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Facilitating Decision Choices with Cascading Consequences in Interdependent Networks

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Facilitating Decision Choices With Cascading Consequences in Interdependent Networks

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Preface & Acknowledgements

Welcome to our Ninth Annual Acquisition Research Symposium! This event is the highlight of the year for the Acquisition Research Program (ARP) here at the Naval Postgraduate School (NPS) because it showcases the findings of recently completed research projects—and that research activity has been prolific! Since the ARP's founding in 2003, over 800 original research reports have been added to the acquisition body of knowledge. We continue to add to that library, located online at www.acquisitionresearch.net, at a rate of roughly 140 reports per year. This activity has engaged researchers at over 60 universities and other institutions, greatly enhancing the diversity of thought brought to bear on the business activities of the DoD.

We generate this level of activity in three ways. First, we solicit research topics from academia and other institutions through an annual Broad Agency Announcement, sponsored by the USD(AT&L). Second, we issue an annual internal call for proposals to seek NPS faculty research supporting the interests of our program sponsors. Finally, we serve as a "broker" to market specific research topics identified by our sponsors to NPS graduate students. This three-pronged approach provides for a rich and broad diversity of scholarly rigor mixed with a good blend of practitioner experience in the field of acquisition. We are grateful to those of you who have contributed to our research program in the past and hope this symposium will spark even more participation.

We encourage you to be active participants at the symposium. Indeed, active participation has been the hallmark of previous symposia. We purposely limit attendance to 350 people to encourage just that. In addition, this forum is unique in its effort to bring scholars and practitioners together around acquisition research that is both relevant in application and rigorous in method. Seldom will you get the opportunity to interact with so many top DoD acquisition officials and acquisition researchers. We encourage dialogue both in the formal panel sessions and in the many opportunities we make available at meals, breaks, and the day-ending socials. Many of our researchers use these occasions to establish new teaming arrangements for future research work. In the words of one senior government official, "I would not miss this symposium for the world as it is the best forum I've found for catching up on acquisition issues and learning from the great presenters."

We expect affordability to be a major focus at this year's event. It is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come. Whether you're a practitioner or scholar, we invite you to participate in that research.

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

- Office of the Under Secretary of Defense (Acquisition, Technology, & Logistics)
- Director, Acquisition Career Management, ASN (RD&A)
- Program Executive Officer, SHIPS
- Commander, Naval Sea Systems Command
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- Office of the Assistant Secretary of the Air Force (Acquisition)

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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 7. Predicting Performance and Interdependencies in Complex Systems Development

Wednesday, May 16, 2012	
1:45 p.m. – 3:15 p.m.	**Chair: Mark Kryzsko,** Deputy Director, Enterprise Information and Office of the Secretary of Defense Studies, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics ***Facilitating Decision Choices With Cascading Consequences in Interdependent Networks*** Anita Raja, Mohammad Rashedul Hasan, and Mary Maureen Brown *University of North Carolina at Charlotte* ***Applications of Lexical Link Analysis Web Service for Large-Scale Automation, Validation, Discovery, Visualization, and Real-Time Program-Awareness*** Ying Zhao, Shelley Gallup, Douglas MacKinnon *Naval Postgraduate School* ***Acquisition Management for System-of-Systems: Requirement Evolution and Acquisition Strategy Planning*** Seung Yeob Han, Zhemei Fang, and Daniel DeLaurentis *Purdue University*

Mark Kryzsko—Mr. Krzysko serves as the deputy director of the Enterprise Information and Office of the Secretary of Defense Studies. In this senior leadership position, he oversees Federally Funded Research and Development Centers and directs data governance, technical transformation, and shared services efforts to make timely, authoritative acquisition information available to support oversight of the Department of Defense's major programs—a portfolio totaling more than $1.6 trillion of investment funds over the life cycle of the programs.

Preceding his current position, Mr. Krzysko served as ADUSD for business transformation, providing strategic guidance for re-engineering the Department's business system investment decision-making processes. He also served as ADUSD for strategic sourcing & acquisition processes and as director of the Supply Chain Systems Transformation Directorate, championing and facilitating innovative uses of information technologies to improve and streamline the supply chain process for the Department of Defense. As the focal point for supply chain systems, he was responsible for transformation, implementation, and oversight of enterprise capabilities for the acquisition, logistics, and procurement communities. In addition, Mr. Krzysko served as advisor to the deputy under secretary of defense for business transformation on supply chain matters and as the functional process proponent to the Department's business transformation efforts, resulting in the establishment of the Business Transformation Agency.

In March 2002, Mr. Krzysko joined the Defense Procurement and Acquisition Policy office as deputy director of e-business. As the focal point for the acquisition domain, he was responsible for oversight and transformation of the acquisition community into a strategic business enterprise. This included driving the adoption of e-business practices across the Department, leading the move to modernize processes and systems, and managing the investment review process and portfolio of business systems. Mr. Krzysko served as the division director of Electronic Commerce Solutions for the Naval Air Systems Command from June 2000 to March 2002. From April 1991 until March 2000, Mr. Krzysko served in various senior-level acquisition positions at the Naval Air Systems Command, including contracting officer of F/A-18 foreign military sales, F/A-18 developmental programs, and the F-14. In addition, he served as program manager of Partnering, the Acquisition Business Process Re-engineering Effort, and as acquisition program manager for the Program Executive Office for Tactical Aircraft.

Mr. Krzysko began his career in the private sector in various executive and managerial positions, including assistant managing director for Lord & Taylor Department Stores and operations administrator for Woodward & Lothrop Department Stores. Mr. Krzysko holds a Bachelor of Science degree in finance from the University of Maryland University College, College Park, MD, and a Master of General Administration degree in financial management from the same institution.

Facilitating Decision Choices With Cascading Consequences in Interdependent Networks

Anita Raja—Raja is an associate professor of software and information systems at The University of North Carolina at Charlotte, and a visiting scientist at the Center for Computational Learning Systems at Columbia University (2011–2012). She received her PhD in computer science from the University of Massachusetts at Amherst in 1998 and 2003, respectively. Professor Raja's research focus is in the field of artificial intelligence, specifically as it relates to the study of decentralized control and reasoning in software agent systems operating in the context of uncertainty and limited computational resources. [anraja@uncc.edu]

Mohammad Rashedul Hasan—Hasan is a PhD candidate at the College of Computing and Informatics at the University of North Carolina at Charlotte. Previously, he taught in the Department of Electrical Engineering and Computer Science at North South University in Bangladesh. [mhasan8@uncc.edu]

Mary Maureen Brown—Brown is a professor of public administration at The University of North Carolina at Charlotte, a senior fellow at the Center for Excellence in Municipal Management at George Washington University; and a visiting scientist at Software Engineering Institute at Carnegie Mellon University (2007–2008). Dr. Brown has extensive experience in cross-organizational information systems integration in government and in researching the development and design of a program methodology for the acquisition of joint information systems. Her research interests center on participatory design, knowledge management, and joint problem solving and program planning. Dr. Brown received her PhD from the University of Georgia. [marbrown@uncc.edu]

Abstract

Our research goal is to proactively model the non-linear cascading effects of interdependencies in highly dependent networks. Specifically, we examine Department of Defense (DoD) acquisition from the context of the joint space of Major Defense Acquisition Programs (MDAPs), the space where MDAPs exchange and share resources for the purpose of establishing joint capabilities. Our hypothesis is that examining the interdependent regions among MDAPs from multiple perspectives using non-linear methods will allow for "what-if" analyses and will help decision-makers gain insight into the cascading effects of perturbations and take appropriate measures to handle them. Additionally, we also ascertain whether a popular decision theoretic model for decision-making and planning for cascading effects in the face of uncertainty is appropriate to study the cascading effects among MDAPs. Our approach is to use a case study to determine whether the data required to build an effective decision-theoretic model is available. We also capture the data investigation process and identify the challenges that were encountered. Our results show that it is possible to recast the study of cascading effects in MDAPs as a sequential decision problem. We also have captured the informational value in the existing data and the challenges inherent in the data collection process.

