorporated in the model. Simulation of this model then provides results to establish the feasibility of such a SoS collaborative system.

## Conclusion

System-of-systems (SoS) acquisition research has identified lack of alignment and lack of collaboration as two important issues leading to problems in SoS acquisition. This paper captures the exploratory work toward improving alignment between and collaboration among the individual system programs in the development of a SoS. Inspired by some existing web-based collaborative systems, such as eBay, Facebook, and Eureka, a collaborative web-based system is proposed, on which personnel of all programs associated with a SoS can input and retrieve information required to align the individual programs.

The overall development of the SoS and component systems is treated as a critical-path network and the need points for component system inputs are identified as intermediate milestones requiring SoS-component system collaboration. An attraction mechanism to effect SoS inter-program collaboration is incorporated in a model capturing this web-based SoS collaborative system. Simulation using this model then provides results to establish the feasibility of such a SoS collaborative system.

This work forms a basis for building a web-based SoS collaborative system to support DoD SoS acquisition programs.

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