3-16-2015

Toward Agent-based Modeling of the U.S. Department of Defense Acquisition System

Karl Schwenn

John M. Colombi
Air Force Institute of Technology

Theresa Wu
Arizona State University

Kyle F. Oyama
Air Force Institute of Technology

Alan W. Johnson
Air Force Institute of Technology

Recommended Citation

Schwenn, K., et al. (2015). Toward Agent-based Modeling of the U.S. Department of Defense Acquisition System. Procedia Computer Science, 44(0), 383–392. https://doi.org/10.1016/j.procs.2015.03.038

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 44 (2015) 383 – 392

Procedia Computer Science

2015 Conference on Systems Engineering Research

Toward Agent-Based Modeling of the U.S. Department of Defense Acquisition System

Karl Schwenn[a]*, John Colombi[a], Teresa Wu[b], Kyle Oyama[a], Alan Johnson[a]

[a]*Air Force Institute of Technology, 2950 Hobson Way, Wright Patterson, AFB, OH 45433*
[b]*Department of Industrial Engineering, Arizona State University, P.O. Box 875906, Tempe, AZ 85287-5906, USA*

Abstract

The systems development, procurement and sustainment of a nation's military equipment is vital to its national interests, but the process is complex, constantly changing and highly adaptive, as well as time consuming and costly. The U.S. Department of Defense (DoD) expends both large amounts of capital and manpower to equip its armed forces. This research seeks to identify opportunities to gain better insight into the functioning of the defense acquisition system, building on previous simulations. A case is made that the DoD Requirements, Planning Acquisition, Technology and Logistics System is a complex adaptive system that has characteristics appropriate for exploration with agent-based modeling. This paper reviews relevant literature, existing models and presents preliminary analysis on an agent-based simulation of the DoD acquisition system. This research finds that agent-based modeling can provide insights to inform new acquisition theory.

Peer-review under responsibility of the Stevens Institute of Technology.

Keywords: Agent-based modeling (ABM),Complex Adaptive Systems, Modeling and Simulation, Defense Acquisitions

1. Introduction

This paper considers simulation of the U.S. system for identifying, funding, developing and fielding military weapon systems. Despite its obvious success in producing superior combat power, the system has been plagued for decades by cost and schedule overruns and, at times, performance shortcomings.[1, 2] Dozens of major reform efforts,

* Corresponding author. Tel.: 1-937-255-3636 x 6186
E-mail address: karl.schwenn@afit.edu

Peer-review under responsibility of the Stevens Institute of Technology.
doi:10.1016/j.procs.2015.03.038

and hundreds of organizational guidelines, policy and process changes, aimed at controlling overruns, have been proposed or implemented over the past six decades. Unfortunately, the changes made only marginal improvements.[1-10] Many experts continue to question why reforms were not more effective and what changes really should be made.[9] A 2011 report by one government panel claimed the existence of over three hundred reports and studies written on acquisition reform since the mid 1980's alone.[11] Despite the large number of government reports and studies, there remains a lack of scholarly research on the theoretical underpinnings of the system.[12, 13] This paper postulates that considering the complexity of the system will lend some new insights to inform military procurement theory. Developments in Systems Theory and Complexity Science may provide a useful set of tools to build a framework for characterizing the system as a whole and the relationship to its parts. This paper introduces a research methodology for examining the U.S. weapon procurement system as a complex adaptive system (CAS) and using agent-based modeling (ABM) to identify significant causal factors that contribute to the performance of the procurement system.

The U.S. weapon procurement system is an interesting subject of study for a number of reasons not least of which is the complexity due to its size and scope. U.S. military Research, Development, Testing and Engineering (RDT&E), Procurement, and Operations and Maintenance (O&M) consumed an average outlay of about $330 billion per year in FY 2015 constant year dollars from 1962 to 2014.[14] Figure 1 is a graph of these outlays during that period. In addition, according to the Office of the Secretary of Defense, as of the first quarter of 2014, the Defense Acquisition System directly employs over 135,000 government civilians and about 16,000 military members.[15] Defense contractors can employ a far greater number of people across the nation.[16]

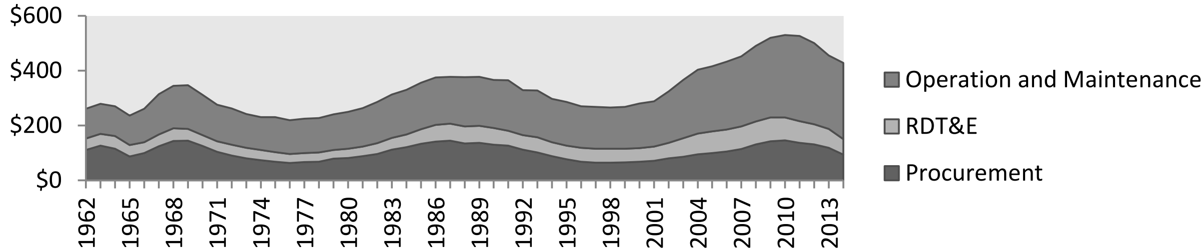

Figure 1. $Billions (FY 2015 Constant) in Defense Department Outlays. Data source is FY15 Green Book Table 6-11 [14]