Introduction

In this research, we seek to understand and model the behavior of non-linear cascading effects in the joint space of Major Defense Acquisition Programs (MDAPs) where their transactions form interdependencies. The flows in and out of an MDAP can be examined to conduct scenario planning or "what-if" analyses. These "what-if" analyses will help decision-makers gain insight into the cascading effects of perturbations and take appropriate measures to handle them. We have developed models that can address "what-if" scenarios: What if my partner reneges on a funding obligation? What if Congress alters my funding? How will the perturbation affect my partners? We also identify and enumerate the characteristics in the existing MDAP data that are critical to building a complete model of MDAP behavior and discuss the challenges in acquiring some of this data so that appropriate governance mechanisms can then be isolated. We emphasize this data acquisition process as much as the behavioral findings with the hope that the lessons learned from the process would allow for more accurate and complete data gathering and modeling in future iterations of this work.

The MDAP data that we analyzed included selected acquisition reports (SARs), defense acquisition executive summaries (DAESs) and program element (PE) documents over multiple years. Although our aim was to work on the entire collection of MDAPs, we observed that this eclectic conglomeration of information is highly unstructured, significantly inordinate, and unmanageably colossal for manual analyses. Hence, we focused on a case study that contains a small set of existing MDAPs. We used fictitious names (e.g., MDAP_A, MDAP_B, etc.) to retain confidentiality of individual program information. In this case study, we did an in-depth analysis of the data and studied their complex interrelationships from multi-perspectives with the hope that some of our observations and lessons learned about MDAPs and the analysis process can then be scaled to the entire network.

Background

The decade-old joint capabilities paradigm at the Department of Defense (DoD) aims to achieve interagency cooperation. Vice Chairman of the Joint Chiefs of Staff Admiral Giambastiani (2004) claimed that the integrated force had to become interdependent by being capabilities-based, collaborative, and network centric. This collaborative approach necessitates integration of three distinct processes, such as the congressional budgeting justification process, the acquisition process, and the system requirements. It is observed, however, that the acquisition process has been largely tailored to suit the needs of the distinct discrete programs without addressing the interdependency issues. To be specific, although many MDAPs are entitled to joint status according to their SARs, DAES reports and milestone reviews tend to evaluate the program performance from an individual program point of view, irrespective of the joint space. There is reason to believe that the exogenous issues generated from the shared domains remain unnoticed to the extent of causing the program to potentially experience severe performance degradation (Brown, 2011).

Although it is critically important to understand the program interfaces and interdependencies, there are few tested and proven tools for program managers and acquisition executives to probe the joint space or to track the cascading effects that the joint space might trigger. We harnessed a network-centric approach to study DoD acquisition and focused on an MDAP network of interrelated programs that exchange and share resources for the purpose of establishing joint capabilities.

We studied whether performance breaches correlate with interdependency characteristics in the context of the JTRS network. We also studied how the various models can be used to determine what elements of the models play a key role in affecting the performance outcomes of each program as well as its subsequent interdependent partners. This enabled us to find, for example, the critical nodes and interdependencies in the system. As a consequence of this work, in future studies we can create a hypothetical breach at a node, or resource cutoff in some in-flow, and discover its likely effects. We can extend that to conjunctures of breaches or breaks in the flows. Similarly, we can determine the most robust and weakest programs in the system (i.e., those most and least likely to have breaches or fail). We can also use the model to examine the changes to the system that might increase its robustness.

The complexity of the joint environment is likely to have consequences related to acquisition activities. The precise effect on acquisition, and its resulting managerial implications, are, as of yet, unknown. The significance of the research is three-fold:

- It aims to forge new ground in identifying the effects of interdependency on acquisition and, if needed, uncovering early indicators of interdependency risk so that appropriate governance oversight methods can then be isolated.
- It provides insight into the nature of the available data and whether it can support the use of non-linear methods to detect and prevent cascading consequences.
- It leverages a decision-theoretic model that captures uncertainty in action outcomes and information of neighboring nodes to describe the sequential decision making process inherent to MDAPs.

We believe that given the frequency with which government agencies are moving toward joint initiatives, the findings of this research project based on DoD programs may prove instrumental to a wide-range audience.

Research Methodology

To perform this study, we designed a methodology that includes four goals. We first selected a small subset of inter-related MDAPs based on a set of criteria to form our case study. We defined Goals 1 and 2 to determine whether the MDAP data in the form of the SARs, DAES, and PEs is sufficient to identify the effects of interdependency on acquisition and uncover any early indicators of an interdependency risk. These goals also determine whether a decision-theoretic model in Goal 3 is a feasible next step. Having verified that this is the case, we then formulated a decision-theoretic model. Finally, we captured the essence of the data acquisition process for our study and the lessons learned.

Goal 1: Identify highly dependent parts of the MDAP network.

- What are the essential features of the network that reveal the joint space dynamics?
- What are the relative priorities associated with these features, and how do they affect the network relationship?

Goal 2: Analyze and understand the data available from MDAP performance reports to extract features of network dynamics.

- What are the local issues that lead toward a breach or near-breach situation?
- How often and why do the local mitigation efforts fail to improve the performance?
- How do we identify the non-local issues that result from the interdependencies?
- How do we determine the cascading effect through the network?

We planned to approach Goal 2 from two perspectives: (1) *local perspective*, where the analyses are based solely on the individual program's own data; and (2) *non-local perspective*, where the analyses are based on the data of MDAPs existing in the joint space of the individual program. Lessons learned from these analyses should enable the stakeholders to take appropriate measures to improve the performance of the programs.

Goal 3: Formulate a decision-theoretic model that harnesses Decentralized Markov Decision Process (DEC-MDP) formalism.

- What are the essential characteristics of the MDAP network that justify a DEC-MDP model?
- How do we model the MDAP network as a decentralized system?

- What are the key challenges in the design of the DEC-MDP?
- What essential features should the DEC-MDP model incorporate for better predictability?

The DEC-MDP is a sub-class of decentralized partially observable MDP (DEC-POMDP; Bernstein, Givan, Immerman, & Zilberstein, 2002), which we propose to model the behavior of the MDAP network. A state is a snapshot in time of the MDAP's status that consists of crucial local and non-local information. A policy is a mapping from a state to an action. This formalism would allow the MDAP to execute the appropriate local policy to achieve higher performance. Our aim is to define a computationally tractable model.

Goal 4: Understand the characteristics of the existing data resources.

- What are the challenges to pre-process the existing data?
- What key information do we gain from the existing data?
- What are the key limitations in the existing data?
- What are the data requirements to design a complete DEC-MDP model?
- How do we integrate the various program-related documents in a coherent and meaningful fashion to aid the decision-makers as well as the researchers in building complete models?

Goal 4 recommends what should be done to capture information so that the decision-making process becomes efficient and complete.

Findings

Our findings indicate that MDAP-related data characteristics support the multiple perspective study of perturbations and it is possible to recast the study of cascading effects as a sequential decision problem. We also note that it is crucial to consider the uncertainty in action outcomes in the decision-making process and that a non-local perspective may help explain a performance breach in situations where a solely local perspective does not. These observations provide evidence supporting our conjecture that MDPs are a good avenue to study interdependencies in the MDAP network and to capture early indicators of interdependency risk. Finally, we have captured the informational value in the existing data and challenges inherent in the data collection process with respect to their role in isolating risks and initiating appropriate government oversight methods.

The rest of the paper is structured as follows: in the Network Model section we identify the network dependencies among the MDAPs and define a sample network for analyses (Goal 1); in the Case Study of MDAP_A Funding Network section we investigate the local and non-local causes for degradation in performance of the nodes in the sample network (Goal 2); in A Decision-Theoretic Model for MDAP Network section we present the DEC-MDP model formulation (Goal 3) followed by observations made about the characteristics of the available data in the Understanding the Characteristics of the Existing Data section (Goal 4); finally, the Conclusions and Future Work section concludes with the lessons that we learn through this process.

Network Model

In this section, we first enumerate various MDAP performance reports (see below) and discuss their significance in light of networking dependencies among the MDAPs. We also define a sample funding network from our chosen MDAPs in an effort to investigate its performance. Specifically, we define a process to choose an MDAP program to be the focus of our investigation and identify its immediate network based on the interrelationships it maintains with neighboring MDAPs. We use the lessons learned from the analyses of this sample network to build an accurate decision-theoretic model.

Available Data Resources on MDAP Performance

The information pertaining to acquisition research is overwhelming and multifarious. It appears to be a daunting task for the acquisition researchers, let alone the program managers, to integrate and understand the vast and dynamic data in a coherent way. To define the interrelationship among the MDAPs from a network-centric viewpoint, and to identify different network dependencies within the domain of MDAPs, the following set of data resources are useful:

- monthly DAES reports that provide an early-warning report on the status of some program features such as cost, schedule, performance, funding, and so forth;
- SARs that summarize the latest estimates of cost, schedule, and technical status to be reported annually in conjunction with the president’s budget; and
- PE documents that are used to justify congressional budgeting process.

Types of Interdependent Networks Within the MDAPs Domain

In addition to these, the program managers also report on four external interdependencies: (1) data interdependencies with other DoD programs; (2) funding received from other DoD programs; (3) contractor interdependencies; and (4) budgeting/spending authority interdependencies. This information is useful in identifying four types of interdependency networks among the MDAPs. As an example, Figure 1 provides a glimpse of the data interdependencies of the 78 MDAPs in 2010. In terms of the data interdependencies, the 78 MDAPs exhibit a total of 989 data interdependencies. (Note that MDAP programs will have interdependencies with non-MDAP programs. For example, the Joint Strike Fighter program identifies data and funding interdependencies with the Italian, German, and French defense departments.) In the current dataset, 17% of the interdependencies are outbound, 37% are inbound, and 45% are bidirectional. Additionally, per managerial reports, multiple perspectives may be critical to the decision-making process. In most cases, the boundaries are drawn and the regions thus identified, based on the entire set of assets that are transferred or exchanged to provide a given capability. As such, the flows in and out of a node can be examined to conduct scenario planning or “what-if” analyses.

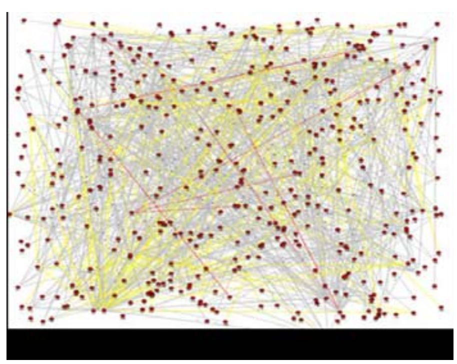

Figure 1. MDAP Data Interdependencies in 2010

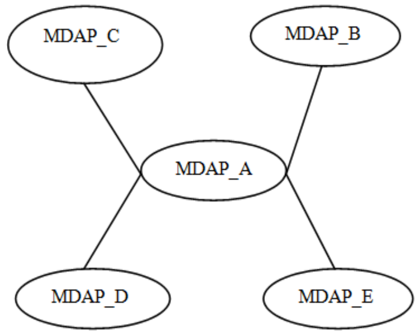

Figure 2. Funding Network of MDAP_A

MDAP_A Funding Network

As we discussed in the Introduction, we chose to do a case study because of the the characteristics of the data. MDAP_A, a communications program initiated in 2004, whose program name has been scrubbed for confidentiality purposes, is the central MDAP for our study. This program is our focus because (a) the data available about this program is significant; and (b) between the years 2006 and 2010, it experienced multiple APB breaches and increase in %PAUC, making it a critical node for reference. Using information about the funding partners of MDAP_A, we defined a logical funding network shown in Figure 2.The other nodes in the graph are neighbor programs of MDAP_A that share common funding agencies. The funding network allows us to do a detailed study of the performance of the member nodes and to understand the cascading effects described in the Case Study of MDAP_A Funding Network section. In the future, we plan to apply the lessons learned from this focused study to the entire MDAP network.

Case Study of MDAP_A Funding Network

In this section, we analyze the data that we gathered from the available performance reports of all the MDAPs in the MDAP_A funding network, from the local and non-local perspectives as defined in the Introduction.

Consider the funding network for MDAP_A in Figure 2. MDAP_A lies at the center of this undirected network that contains five nodes. The link between any two nodes refers to the funding relationship and serves as interface among the programs. These links illustrate the interdependent regions of the case study network. We analyze the performance of the programs based on the APB breaches and amount in increase in %PAUC. Five types of APB breaches are reported in the performance reports, which are schedule; performance; research, development, test, and evaluation (RDT&E); procurement; and PAUC. A program is considered to perform poorly if it experiences frequent APB breaches and/or increase in %PAUC.

Suppose that the central program MDAP_A has been under-performing for a period of time, and also assume that any two neighboring programs have been under-performing as well in subsequent periods. We want to understand their performance degradation by investigating the following questions:

- Q1: What are the local reasons for a program (e.g., MDAP_A) to underperform?
- Q2: How often and why do the forecasting of mitigation efforts, as captured in monthly DAES reports, turn out to be ineffective?
- Q3. What are the non-local reasons for poor performance?

- Q4: How does the effect of one underperforming program propagate through the link towards a neighbor program and affect it?
- Q5: Why is a program that is performing as expected not affected by this perturbation?
- Q6: How does this network-centric approach facilitate the understanding of the underlying problems leading to cascade in breaches and help the stakeholders take appropriate measures?

To address the above questions, we employed the following three-phase approach:

- Phase 1: Identify programs in the MDAP_A funding network that underperform by analyzing SAR files of all programs specifically for information pertaining to APB breaches and increase/decrease in %PAUC.
- Phase 2: Study the local reasons for the poor performance of the programs based on their respective DAES reports.
- Phase 3: Study the non-local reasons for poor performance by analyzing the SAR files.

In the remainder of this section, we discuss the details of this three-phase approach.

Phase 1: Identify Programs in the MDAP_A Funding Network That Exhibit Poor Performance

We studied the yearly performance of MDAP_A funding network using the SAR files. Table 1 shows the APB breaches and %PAUC during 2004–2010 for the nodes in the MDAP_A network. Programs initiated after 2004 have data from their respective start date.