The U.S. weapon procurement system can be thought of as a "meta-organization"[17, 18] formed by the integration of several autonomous and semi-autonomous organizations. To begin with, the U.S. Department of Defense (DoD) uses three separately led "decision-making support systems" to identify requirements, plan, budget, develop, acquire, test and field weapon systems. The three systems are the Joint Capability Integration and Development System (JCIDS), Planning Programming, Budgeting and Execution (PPBE) system and the Defense Acquisition System (DAS).[19]

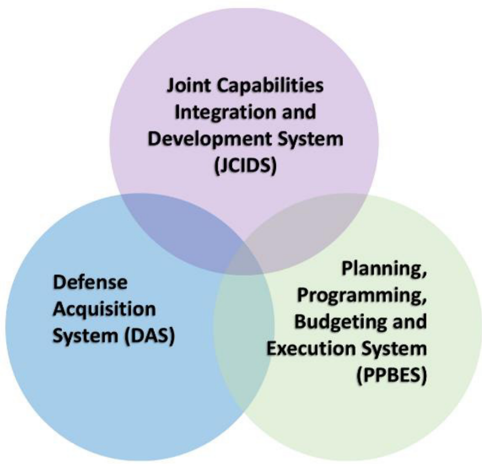

Figure 2. Three decision systems are used to acquire US Defense weapon systems.

Taken together these three systems are known as Big "A" where "A" stands for acquisition.[20] See Figure 2. It is called Big "A" to distinguish the aggregate from one of the component systems, the DAS which is sometimes referred to as little "a". The Big "A" interfaces with two other organizations: the U.S. Congress, and a number of defense contractors to form an even more complex interconnected "meta-organization" which ultimately designs, produces and maintains equipment for U.S. military forces as described in Table 1. For the purpose of this paper, this entire meta-organizational system is referred as the "U.S. military procurement system" or simply "the system". The complexity of the system frustrates predictive analysis and reform efforts.

Table 1: Participating organizations in the U.S. military procurement meta-organization

Participating Organization	Acquisition Function	Leader / Decision Maker
Planning, Programming, Budgeting and Execution System (PPBES)	Plan, program and determine resources	DoD Comptroller
Joint Capabilities and Development System (JCIDS)	Identify capability gaps that translate to weapon system requirements	U.S. Chairman of the Joint Chiefs of Staff
Defense Acquisition System (DAS), known as Little "a"	Develop, acquire, test and field weapon systems	Under Secretary of Defense for Acquisition Technology and Logistics
Congress	Legislative oversight and appropriations	U.S. House and Senate Armed Services Committee Chairmen and members
		U.S. House and Senate Appropriations Subcommittees on Defense, Chairmen and members
Office of the Secretary of Defense	Execute defense policy	Secretary of Defense
Defense Contractors, Integrators, Suppliers	Produce systems, make profit	Business Leaders
Warfighters	Use/ operate systems	Combatant Commanders

Agent-based modeling is particularly well suited for developing and testing theory about the complex behavior of the meta-organization described above. The paper is organized as follows. In the next section, a literature review identifies authoritative references describing the defense acquisition system, its problems, attempts at solutions, applicable complex adaptive systems theory and an overview of some existing simulations. Research questions are posed, potential agents and potential factors affecting the system are proposed as candidates for initial simulation studies.

2. Review of Literature

It should be clear that a better understanding of the behavior and dynamics of the military procurement system is essential for efficient and effective program management and systems engineering efforts for the DoD. Wilson, a political scientist, studied government agencies from "the bottom up", vice top down in his book, *Bureaucracy: What government agencies do and why they do it*.[21] He writes "by looking at bureaucracies from the bottom up, we can assess the extent to which their management systems and administrative arrangements are well or poorly suited to the tasks the agencies actually perform". Wilson traces the failures of some government reorganizations to a lack of understanding by the architects about what the employees actually do. Sources were obtained beginning with recent government reports on ongoing reform efforts, foundational literature on the utility of complexity science and agent-based modeling and finally existing research on simulations of the U.S. weapon procurement system. The search included a review of secondary sources which inform and influence current reform trends. Some prominent sources of information and analysis on the system are produced by the Defense Acquisition University (DAU), Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (OUSD AT&L), Office of Management and Budget (OMB), Naval Postgraduate School (NPS) Acquisition Research Program, the Government Accountability Office (GAO), Congressional Research Service (CRS) and industry groups such as the National Defense Industrial Association (NDIA) as well as academic literature from several domains.

Fox describes the following characteristics of the military procurement system: “price is usually not an overriding factor; product and quantity are determined, not by the management of the firm, but by governmental authority; and competition normally focuses on proposed design rather than the physical product, and on promises of performance rather than the performance itself…the supplier often holds a monopoly and the purchaser holds a monopsony (i.e., one buyer only).”[7] Many authors list similar characteristics to demonstrate difference between the military procurement system and typical commercial markets upon which many economic theories are based.[7, 22, 23] McNaugher noted three separate “dimensions” to the procurement system: technical, military and political that can each possess “divergent needs”.[24] These descriptions highlight the unique nature of the military procurement system and provide some clues about why theories from other fields can fail to anticipate important behaviors of this system. The review suggests that aspects of the military procurement system may yield to some amalgamation of business management theory, organizational science, political science, public administration theory, economic theory, military theory, systems theory, system engineering, architecting, operations research and perhaps theory from other fields. In fact, Shafer and Snider recently proposed that the lack of theory on the behavior of the U.S. military procurement system is due in part to the interdisciplinary nature of the problem.[12]

2.1. U.S. Military Procurement System Issues and Recommendations

There are a few highly visible issues with the military procurement system discussed in the literature. The first is the high average cost and schedule growth from initial estimates along with instances of dramatic cost and schedule growth on specific programs.[1, 2] As of March 2014, GAO reports that the current portfolio of 80 major defense programs has a current estimated total cost of $1.5 trillion which includes a current total cost growth of $448 billion.[25] The GAO also reports an average program delay of 28 months for all active programs. Another reason for heightened interest by policy makers and other interested parties are the prevalence of large program cancellations. In 2011, the Defense Business Board, an advisory body under the Office of the Secretary of Defense reported that from 2001 to 2011, the DoD cancelled programs worth over $50 billion without taking substantial deliveries.[11] The OUSD AT&L released an annual performance report in 2013 which reported that over $1 billion per year in the period between 1996 and 2010 was spent on terminated Army programs alone. A third recurring issue is lower than expected technical performance of some systems. Some criticisms of performance can be subjective.[26] However, empirical data on the performance of weapon systems was provided in the 2013 report on the performance of the DAS. According to the report, 30% of the 181 major defense programs evaluated by the Director of Operational Test and Evaluation (DOT&E) between1984-2011 were not deemed operationally suitable, and 11% were not deemed operationally effective.[1] A fourth important issue are some cases of real and perceived fraud and abuse which can erode public trust. This issue was prominent in the Packard Commission’s 1986 report to the President on reform findings and recommendations.[27] In summary, the top issues with the military procurement system were found to be: 1) program schedule and cost growth, 2) waste (through cancellations) and 3) poor performance and 4) real and perceived abuses.

The solutions to these issues are not straightforward. There is uncertainty reflected in the literature regarding causation and remedies. Table 2 summarizes some common recommendations for procurement system changes/reforms found in the literature. The recommendations are grouped under categories of potential causal factors representing similar controls. Proponents believe these factors to effect some aspect of program cost, schedule and performance. Many of the factors in Table 2 have been proposed repeatedly over several decades and many were attempted during the various reforms since the 1950s. The similarity of the recommendations across time indicate that authors may be basing their recommendations on similar theories. The lackluster results of the reforms mentioned in the introduction call into question the recommendations along with their theoretical basis. In fact, there are some examples of frequently cited causal factors which upon closer inspection cannot be linked to the system performance using empirical methods. One such factor is the lack of program management "tenure" – the time a program manager remains in their role before reassignment.[6, 7, 28] Despite the widespread belief, recent analyses found no significant correlation between program management tenure and programmatic outcomes.[1, 2, 29] Other work suggests that there is a lack of commonly held theory. In 1990 Burgess and Clark conducted 39 interviews of senior officials and found substantial differences of opinion and a lack of agreement on the structure of the system. They also highlight the need for theoretical work in Big “A" acquisition processes and organizations, as recently proposed by Shaffer and Snider.[12]