Table 1. SAR Summary of the MDAP_A Funding Network for 2004–2010

			APB Breach		
MDAP_A	Schedule	Performance	RDT&E	Procurement	PAUC
2004	None	None	None	None	None (-9.98%)
2005	None	None	None	None	None (-11.65%)
2006	Yes	Yes	Yes	None	None (-6.14%)
2007	None	None	None	None	None (-1.24%)
2009	Yes	None	Yes	None	None (3.14%)
2010	Yes	None	Yes	None	None (3.82%)
MDAP_B					
2004	None	None	None	None	None
2005	Yes	Yes	Yes	None	None (3.85%)
2006	Yes	Yes	Yes	None	None (3.85%)
2007	None	None	None	None	None (7.69%)

2009	Yes	None	None	Yes	None (-26.92%)
2010	Yes	None	Yes	Yes	None (-19.23%)
MDAP_C					
2005	Yes	None	None	None	None (6.51%)
2006	None	Yes	None	None	Yes (13.22%)
2007	Yes	None	None	None	None (0.93%)
2009	Yes	None	None	Yes	None (-37.79%)
2010	Yes	None	None	Yes	None (-26.75%)
MDAP_D					
2009	None	None	None	None	None (2.45%)
2010	Yes	None	None	None	None (1.05%)
MDAP_E					
2006	None	None	None	None	None (-10.685%)
2007	None	None	None	None	None (-4.81%)
2009	None	None	None	None	None (-3.98%)
2010	None	None	None	None	None (-11.24%)

In SAR files, APB breach is defined as a condition in which the value of the respective breach parameters (schedule, performance, RDT&E, procurement, and PAUC) is in the range of 10%–15%, beyond which the condition is defined as a Nunn-McCardy breach. Table 1 captures whether a program has APB breaches in a given year and what is the %PAUC of that program. A program may have more than one APB breach but experience a decrease in %PAUC. For example, in the year 2006, the program MDAP_A experienced schedule, RDT&E, and performance breaches, yet its %PAUC decreased. Two possible reasons could account for this fact: (1) the decrease in %PAUC could be due to lagging effect from previous year; and/or (2) according to project management triangle model (Bethke, 2003), program managers may intentionally choose biases towards better performance of one component of the program by trading it off with performance of other components.

Table 1 indicates that MDAP_A, MDAP_B and MDAP_C programs have been experiencing frequent APB breaches and increase in %PAUC during 2004 and 2010.We intend to understand the causes of poor performance for these programs in the Phase 2: Investigation of Local Reasons for Poor Performance subsection. Of the three poorly performing programs, we chose to analyze MDAP_A and MDAP_B. We identified the local causes for these two programs and then determined whether interdependency issues existed among them. In other words, in the subsection Phase 3: Study the Non-Local Reasons for Poor Performance by Analyzing the SAR we observed whether any of these "poorly performed" programs propagate their performance effects to the other program, causing the other programs to perform poorly as well.

Phase 2: Investigation of Local Reasons for Poor Performance

In this subsection, we investigate the performance issues local to individual MDAPs and also track how effective "mitigation forecasting" is to resolve pertaining issues.

We used the DAES reports of individual programs to analyze their performance from a local perspective. We observed that the DAES reports capture the performance issues of a program's local domain. We focused on four performance issues recorded in the DAES reports, namely, cost, schedule, performance, and funding.

Understanding the Local Causes for MDAP_A to Perform Poorly

We studied a total of 40 available DAES reports for MDAP_A between 2006 and 2010. These reports are published monthly each year, including the election year of 2008, unlike the SAR, which did not report in 2008. The program status is presented in DAES reports through the following parameters: cost, schedule, funding, performance, and life cycle sustainment. We focus on cost, schedule, performance, and funding parameters. Each parameter reflects both the APB and contract status. The status for each month is represented in one of three colors depending on the severity of the pertaining issue. Green reflects the normal state meeting all requirements, while yellow reflects resolvable issues (resolvable APB/contract), and red refers to a state that could not meet the requirements (critical APB/contract).

We first understood how effective the APB and contract forecasting were to mitigate the pertinent problems by (1) recording the instances where the forecasting was effective, as well as where it was not ineffective; and (2) identifying the issues that caused the predictions to slip. We then analyzed the issues for deeper understanding and categorization.

We present our analyses in tabular format for three parameters: cost, schedule, and funding in the three following subsections. Because MDAP_A did not have any performance issues, we focused on the cost, schedule, and funding issues.

MDAP_A Cost Analysis

Table 2 captures cost-related issues for the program.

Table 2. MDAP_A Cost Analysis Using DAES Reports From 2006 to 2010

Current Status	Status at the Predicted Month	Causes
Month: April 2007 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: September 2007 Status: Contract - Red Note: After 5 months the contract issue turns into critical	**<u>Issue 1:</u>** Hardware building **<u>Issue 2:</u>** Hardware design **<u>Issue 3:</u>** Logistics issue
Month: September 2007 Issue: Contract - Red APB - Yellow Mitigation forecast: 8 months	Month: May 2008 Status: Contract - Yellow APB-Green	**<u>Issue 1-3:</u>** Resolved **<u>Issue 4:</u>** Contractor unable to forecast cost
Month: May 2008	Month: July 2008	**<u>Issue 4:</u>** Contractor

Issue: Contract - Yellow Mitigation forecast: 8 months	Status: Contract - Red Note: After 5 months the contract issue turns into critical	unable to forecast cost **Issue 5:** Schedule delay increased contract cost
Month: July 2008 Issue: Contract - Red Mitigation forecast: 4 months	Month: November 2008 Status: Contract - Red	**Issue 4:** Contractor unable to forecast cost **Issue 5:** Schedule delay increased contract cost
Month: November 2008 Issue: Contract - Red Mitigation forecast: 1 month	Month: December 2008 Status: Contract - Red	**Issue 4:** Contractor unable to forecast cost **Issue 5:** Schedule delay increased contract cost
Month: December 2008 Issue: Contract - Red Mitigation forecast: 2 months	Month: February 2009 Status: Contract - Red	**Issue 4:** Contractor unable to forecast cost **Issue 5:** Schedule delay increased contract cost
Month: February 2009 Issue: Contract - Red Mitigation forecast: 4 months	Month: June 2009 Status: Contract - Yellow	**Issue 4:** Remains **Issue 5:** Remains
Month: June 2009 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: February 2010 Status: Contract - Yellow	**Issue 4:** Remains **Issue 5:** Remains
Month: February 2010 Issue: Contract - Yellow Mitigation forecast: 1 month	Month: March 2010 Status: Contract - Yellow	**Issue 4:** Remains **Issue 5:** remains
Month: March 2010 Issue: Contract - Yellow Mitigation forecast: 2 months	Month: April 2010 Status: Contract - Yellow Note: May 2010 report is incomplete	**Issue 4:** Remains **Issue 5:** Remains

Lessons Learned. Although Table 2 suggests that there are some instances where the forecasting turned out to be effective, we observed and focused on the instances where the cost-related forecasting was not effective. We identified two local issues, namely, (1) contractors inability to forecast cost, and (2) schedule delay leading to increased contract cost, which appear to recur and lead to increased program costs.

MDAP_A Schedule Analysis

Table 3 captures schedule-related issues for the program.