Table 2. A Summary and Categorization of Recommendations from Literature

Possible Causal Factor	Recommendations from Literature
Incentives [7, 17, 30]	Use incentive fee contracts[9]
	Require PM to serve after major milestones[9]
	Revise perverse incentives like pulling funding based on spending rate, program awards based on cost[9, 31, 32]
	Use independent cost estimates [25, 33]
	Create incentives for Commanders and PMs to drive individual efficiency efforts[31]
	Use competition or competitive forces[34]
Organizational/ Structural	Centralize control of system (Joint and OSD control or integrate services' acquisitions under OSD)[9, 27]
	Decentralize control of system[5]
	Manage programs as "Portfolios"[27, 35]
	"Zero-base" acquisitions (wholesale redesign, transformation/reengineering)[11, 13, 36]
	Establish "clear chain of command" [27, 37]
Workforce Education/ Experience	Prepare program managers and other acquisition personnel with skills and experience[6, 7, 38]
	Professionalize the acquisition career fields[11, 27]
	Cross flow program managers into operations and vice versa[11]
	Program managers should have experience with program management[7, 29]
Rules/Norms/ Policy	Revise "harmonize" and eliminate law, regulation and rules in phases in partnership with stakeholders[9], or quickly remove all or most rules[11, 27]
	Forbid "excessive concurrency" [25]
	Require Services to estimate and consider lifecycle affordability before program start[27, 28]
	Require higher program manager tenure[27, 37]
	Use evolutionary acquisition model as opposed to revolutionary[25, 28, 36, 36]
	Prototype[25, 27]
	Freeze requirements early in the process[11, 25]
	Reduce number of decision reviews[5, 11, 27]

2.2. Complex Adaptive Systems

Holland says Complex Adaptive Systems: "are systems that have large numbers of components, often called agents, that interact and adapt or learn."[39] Gell-Mann uses a similar definition.[40] The individuals and organizations that make up the Contractors, the Program Office, PPBE, JCIDS, Congress, and threats may be considered as interacting agents and meta-agents. If a system is complex, Lewin[41] suggests the following characteristics should be expected:

- sensitivity to initial conditions,
- emergent behaviors,
- composition of components,
- uncertain boundaries,
- nesting,
- state memory,
- non-linear relationships, and feedback loops.

These properties can make predictive analysis difficult or impossible using analytical methods so researchers often turn to simulation.

Authors in many fields are finding varied uses for complexity science. Examples of CAS identified in the literature include healthcare systems[42], and supply chains[43] among others. Military theorists note complexity arising from the demand for increased interagency cooperation by the U.S. military and U.S. and Coalition governments, in response to the wars in Afghanistan and Iraq and the international terrorist threat. Common among the literature on the "interagency" problem is a lack of central control.[44-46] Reed considers the entire U.S. Department of Defense a complex system and found that participants' activities can cause unpredictable outcomes.[47] Complexity is not confined to social systems. Today's system engineers and system architects are engineering and analyzing "Systems of Systems" (SoS) which arise from interconnected, independent component systems. Maier found three types of SoS: Directed, Collaborative and Virtual (listed in the order of increasing independence of their component systems).[48] He warns architects that misclassifying a System of Systems as "directed" vice "collaborative" can lead to systems which depend on unreliable cooperation across boundaries. The problem of anticipating and shaping the behavior of a loosely coupled group of autonomous or semi-autonomous entities has an increasing number of applications across technology, business, government and society in general. In answer to Shaffer and Snider[12], one academic field that accounts for the interdisciplinary nature of the military procurement system is the study of complex adaptive systems.

2.3. Existing Models and Simulations

This section describes three existing dynamic simulations of the entire U.S. military procurement system. The review omits static process modeling such as the Acquisition Process Model[49] or The Integrated Defense Acquisition, Technology and Logistics Life Cycle Management System Chart[50] due to space limitation. The review also omits some existing dynamic simulations that focus only on parts of the system.

Work by Burgess and Clark beginning in the mid 1980's culminating in the early 1990's appears to be the first published attempts at formulating a dynamic simulation of the entire U.S. military procurement system.[17, 51, 52] Their research utilized a model of the Defense Acquisition System created under the System Dynamics paradigm. The simulation purpose was to assess policy changes.[52] Burgess and Clark also introduce the term meta-organizational system which is "several independent organizations working toward a common set of objectives." The participating "organizations may or may not have competing goals as well as their common objectives."[17] Interestingly, complex organizational structures like this appear to be becoming more common over time. Gulati observed similar behavior in business organizations and coined the same term using a very similar definition in 2012.[18] The idea that the defense acquisition system is a meta-organization is a key insight because just as Maier notes with Systems of Systems, this loosely coupled structure seems to impart otherwise unexplainable dynamics. Burgess and Clark classify the Defense Acquisition System as a meta-organizational system with various independent sectors. In their System Dynamics model, the sectors are called: Defense, Industry, Threat and National. Burgess and Clark suggest that study of meta-organizations will require a different theoretical framework than traditional organizations.

A second set of system level simulations and mathematical models of the military procurement system is presented in work by Pennock[36], Pennock, Rouse and Kollar[13] and Bodner, Smith and Rouse.[53] This set of research uses a variety of modeling methods such as stochastic models, game theory, dynamic programming, economic valuation models and discrete event simulation to represent various aspects of the military procurement system. Pennock presents a stochastic model of a weapon program with multiple rational stakeholders who place non-cooperative technology demands on the program.[36] The model's resulting stable technology policy is one that utilizes immature technology. This model helps to explain the prevalence of immature technology observed in programs by GAO and others despite the fact that it is contrary to official DoD policy. Pennock also presents a discrete event simulation of the defense acquisition system which is used to assess evolutionary acquisition policies. The results show that evolutionary acquisition should increase weapon system performance however, it does not reduce cost unless overhead can be significantly reduced. Bodner, Smith and Rouse use a version of this discrete event simulation in a 2009 report to determine the effect of weapon system modularity policies on the performance of the military procurement system.[53] Other research by Pennock, Rouse and Kollar recommends a methodology to assign economic value to different procurement system reform projects based on phased reforms with real options to proceed.[36] Their study found that in some cases relatively small process improvement projects can produce dramatic increases in buying power.

In 2009, Wirthlin developed the Enterprise Requirements and Acquisition Model (ERAM) simulation to identify enterprise leverage points in defense acquisition program performance.[35] Data about the events and products were gathered through analysis of existing policy and guidance, as well as numerous interviews with defense acquisition experts, which provided face validity. The events and products were those required for a typical aerospace defense program throughout the lifecycle, with emphasis placed on activities and events prior to Milestone C. Because the DoD acquisition process entails great complexity and has lots of stochastic processing times, discrete event system simulation is one appropriate analysis methodology for improving the current system. Tasks within JCIDS, DAS, PPBES and the defense contractors are characterized by triangular probability density functions representing task time. Decision logic is characterized by the probability of occurrence for each type of decision. The overall schedule (time in months) for simulated programs are collected and analyzed with various interventions in the process.

2.4. Agent-Based Modeling

Agent-Based Modeling (ABM) is a modeling paradigm that has proven useful in describing complex systems.[54-56] ABM is gaining greater popularity due to availability of large datasets and increased computing power.[54, 57] Bonabeau says "an agent-based model consists of a system of agents and the relationships between them." He uses the term "microscopic modeling" to distinguish ABM from "macroscopic modeling" techniques like differential equation models. Bonabeau enumerates three benefits of ABM over other modeling techniques: "1) ABM captures emergent phenomena; 2) ABM provides a natural description of a system; and 3) ABM is flexible". Carley summarizes organizational design possibilities using agent-based modeling techniques.[58] North and Macal offer extensive practical advice on many aspects of ABM design such as construction, verification and validation.[55] Borshchev and Filippov describe how to translate a discrete event simulation or a system dynamics simulation into an agent-based model.[59] Rahmandad and Sterman explore the effect of network heterogeneity on differential equation models and corresponding agent-based models that employ various agent interaction network configurations.[57] They find that network heterogeneity is more easily accounted for using an agent-based approach and that network configurations can cause significant differences in model output. Macal extends both the Borshchev and Flippov and the Rahmandad and Sterman research by offering a generic transformation from a class of System Dynamics models to equivalent agent-based models.[60] Future research with agent-based modeling may be able to use similar techniques to capitalize on the existing system level simulations of the military procurement system that are based on discrete event and system dynamics paradigms.

3. Preliminary Modeling Considerations

The literature suggests that ABM is an appropriate tool for characterizing the military procurement system. An agent-based simulation will allow us to examine system limitations, estimate baseline performance, assess tradeoffs and hopefully architect better arrangements. Agent-based simulation of the system should provide additional insight not available through analytical, system dynamics or discrete event methods. ABM allows for heterogeneity in the stakeholders in the system. Each class of stakeholder may derive value from separate aspects of a program. In addition, ABM can more easily account for the many situations where programs in development deviate from the standard process. The ABM can also model the network effects arising from interactions between weapons programs or between the various organizations involved. This section presents our initial work on specifying model components.

3.1. Desired Outputs

An ABM architecture will produce outputs useful to make choices between different system configurations. Cost, schedule and performance for products of the acquisition system are the primary performance measures of interest. Depending on the focus of the study, some additional outputs will be reaction time of alternate systems to crisis events, relative technical superiority and measures of efficiency. The model should produce performance metrics for an ideal system along with a representation of the current system and interventions. The performance metrics can be used to establish a baseline to measure performance against and inform us on some system limitations.