Table 3. MDAP_A Schedule Analysis Using DAES Reports From 2006 to 2010

Current Status	Status at the Predicted Month	Causes
Month: June 2007 Issue: Contract - Yellow Mitigation forecast: 2 months	Month: September 2007 Status: Contract - Yellow Note: August 2007 report is not available	**Issue 1:** Delay in MOU sign with Australia

Month: September 2007 Issue: Contract - Yellow Mitigation forecast: 1 month	Month: October 2007 Status: Contract - Green	**<u>Issue 1:</u>** Remains **<u>Issue 2:</u>** Software testing, delivery, and other waveform issues
Month: October 2007 Issue: APB - Yellow Mitigation forecast: 1 month	Month: November 2008 Status: APB - Green	**<u>Issue 1:</u>** Resolved **<u>Issue 2:</u>** Resolved
Month: March 2008 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 8 months	Month: November 2008 Status: APB - Red Contract - Red	**<u>Issue 3:</u>** Hardware testing and performance failure **<u>Issue 4:</u>** Execution delay in contractor's schedule & lack in funding
Month: November 2008 Issue: APB - Red Contract - Red Mitigation forecast: 2 months	Month: December 2008 Status: APB - Red Contract - Red	**<u>Issue 3:</u>** Hardware testing and performance failure **<u>Issue 4:</u>** Execution delay in contractor's schedule & lack in funding
Month: December 2008 Issue: APB - Red Contract - Red Mitigation forecast: 2 months	Month: February 2009 Issue: APB - Red Contract - Red Mitigation Forecast: 2 months	**<u>Issue 3:</u>** Hardware testing and performance failure **<u>Issue 4:</u>** Execution delay in contractor's schedule & lack in funding
Month: February 2009 Issue: APB - Red Contract - Red Mitigation forecast: 4 months	Month: June 2009 Status: APB - Red Contract - Red	**<u>Issue 4:</u>** Execution delay in contractor's schedule & lack in funding **<u>Issue 3:</u>** Hardware testing and performance failure
Month: June 2009 Issue: APB - Red Contract - Yellow Mitigation forecast: APB: 4 months Contract: 8 months	Month: October 2009 Status: APB - Green Contract - Yellow	
Month: October 2009 Issue: Contract - Yellow Mitigation forecast: Contract: 5 months	Month: March 2010 Status: APB - Red Contract - Yellow	**<u>Issue 4:</u>** Execution delay in contractor's schedule & lack in funding **<u>Issue 3:</u>** Hardware testing and performance failure

Lessons Learned. Although there are some instances for which the forecasting turned out to be effective, we observed and focused on the instances where the schedule-related forecasting was not effective. We identify two local issues, namely, (1) hardware testing and performance failure, and (2) execution delay and lack of funding that appear to recur and lead the program towards schedule delay.

MDAP_A Funding Analysis

Table 4 captures funding related issues for the program.

Table 4. MDAP_A Funding Analysis Using DAES Reports From 2006 to 2010

Current Status	**Status at the Predicted Month**	**Causes**
Month: April 2007 Issue: APB - Yellow Mitigation forecast: Contract: 5 months	Month: September 2007 Status: APB - Yellow	**Issue 1:** WPN fund cut
Month: September 2007 Issue: APB - Yellow Mitigation forecast: Contract: 1 month	Month: October 2007 Status: APB - Yellow	**Issue 1:** WPN fund cut
Month: October 2008 Issue: APB - Red Contract - Red Mitigation forecast: APB: 4 months Contract: 2 months	Month: December 2008 Status: APB - Red Contract - Red	**Issue 1:** WPN fund cut
Month: December 2008 Issue: APB - Red Contract - Red Mitigation forecast: APB: 4 months Contract: 2 months	Month: February 2009 Status: APB - Red Contract - Red	**Issue 1:** WPN fund cut
Month: February 2009 Issue: APB - Red Contract - Red Mitigation forecast: APB: 1 month Contract: 1 month	Month: March 2009 Status: APB - Green Contract - Green	
Month: April 2009 Issue: APB - Red Contract - Red Mitigation forecast: By the current month	Month: May 2009 Status: APB - Red Contract - Red	**Issue 1:** WPN fund cut
Month: May 2009 Issue: APB - Red Contract - Red Mitigation forecast: 4 months	Month: September 2009 Status: APB - Green Contract - Green	

Lessons Learned. Although there are some instances for which the forecasting turned out to be effective, we observed and focused on the instances where the funding-related forecasting was not effective. We identified one local issue, namely the weapons procurement cut (WPN), that appears to recur and lead the program towards experiencing funding-related problems (for example, lack of funding caused schedule delay, as captured in the MDAP_A schedule analyses section).

Based on the above lessons from the cost, schedule, and funding analyses of MDAP_A, we identified the following observations that appear to be responsible for APB cost and schedule breach of MDAP_A:

- Observation 1: Design of MDAP_A relies on cutting edge technology. It seems that the contractor underestimated or could not accurately estimate the technical challenges and the amount of funding required to accomplish the tasks.
- Observation 2: MDAP_A suffered greatly due to budget cuts. The program did not receive required amount of funding from the government (congressional committee), which delayed the schedule, and as a consequence cost increased.

Understanding the Local Causes for MDAP_B to Perform Poorly

We studied a total of 44 available DAES reports for MDAP_B between 2006 and 2010. We first understood the effectiveness of APB and contract forecasting to mitigate the pertinent problems. We did this by recording the instances when the forecasting was effective, as well as when it was not ineffective. We then sought to identify and analyze the issues that caused the predictions to slip.

We present our analyses in tabular format for three parameters: cost, schedule, and funding in three following subsections. Because MDAP_B did not have any performance issues, we focused on cost, schedule, and funding issues.

MDAP_B Cost Analysis

Table 5 captures cost-related issues for the program.

Table 5. MDAP_B Cost Analysis Using DAES Reports From 2006 to 2010

Current Status	Status at the Predicted Month	Causes
Month: February 2007 Issue: APB - Yellow Mitigation forecast: 3 months	Month: May 2007 Status: APB - Yellow	**Issue 1:** Require procurement funding
Month: May 2007 Issue: APB - Yellow Mitigation forecast: 1 month	Month: June 2007 Status: APB - Yellow	**Issue 1:** Require procurement funding
Month: June 2007 Issue: APB - Yellow Mitigation forecast: 2 months	Month: August 2007 Status: APB - Yellow	**Issue 1:** Require procurement funding **Issue 2:** Contractor cost increase
Month: August 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 1 month	Month: September 2007 Status: APB - Yellow Contract - Yellow	**Issue 1:** Require procurement funding **Issue 2:** Contractor cost increased

Month: September 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: APB: 1 month Contractor: 8 months	Month: October 2007 Status: APB - Green Contract - Yellow	**<u>Issue 1:</u>** Require procurement funding **<u>Issue 2:</u>** Contractor cost increased
Month: October 2007 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: June 2008 Status: Contract - Yellow	**<u>Issue 1:</u>** Require procurement funding **<u>Issue 2:</u>** Contractor cost increased
Month: June 2008 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: February 2009 Status: Contract - Yellow	**<u>Issue 1:</u>** Require procurement funding **<u>Issue 2:</u>** Contractor cost increased
Month: February 2009 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: October 2009 Status: Contract - Yellow	**<u>Issue 1:</u>** Require procurement funding **<u>Issue 2:</u>** Contractor cost increased
Month: October 2009 Issue: Contract - Yellow Mitigation forecast: 8 months	Month: April 2010 Status: Contract - Yellow Note: No data available beyond April 2010	**<u>Issue 1:</u>** Require procurement funding **<u>Issue 2:</u>** Contractor cost increased

Lessons Learned. Although there are some instances for which the forecasting turned out to be effective, we observed and focused on the instances where the cost-related forecasting was not effective. We identified two local issues, namely, (1) the lack in procurement funding, and (2) increased contract costs that appear to recur and lead the program towards cost increase.

MDAP_B Schedule Analysis

Table 6 captures schedule issue for the program.