3.2. Agent Candidates and Selection

Initial models will use a simplified subset of the multitude of agent types in the real system. The research team utilized available reports on the acquisition system along with simplifying assumptions to choose a number of agents for a preliminary model. Programs are modeled as meta agents which represent the program manager and staff. Other necessary meta agents are decision making entities from other organizations in Table 1 such as congressional members and their staff, JCIDS (Joint Staff) organizations, PPBES (financial management) agents, Defense contractors, user agents along with perhaps threat agents. All of these interacting meta-agents begin to establish an inherent structure, which could be examined; a notional graph is shown in Figure 3. Nodes of various types represent agents. The three decision making support systems from Figure 2 are shown consisting of a variety of heterogeneous nodes. Icons of airplanes, tanks satellites etc representing major defense acquisition programs are shown in the DAS group. Around each of the program icons, are six nodes representing standard leadership positions in each program office. The large yellow geometric shapes (square, circle, triangle) are the three distinct leaders of the three decision making support functions listed in Table 1. Subordinate agents in each decision making support function are shown as smaller agents with corresponding geometric shapes. The five largest prime contractors are represented by the group of large grey circular nodes labeled “Industry”. Blue and Red nodes representing members of congressional committees in two houses of congress are shown in the group labeled “Congress”. Major functions supported by each agent group are represented by icons such as, dollar signs for programming and budgeting, lightbulbs for concept generation and parchment for laws and regulation. Agents in the notional model are linked by way of communication or command channels. The bolded red links represent DoD level coordination between the leads of the three decision making support systems. The nodes and links between subordinate members of the decision making support systems overlap representing the interactions required between the three systems. This figure is intended to highlight the heterogeneity and interconnectedness of actors in the military procurement system and to illustrate the application of an agent approach to modeling it. Publicly available information and data from previous studies provide a framework to populate the notional model. This construct will allow future work in refining models of these meta-agents with additional data as it becomes available.

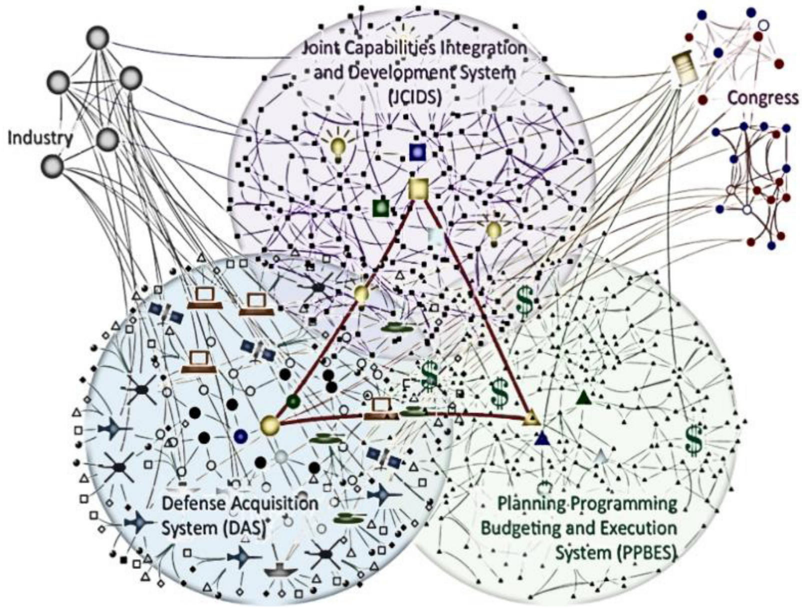

Figure 3. Notional structure of agents interacting across the entire military procurement meta-organizational system

3.3. Early Modeling

The team constructed a number of preliminary agent-based models of aspects of the military procurement system based on the agent types shown in Figure 3. The early efforts have focused on building a model framework using NetLogo[62] which can be modified to allow future designed experiments. The experimental phase will include embellishments designed to assess the influence of factors such as those found Table 2 or other "factors the Department can actually affect (policies, contract terms, incentives, workforce skills, etc.)".[1] The preliminary efforts increased the team's confidence in the utility of the ABM approach for modeling this system. The preliminary agent simulations easily run on desktop computers. These models utilize hundreds of meta-agents with simple if-then behavior rules. Models of a much larger scale are possible. Examples of models with millions of agents can be found in the literature. Several challenges of the agent approach are: lack of existing valid models of agent behavior as well as difficulty in data collection and parameterization of the model. Construction of a valid and useful agent-based model of this system will be iterative and phased.

4. Concluding Remarks

The literature review revealed a lack of dramatic performance improvements in the system after years of reforms. One reason might be misunderstandings and false assumptions about how the system behaves. Additionally, there is no practical way to test alternative structures and policies on the system to gain insight into effectiveness before implementation. Modeling and simulation shows promise in cases like this where experimenting is impractical or expensive. Several researchers have modeled various aspects or the whole of the military procurement system. Yet none so far have explicitly recognized it to be a complex adaptive system and taken an agent approach. Previous system level simulations are based on system dynamics[17], discrete event[13, 35] and business process modeling[49] paradigms. There are also a small number of mathematical descriptions of some of the dynamics.[36] Agent-based modeling is a useful tool in the study of complex adaptive systems and taking and agent perspective should provide new insights into the complex interactions between component programs, organizations and other agents in the military procurement system. Dynamic simulation studies can help formulate theory and demonstrate likely outcomes of several proposed strategies. The paper sought to excite researchers to provide further system characterization and to continue to build an academic body of knowledge on the functioning of this system through simulation.

Acknowledgements

This publication was developed under work supported by the Naval Postgraduate School Acquisition Research Program Assistance for "Enterprise Requirements and Acquisition Model (ERAM) II" an NPS-BAA-13-003 award by the Naval Supply Systems Command (NAVSUP) Fleet Logistics Center San Diego (NAVSUP FLC San Diego).

References

1. Undersecretary of Defense Acquisition, Technology and Logistics. Performance of the Defense Acquisition System. Report no. 2013.
2. Undersecretary of Defense Acquisition, Technology and Logistics. Performance of the Defense Acquisition System. Report no. 2014.
3. Arena MV, Blickstein I, Younossi O, et al. Why Has The Cost of Navy Ships Risen?. Report no. RAND-MG-484-Navy, 2006.
4. Arena MV, Younossi O, Brancato K, et al. Why has the cost of fixed-wing aircraft risen? A macroscopic examination of the trends in us military aircraft costs over the past several decades. Report no. RAND-2008026145, 2008.
5. Dillard JT. Centralized control of defense acquisition programs: a comparative review of the framework from 1987-2003. Report no. NPS-AM-03-003.
6. Fox JR. Arming America. Harvard University 1974.
7. Fox JR, Allen DG, Lassman TC, et al. *Defense Acquisition Reform, 1960–2009 An Elusive Goal*. Washington, D.C.: Washington, D.C., 2011.
8. Schwartz M. Defense acquisitions: How DoD acquires weapon systems and recent efforts to reform the process. Report no. RL34026.
9. U.S. Senate Committee on Armed Services. Department of Defense Authorization of Appropriations for Fiscal Year 2015 and the Future Years Defense Program Reform of the Defense Acquisition System Transcript 2014.
10. Christensen DS, Stearle DA and Vickery C. The impact of the Packard Commission's recommendations on reducing cost overruns on defense acquisition contracts. Acquisition Review Quarterly 1999.
11. Defense Business Board. Linking and Streamlining the Defense Requirements, Acquisition and Budget Processes. Report no. FY12-02.
12. Shaffer KL and Snider KF. Seven Years of U.S. Defense Acquisition Research: Analysis of Proposals and Projects. J Pub Proc 2014.