Table 6. MDAP_B Schedule Analysis Using DAES Report From 2006 to 2010

Forecasting	**Status at the Predicted Month**	**Causes**
Month: September 2006 Issue: APB - Yellow Mitigation forecast: 6 months	Month: March 2007 Status: APB - Yellow	
Month: March 2007 Issue: APB Yellow Mitigation forecast: 2 months	Month: May 2007 Status: APB - Yellow	
Month: May 2007 Issue: APB Yellow Mitigation forecast: 1 month	Month: June 2007 Status: APB	
Month: June 2007 Issue: APB - Yellow Mitigation forecast: 2 months	Month: August 2007 Status: APB - Yellow	

Month: August 2007 Issue: APB - Yellow Mitigation forecast: 1 month	Month: September 2007 Status: APB - Yellow	
Month: September 2007 Issue: APB - Yellow Mitigation forecast: 2 months	Month: November 2007 Status: APB - Green	
Month: November 2010 Issue: APB - Yellow Mitigation forecast: 5 months	Month: April 2010 Status: APB - Red Note: No data available beyond April 2010	**Issue 2:** Phase 1 (Rifleman Radio) Milestone C decision date postponement and potential to move right beyond threshold date; A MS C Threshold Breach causes the Phase 1 (AN/PRC-154) to be Red through +3 months

Lessons Learned. Although there are some instances for which the forecasting turned out to be effective, we observed and focused on the instances where the schedule-related forecasting was not effective. We, however, could not identify the issues that caused schedule delay for MDAP_B.

MDAP_B Funding Analysis

Table 7 captures funding related issues for the program.

Table 7. MDAP_B Funding Analysis Using DAES Report From 2006 to 2010

Forecasting	**Status at the Predicted Month**	**Causes**
Month: February 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 3 months	Month: May 2007 Status: APB - Yellow Contract - Yellow	**Issue 1:** Require procurement funding
Month: May 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 1 month	Month: June 2007 Status: APB - Yellow Contract - Yellow	**Issue 1:** Require procurement funding
Month: June 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 2 months	Month: August 2007 Status: APB - Yellow Contract - Yellow	**Issue 1:** Require procurement funding
Month: August 2007 Issue: APB - Yellow Contract - Yellow Mitigation forecast: 1 month	Month: September 2007 Status: APB - Green Contract - Green	
Month: March 2008 Issue: APB - Yellow Mitigation forecast: 4 months	Month: July 2008 Status: APB - Yellow	**Issue 1:** Require procurement funding

Month: July 2008 Issue: APB - Yellow Mitigation forecast: 3 months	Month: October 2008 Status: APB - Yellow	**<u>Issue 1:</u>** Require procurement funding
Month: October 2008 Issue: APB - Yellow Mitigation forecast: 3 months	Month: January 2009 Status: APB - Yellow	**<u>Issue 1:</u>** Require procurement funding
Month: January 2009 Issue: APB - Yellow Mitigation forecast: current month	Month: February 2009 Status: APB - Yellow	**<u>Issue 1:</u>** Require procurement funding
Month: February 2009 Issue: APB - Yellow Mitigation forecast: current month	Month: March 2009 Status: APB - Green	
Month: June 2009 Issue: APB - Yellow Mitigation forecast: 5 months	Month: November 2009 Status: APB - Red	**<u>Issue 2:</u>** R&D shortfall driven by overall technical and schedule issues **<u>Issue 3:</u>** Hardware testing issue to increase program cost
Month: November 2009 Issue: APB - Red Mitigation forecast: 8 months	Month: April 2010 Status: APB - Red Note: No data available beyond April 2010	**<u>Issue 2:</u>** FY 12-15 R&D shortfall driven by overall technical and schedule issues **<u>Issue 3:</u>** Hardware testing issue to increase program cost

Lessons Learned. Although there are some instances for which the forecasting turned out to be effective, we observed and focused on the instances where the funding-related forecasting was not effective. We identified three local issues, namely, (1) the requirement of procurement funding, (2) R&D shortfall driven by overall technical and schedule issues, and (3) hardware testing issue to increase program cost. These issues appear to recur and lead the program towards experiencing funding related problem (for example, cost increase as captured in the MDAP_B cost analyses section).

Based on the above lessons learned from the cost, schedule and funding analyses of MDAP_B, we made the following observations about what is responsible for APB cost and schedule breach of MDAP_B:

- Observation 3: Lack in procurement funding is the most beleaguering issue for MDAP_B for its observed cost and funding problems.
- Observation 4: The above DAES report-based analyses, however, do not provide any clue for shortfall in funding. This underscores the importance of looking beyond the local view of a program and to search for non-local causes that could have contributed to the degradation in performance. This motivated us to investigate the interdependent region between MDAP_A and MDAP_B to identify possible cascading effects.

Phase 3: Study the Non-Local Reasons for Poor Performance by Analyzing the SAR

In Table 8, we provide a summary of our findings from our study of DAES reports for MDAP_A and MDAP_B, in an effort to understand the non-local issues.

Table 8. MDAP_A and MDAP_B Local Issue Summary for 2006 to 2010

MDAP_A Issues	MDAP_B Issues
• Contractors inability to forecast cost • Schedule delay increased contract cost • Hardware testing and performance failure • Execution delay and lack of funding	• Lack in procurement funding • Increased contract cost • Require procurement funding • R&D shortfall driven by overall technical and schedule issues • Hardware testing issue to increase program cost

Table 8 indicates that although contractor's ineffective forecasting and schedule delays (due to hardware and design issues) led MDAP_A to incur cost overrun, lack in procurement funding appears to be the plaguing issue for increase in cost of MDAP_B. Based on this observation we propound the following hypothesis: The cost increase of MDAP_A in year 2009 could have caused procurement funding shortfall for MDAP_B in 2010, which in effect increased the cost of MDAP_B (as the DAES reports on MDAP_B suggest).

To verify the hypothesis, we prepared the following two tables of the funding summary (based on base year dollar) from the SAR files of MDAP_A and MDAP_B for the period 2004–2010. Our study indicated that a comparative analysis of SAR files for the programs of MDAP_A funding network provides insight about the joint space and hence is useful for us in indentifying the non-local issues. SAR captures the yearly APB breach status, %PAUC, cost and funding data; hence, it is suitable for quantitative analyses.

Table 9. MDAP_A SAR Funding Summary ($BY) for the Period 2004–2010

MDAP_A	Baseline Quantity	Current Quantity	%PAUC	Current Year Required Funding (x)	Received Funding (y)	Delta (y - x)
2004	6	6	-9.98		221.1	
2005	6	6	-11.65	598.5	579.8	-18.7
2006	6	6	-6.14	1012.1	997.3	-14.8
2007	6	6	-1.24	1588.4	1574.6	-13.8
2009	6	6	3.14	3163.2	3006.3	-156.9
2010	6	6	3.82	3750.7	3813.2	62.5

Table 10. MDAP_B SAR Funding Summary ($BY) for the Period 2004–2010

MDAP_B	Baseline Quantity	Current Quantity	%PAUC	Current Year Required Funding (x)	Received Funding (y)	Delta (y-x)
2004	329574	329574	0	44.2	44.2	0
2005	329574	328514	3.85	137.2	135.5	-1.7
2006	329574	328514	3.85	255.5	250.3	-5.2

2007	329574	95961	7.69	350.5	348.1	-2.4
2009	329574	215961	-26.92	644.1	593.2	-50.9
2010	329574	221978	-19.23	751.6	711.1	-40.5

In Tables 9 and 10, we focused on the parameter "delta," which captures the difference in the amount of required and received funding for the respective year. For MDAP_A, we noticed that from 2009 to 2010, the %PAUC increased while delta turned out to be positive. On the other hand, for MDAP_B, from 2009 to 2010, delta retained a large negative value, even though given the trends over the years, the increase in quantity (~4000 units) is not large enough to justify this increase. Both the DAES and SAR files of MDAP_B did not provide reasons for the large negative value of delta in 2009 and 2010. We suspect that the cost overrun of MDAP_A in 2009 onwards might have affected MDAP_B in 2010 through a procurement funding short fall. This observation, even if it may not be conclusive, suggests cascading effects between neighboring MDAPs. We believe that a thorough study of the entire set of MDAPs may enable us to find more interesting interdependencies and would be able to predict the flow of the cascading effects.

Observations from the Performance Reports-Based Analyses

In Subsection Phase 2: Investigation of Local Reasons for Poor Performance and subsection Phase 3: Study the Non-Local Reasons for Poor Performance by Analyzing the SAR, we studied the available DAES and SAR files of MDAP_A and MDAP_B from 2006 to 2010 in an effort to identify cascading effect in the MDAP_A funding network. We tried to understand the local as well as non-local issues that led the programs towards breach condition. The following is the summary of observations from this process:

- Observation 1: Design of MDAPs relies on cutting edge technology. It appears that the contractor either underestimates or cannot accurately estimate the technical challenges and the amount of funding required to accomplish the tasks.
- Observation 2: Programs are observed to suffer greatly because of budget cuts. Sometimes programs do not receive required amount of funding from the government (congressional committee), which delays the schedule, and as a consequence cost increases.
- Observation 3: Lack in procurement funding is another cause that leads to cost and funding problems.
- Observation 4: Analyses of the local issues and the fact that some of the issues are recurrent indicate that either the root cause of the problem is not captured in the DAES documents or that the cause is exogenous of the program boundary.
- Observation 5: Analyses of SAR files, on the other hand, offer some insights about the interdependency of the programs.
- Observation 6: The observed instance of possible cascading effect in the MDAP_A network (in the Phase 3: Study the Non-Local Reasons for Poor Performance by Analyzing the SAR section) motivates us to design an automated scheme that would be able to identify and predict the likelihood of cascading effects.

A Decision-Theoretic Model for MDAP Networks

A Markov Decision Process (MDP; Bertsekas, 1987) is a probabilistic model for decision-making and planning. It uses dynamic programming to decide on the optimal actions (in this case, "cut funding by 50%" or "delay schedule by six months") that yield the highest expected utility (for example, no PAUC growth or no APB breaches). MDPs capture the essence of sequential processes and are used to compute *decision* policies that lead to best long-term performance for the entire network.

In theory, MDPs implement two forms of hedging that can allow managers (1) to test their decisions to avoid the possibility of failure, and (2) to choose actions that ensure higher overall expected reward. These hedging strategies alter expectations about future problems in a manner that allows managers to shift behaviors to improve performance.

In our approach, MDAPs are considered as individual agents that are part of a cooperative multi-agent system, and decision-making in an MDAP network is viewed as a multi-agent sequential decision problem because the utility gained by each agent depends on a sequence of actions over time. Our goal is to determine the behavior of the agents that best balances the risks and rewards while acting in an uncertain environment with stochastic actions.

Each MDAP makes its individual decisions in an environment where the state space is not fully observable, meaning that the nodes in the network (the programs) do not exactly know which state they are in at any particular instant because they do not have complete information about their neighbors. With the partial-state information, the individual agents aim to optimize the joint reward function. This class of problems is modeled as a decentralized partially observable MDAP (DEC-POMDP) in literature (Bernstein et al., 2002), where at each step when an agent takes an action, a state transition occurs, and the agent receives a local observation. Following this, the environment generates a global reward that depends on the set of actions all agents take. The complexity, however, of this decentralized control model is NEXP-hard (Bernstein et al., 2002), and hence it is computationally intractable. In our previous work (Cheng, Raja, & Lesser, 2012), we made the DEC-POMDP problem for a tornado-tracking tractable by approximating the DEC-POMDP with a stochastic DEC-MDP[1] model and using a factored reward function to define a Nash Equilibrium instead of the global reward function. A necessary condition for stable equilibrium among agents in a multi-agent system is that each agent plays a best-response to the strategy of every other agent: This is called a Nash Equilibrium. We applied this technique to the MDAP domain. We defined the reward function of this model to be composed of two different components: local reward function, and global reward function. The local reward functions are dependent only on the individual agents' actions, while the global reward function depends on the action of all agents.

The DEC-MDP model is defined as a tuple $<\mathcal{S}, \mathcal{A}, \mathcal{T}, \mathcal{R}>$ where
$\mathcal{S} = S_1 \times S_2 \times \ldots\ldots \times S_n$ is a finite set of factored world states, where S_i is the state space of agent i.
$\mathcal{A} = A_1 \times A_2 \times \ldots \times A_n$ is a finite set of joint actions, where A_i is the action set for agent i.
$\mathcal{T}: \mathcal{S} \times \mathcal{A} \times \mathcal{S} \rightarrow \mathcal{R}$ is the transition function. $T(s' \mid s, a)$ is the probability of transiting to the next state after a joint action $a \in A$ is taken by agents in state s.
$\mathcal{R} = \{R_1, R_2, \ldots, R_n\}$ is a set of factored reward functions. $R_i : S \times A \rightarrow \mathcal{R}$ provides agent i with an individual reward $r_i \in R_i(s, a)$ for taking action a in state s.

We made this a stochastic DEC-MDP by defining a solution as a stochastic policy for each agent. A stochastic policy of an agent is denoted by $\Pi_i(s) \in PD(A_i)$, where PD (A_i), is the set of probability distributions over actions A_i. Stochastic policies can cope with the uncertainty of observation and perform better than deterministic policies in a partial observable environment.

[1] A DEC-MDP is a DEC-POMDP with joint full observability (Bernstein et al., 2002).

State Space

Feature 1: Program ID

Feature 2: Current Year

Feature 3: Current Month

Feature 4: Cost (APB) Status: for 9 months, starting from the current month

Feature 5: Cost (Contract) Status: for 9 months, starting from the current month

Feature 6: Schedule (APB) Status: for 9 months, starting from the current month

Feature 7: Schedule (Contract) Status: for 9 months, starting from the current month

Feature 8: Performance (APB) Status: for 9 months, starting from the current month

Feature 9: Performance (Contract) Status: for 9 months, starting from the current month

Feature 10: Funding (APB) Status: for 9 months, starting from the current month

Feature 11: Funding (Contract) Status: for 9 months, starting from the current month

Each of the above features (4–11) is represented by one of three colored bubbles (green, yellow, and red) in the Program Status page of the DAES report. Yellow bubbles refer to resolvable issues, and red bubbles refer to critical issues. But if there is no issue, then the feature is represented by a green bubble. The number of bubbles starting from the current month indicates the number of months during which the issue will sustain. We assigned the green, yellow, and red bubble weights of 0.0, 0.1, and 1.0, respectively. Hence, in the feature value, the count of yellow bubbles appears at the right side of the decimal point, and the count of red bubbles appears at the left side of the decimal point of the feature value. For example, consider the value of Feature 4: Cost (APB) = 4.0. This value indicates that the cost (APB) issue is critical and that it would continue to be critical for the next consecutive four months. Then it is predicted to be resolved.

Action Space

We capture both local and non-local actions.

Local action 1 (LA1): PM takes action to resolve APB cost issue

Local action 2 (LA2): Contractor takes action to resolve Contractor cost issue

Local action 3 (LA3): PM takes action to resolve APB schedule issue

Local action 4 (LA4): Contractor takes action to resolve Contractor funding issue

Local action 5 (LA5): PM takes action to resolve APB/Contractor funding issue

Local action 6 (LA6): PM takes action to resolve APB performance issue

Local action 7 (LA7): Contractor takes action to resolve Contractor performance issue

Local action 8 (LA8): PM initiates inter-governmental dialogue to resolve the pertaining issue

Non-Local Action (NLA): Coordinate with program *i*. (i refers to a neighbor program)

Transition Probabilities

The transition probability function will be computed empirically based on the past performance breaches of programs in the network.