13. Pennock MJ, Rouse WB and Kollar DL. Transforming the acquisition enterprise: A framework for analysis and a case study of ship acquisition. Systems Engineering 2007.
14. Under Secretary of Defense (Comptroller). National Defense Budget Estimates for FY 2015. Report no. 6-D34CF28, 24 Mar 2014.
15. OUSD AT&L. Defense Acquisition Portal HCI Archived Data & Information Summaries, https://dap.dau.mil/workforce/Pages/HCIDataReports.aspx (2014, accessed 09/15 2014).
16. GAO. Defense Sector Trends in Employment and Spending. Report no. GAO/NSIAD-95-105BR.
17. Burgess GM and Clark TD. The defense acquisition system: A meta-organizational analysis. Systems Research 1990.
18. Gulati R, Puranam P and Tushman M. Meta-organization design: Rethinking design in interorganizational and community contexts. Strategic Manage J 2012.
19. Defense Acquisition University. *Defense Acquisition Guidebook*. https://dag.dau.mil/: https://dag.dau.mil/, 2013.
20. Schwartz M. Defense acquisitions: How DoD acquires weapon systems and recent efforts to reform the process. Report no. Congressional Research Service-RL34026, 23 May 2014.
21. Wilson JQ. *Bureaucracy: What government agencies do and why they do it*. United States of America: United States of America, 2000, p.464.
22. Cleland DI and King WR. The Defense Market System. Defense Industry Bulletin 1968; January: 7.
23. Peck MJ and Scherer FM. THE WEAPONS ACQUISITION PROCESS; AN ECONOMIC ANALYSIS. 1962.
24. McNaugher TL. *New weapons, old politics: America's military procurement muddle*, 1989.
25. GAO. Defense Acquisitions Assessment of Selected Weapon Programs. Report no. GAO-14-340SP, March 2014.
26. Cancian M. Acquisition reform: It's not as easy as it seems. Acquisition Review Quarterly 1995.
27. Packard Commission. A quest for excellence: Final report to the President. Washington, DC 1986.
28. Sullivan MJ. Testimony before the Committee on Armed Services, U.S. Senate Defense Acquisitions Addressing Incentives is Key to Further Reform. U S Government Accountability Office 2014.
29. Snider KF. An Analysis of the Relationship Between the Professionalism of Defense Acquisition Program Managers and Program Outcomes. Report no. NPS-AM-11-200.
30. Scherer FM. *The weapons acquisition process: economic incentives*. Boston: Boston, 1964, p.447.
31. Hale RF. *Promoting Efficiency in the Department of Defense: Keep Trying, but Be Realistic*, 2002.
32. Schwartz M. Reform of the Defense Acquisition System, Statement of Moshe Schwartz, Specialist in Defense Acquisition Before the United States Senate Committee on Armed Services. Report no. Congressional Research Service 7-5700, April 30, 2014.
33. Berteau DJ. Testimony before the Committee on Armed Services, United States Senate Acquisition Improvements for 2015 and Beyond Written Statement. Center for Strategic and International Studies 2014.
34. Kendall F. Testimony Before the Senate Committee on Armed Services. Witness Statement 2014.
35. Wirthlin JR. *Identifying enterprise leverage points in defense acquisition program performance*. PhD, MIT, 2009.
36. Pennock MJ. *The economics of enterprise transformation: an analysis of the defense acquisition system*. PhD, Georgia Tech, 2008.
37. Kendall F. Memorandum for Secretaries of the Military Departments Component Acquisition Executives Directors of the Defense Agencies, Subject: Key Leadership Positions and Qualification Criteria 2013.
38. Etherton J. Reform of the Defense Acquisition System Testimony before the Committee on Armed Services, United States Senate Jonathan Etherton National Defense Industrial Association Fellow. National Defense Industrial Association 2014.
39. Holland JH. Studying complex adaptive systems. Journal of Systems Science and Complexity 2006.
40. Gell-Mann M. Complex adaptive systems. Complexity: Metaphors, models and reality 1994.
41. Lewin R. Complexity. University of Chicago Press Economics Books 2000.
42. Rouse WB. Health care as a complex adaptive system: implications for design and management. Bridge-Nat Acad Eng 2008.
43. Choi TY, Dooley KJ and Rungtusanatham M. Supply networks and complex adaptive systems: control versus emergence. J Oper Manage 2001. DOI: http://dx.doi.org/10.1016/S0272-6963(00)00068-1.
44. Cronin PM. Global strategic assessment 2009: America's security role in a changing world 2009.
45. Marcella G. Affairs of state: the interagency and national security. Report no. Strat Stud Inst-ISBN 1-58487-369-8, December 2008.
46. Dale C, Serafino N and Towell P. Organizing the US Government for National Security: Overview of the Interagency Reform Debates.
47. Reed GE. Leadership and systems thinking. Defense AT&L 2006.
48. Maier MW. Architecting principles for systems-of-systems. Systems Engineering 1998.
49. DSD Tech on Behalf of SAF/AQX. USAF Acquisition Process Model, http://afacpo.com/acpo/index.html (2014, accessed 09/30 2014).
50. DAU. The Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System Chart Version 5.4 2010.
51. Clark TJ, Whittenberg EL and Woodruff AH. A policy analysis of defense weapons acquisition. Policy Studies Journal 1985.
52. Burgess GM. *A Management Analysis and Systems Model of Department of Defense Acquisition Structure and Policy*. PhD, FSU, 1988.
53. Bodner D, Smith R and Rouse B. Simulation-based decision support for acquisition policy and process design: The effect of system and enterprise characteristics on acquisition outcomes. Report no. NPS-AM-09-034, 22 April 2009.
54. Bonabeau E. Agent-based modeling: methods and techniques for simulating human systems. Proc Natl Acad Sci U S A 2002.
55. North MJ and Macal CM. *Managing business complexity: discovering strategic solutions with agent-based modeling and simulation*, 2007.
56. North MJ, Collier NT, Ozik J, et al. Complex adaptive systems modeling with repast simphony. CAS Modeling 2013.
57. Rahmandad H and Sterman J. Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models. Management Science 2008.
58. Carley KM. Computational organizational science and organizational engineering. Simulation Modelling Practice and Theory 2002.
59. Borshchev A and Filippov A. From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. In: *Proceedings of the 22nd international conference of the system dynamics society* (eds Kennedy M, Winch GW, Langer RS, et al), Oxford, England, July 25 - 29, 2004: Wiley.
60. Macal CM. To agent-based simulation from system dynamics. In: *Proceedings of the 2010 Winter Simulation Conference* (ed B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan), 2010, pp.371-382: IEEE.
61. Wilensky U. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL. 1999; 5.1.0.