Reward Function

The joint reward function is composed of local and global rewards. Local rewards are achieved both monthly and yearly.

We will calculate local reward value from the Acquisition Baseline Program section of DAES reports. The following two parameters (LR1 and LR2) capture the change in %PAUC and schedule on a monthly basis. We will use the following code to depict their changes:

If current %PAUC < 10% of the APB, then status = 0

If current %PAUC > 0 && PAUC < 10% of the APB, then status = +

If current %PAUC >= 10% && < 15% of the APB, then status = 1

If current %PAUC > 15% of the APB, then status = 10 (breach has occurred)

Schedule: # of months beyond the threshold.

LR1: PAUCMonthly (APB)

LR2: ScheduleMonthly (APB)

To calculate the local reward value, which is calculated yearly, we will use the following parameters captured from SAR files:

LR3: APB Breach RDT&E (Values: 0/1)

LR4: APB Breach Procurement (Values: 0/1)

LR5: APB Breach Schedule (Values: 0/1)

LR6: APB Breach Performance (Values: 0/1)

LR7: APB Breach PAUC (Values: 0/1)

LR8: Nunn-McCurdy Breach PAUC (Values: 0/1)

LR9: %PAUC (amount that appears in SAR)

For the calculation of global reward, which is to be calculated yearly, we will use following parameters:

GR 1: Criticality value of neighbor 1 (CR_ID of neighbor)

GR 2: Criticality value of neighbor 2 (CR_ID of neighbor)

GR 3: Criticality value of neighbor 3 (CR_ID of neighbor)

GR 4: Criticality value of neighbor 4 (CR_ID of neighbor)

Etc.

Criticality value indicates the importance of the neighbor nodes in terms of creating impact over the other nodes in the MDAP network. It is based on centrality measures defined in network theory where the centrality quantifies the importance of the nodes in a networked system (Newman, 2011). We calculated the criticality of the nodes for the global reward based on the composite parameter of a neighbor program from the SAR files as follows:

CR = APB_RDT&E + APB_Procurement + APB_Schedule + APB_Performance

+APB_PAUC+Nunn-McCardy_PAUC+%PAUC

Based on the local and global rewards, we will calculate the joint reward by summing up the contributions of both the local and global reward functions. The aggregate local and global reward value may have different weights associated with it.

Understanding the Characteristics of the Existing Data

In this section, we describe the importance of the data set that facilitates deeper understanding about the dynamics of the MDAP network. We also enumerate the issues related to the quality of the data, as well as about its completeness and availability in the subsection Structure of the Data and the subsection Availability of the Data. We believe that by addressing these issues, the accuracy of the proposed decision-theoretic model would be enhanced.

Significance of the Data Set

The available data that we used for an in-depth study of the MDAP_A funding network offers significant insight into each individual program, as well as into their interdependency relationships. DAES reports, which are published monthly, provide a granular view of the local issues pertaining to the program and the mitigation actions that have been taken to resolve the issues. Analyses of monthly forecasting on the program features helped us identify the root cause of the program or its absence, which in effect led us to search for non-local causes originated through cascading effects. SAR files, on the other hand, provide a quantitative depiction of the program status on the basis of accrued breaches, increase in %PAUC, cost, and funding figures. This resource helped us with comparative quantitative analyses and to gain insight into the cascading effects.

Structure of the Data

- We note that none of the performance reports directly capture the interdependent regions.
- Although the PE documents provide a set of programs that share a common funding source, they do not provide a comparative status of the programs.
- The DAES reports show the data interdependency, but they do not provide at least a summary status of the data neighbors.
- To determine the cascading effect between MDAP_A and MDAP_B, we had to build a “funding summary” table for both the programs based on base year dollars. The existing SAR format provides only the then-year funding summary. For comparison and analyses, this table should be provided in terms of base year dollar.
- We observe that some DAES reports provide a better understanding of the issues and mitigation measures, although others do not. There should be a uniform standard to prepare this document.

Availability of Data

- We observe that monthly DAES reports for the nodes in the MDAP_A funding network provide a very small spectrum of useful data for analyses. Although some programs report from 2006, the complete data set for all the members of the MDAP_A network is available only for the years 2008 and 2009. For the year

2007, only some programs possess a complete report. Some DAES reports provide partial information (containing only the risk summary page); hence, they are not suitable for our analysis.

- So far, SAR seems to be the only resource that captures some aspects of interdependency. But the fact that SAR was not published in 2008 caused discontinuity in our analyses.
- We find that some programs stopped reporting after a certain time. Therefore, we had no way to learn the status of the program, even if it performs poorly. This unavailability problem appears to be a challenge understanding interdependency issues.

Conclusions and Future Work

We have conducted a case study of the MDAP_A funding network based on the available DAES and SAR files for the period 2004 to 2010. In the Network Model section, our analyses of these disparate yet intrinsically related data indicated that the programs are related to other programs based on funding and data relationships. This supported our belief that a network-centric predictive model would be a good candidate for MDAP performance analyses. We also noticed that although the available data provides useful information about the MDAPs, it was challenging to integrate and understand this data coherently so that network dependencies can be revealed accurately.

In the Case Study of MDAP_A Funding Network section, we observed that issues that led a program towards experiencing APB breach and/or increase in %PAUC were not solely local, and that the non-local issues might affect the performance of the program. We studied two related programs, MDAP_A and MDAP_B, from a local perspective based on their respective DAES reports and showed that local mitigation efforts, although successful at times, still resulted in APB breaches at other times. Specifically, we observed from the SAR files that the cost overrun of MDAP_A in 2009 onwards might have affected MDAP_B in 2010 in the form of a procurement funding shortfall. This observation, even if it may not be conclusive, suggests cascading effects between neighboring MDAPs. Our study of MDAP_B in 2009 and 2010 led us to address two questions: (1) Why would the procurement funding requirement increase in 2009 and 2010? and (2) What is the reason for MDAP_B not receiving its requested amount of funding that resulted in a funding shortfall condition for two consecutive years? Although the SAR files provide an answer to the first question, which is that the increase in quantity led to the need for increased funding, our data did not provide an answer to the second question. Hence, it appears that this lack of knowledge about one's own program domain (not being able to understand the root cause of the APB breach issues) may result in producing unexpected cascading effects through the neighbor programs.

In A Decision-Theoretic Model for MDAP Network section, we first argued that a decision-theoretic model based on MDPs would be a good candidate to isolating cascading risks for the MDAP network. We then showed that the partially observable state space of each program warrants a DEC-POMDP model, which belongs to the class of MDPs. The computational complexity of the original DEC-POMDP led us to explore feasible approximations that will still provide the performance guarantees. We are currently working on automating this decision-theoretic model for the nodes in the MDAP_A funding network.

We believe that true joint capability relies on the understanding of the scope and challenges of the interdependencies among MDAPs. Our manual analyses of the DAES and SAR documents for a focused MDAP case study reveal indications about possible cascading effects and offer better understanding about the root causes for poor performance of programs. In the future, we plan to automate this process based on the proposed DEC-MDP model leveraging larger data sets. It would be important to observe how the second and higher order neighbors contribute to the cascading effects. We also plan to extend these analyses for MDAP data network focusing on data relationships that are relatively stable over the multiple years.

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