Facilitating Decision Choices with Cascading Consequences in Interdependent Networks

Anita Raja*, Mohammad Rashedul Hasan*, and Mary M. Brown+
Department of Software and Information Systems*
Department of Political Science+
University of North Carolina at Charlotte
9201 University City Blvd
Charlotte, NC 28223-0001
Email: {anraja, mhasan8, 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 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 on 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 challenges inherent in the data collection process

1. Introduction

This research seeks 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 on the cascading effects of perturbations and take appropriate measures to handle them. We develop models that can address "what-if" scenarios such as "what if my partner reneges on a funding obligation?" or "what if Congress alters my funding? How will the perturbation affect my partners?" The research also identifies and enumerates the characteristics in the existing MDAP data that are critical to building a complete model of MDAP behavior and discusses the challenges in acquiring some of this data so that appropriate governance mechanisms can then be isolated. This data acquisition process is emphasized 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 analyze include Selected Acquisition Reports (SAR), Defense Acquisition Executive Summaries (DAES) and Program Element (PE) documents over multiple years. While our aim is to work on the entire collection of MDAPs, we observe that this eclectic conglomeration of information is highly unstructured, significantly inordinate and unmanageably colossal for manual analyses. Hence we focus on a case study that contains a small set of existing MDAPs. We use fictitious names (e.g., MDAP_A, MDAP_B etc.) to retain confidentiality of individual program information. In this case study, we do an in-depth analysis of the data and study 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.

1.1 Background:

The decade old Joint Capabilities paradigm at the Department of Defense aims to achieve interagency cooperation. Vice Chairman of the Joint Chiefs of Staff Admiral Giambastiani (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 congressional budgeting justification process, the acquisition process and the system requirements. It, however, is observed that the acquisition process has been largely tailored to suit the need of the distinct discrete programs without addressing the interdependency issues. To be specific, while 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).

While 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 harness a network-centric approach to study DoD acquisition and focus on a MDAP network of interrelated programs that exchange and share resources for the purpose of establishing joint capabilities.

We study whether performance breaches correlate with interdependency characteristics in the context of the JTRS network. We also study 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 their subsequent interdependent partners. This enables 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 also can 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 on 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:

- 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;
- 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.
- 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.

1.2 Research Methodology:

To perform this study, we design a methodology that includes four goals. We first select a small subset of inter-related MDAPs based on a set of criteria to form our case study. We define 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 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 formulate a decision-theoretic model. We finally capture 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 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?
- Determine the cascading effect through the network?

We plan to approach Goal 2 from two perspectives: *Local perspective* where the analyses are based solely on the individual program's own data; and *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 to 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?

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 to integrate the various program related documents in a coherent and meaningful fashion to aid the decision makers as well as the researchers to build complete models?

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

1.6 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 following: in Section 2, we identify the network dependencies among the MDAPs and define a sample network for analyses (Goal 1); Section 3 investigates the local and non-local causes for degradation in performance of the nodes in the sample network (Goal 2); Section 4 presents the DEC-MDP model formulation (Goal 3) followed by observations made about the characteristics of the available data in Section 5 (Goal 4); finally Section 6 concludes with the lessons that we learn through this process.

2. Network Model

In this section, we first enumerate various MDAP performance reports (see below) and discuss their significance in the 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 will use the lessons learned from the analyses of this sample network to build an accurate decision-theoretic model.

2.1 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, 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 etc.
- SARs that summarize the latest estimates of cost, schedule, and technical status to be reported annually in conjunction with the President's budget

PE documents that are used to justify congressional budgeting process.

2.2 Types of Interdependent Networks within the MDAPs Domain

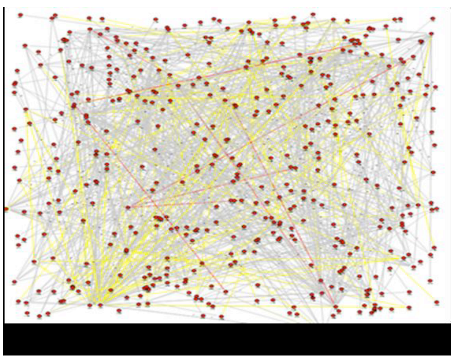

Figure 1: MDAP Data Interdependencies in 2010

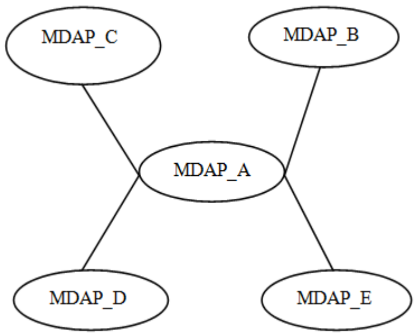

Figure 2: Funding Network of MDAP_A

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 to identity 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 France defense departments.] In the current dataset, 17 percent of the interdependencies are outbound, 37 percent are inbound, and 45 percent are bidirectional. Additionally, per managerial reports, multiple perspectives may be critical to the decision making process. In most cases the boundaries will be 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.

2.2 MDAP_A Funding Network

As discussed is section 1, we choose 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; (b) between the years 2006 to 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 define 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 in section 3. In the future, we plan to apply the lessons learned from this focused study to the entire MDAP network.

3. Case Study of MDAP_A Funding Network

In this section, we analyze the data that we gather 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 Section 1.

Consider the funding network for **MDAP_A** in figure 2. **MDAP_A** lies at the center of this undirected network that contains 5 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, RDT&E, procurement and PAUC. A program is considered to perform poorly if it experiences frequent APB breaches and/or increase in %PAUC.

Now, suppose 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 period. 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 under-perform?
- Q2: How often and why the forecasting of mitigation efforts, as captured in monthly DAES reports, turns out to be ineffective?
- Q3. What are the non-local reasons for poor performance?
- Q4: How does the effect of one under-performing program propagates through the link towards a neighbor program and affects it?
- Q5: Why a program that is performing as expected is not affected by this perturbation?
- Q6: How this network-centric approach facilitates the understanding of the underlying problems leading to cascade in breaches and help the stake-holders to take appropriate measures?

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

Phase 1: Identify programs in the **MDAP_A** funding network that under-perform 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

3.1 Phase 1: Identify programs in the MDAP_A funding network that exhibit poor performance

We study the yearly performance of **MDAP_A** funding network using the SAR files. The following table 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.

	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%)

Table 1: SAR summary of the **MDAP_A** Funding Network for 2004-2010

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 Nunn-McCardy breach. The above table 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 breaches but experience decrease in %PAUC. For example, in year 2006 the program **MDAP_A** experiences schedule, RDT&E and performance breaches yet its %PAUC decreased. Two possible reasons could account for this fact: a) the decrease in %PAUC could be due to lagging effect from previous year or/and b) 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.

The above table 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 subsection 3.2. Of the three poorly performing programs, we choose to analyze **MDAP_A** and **MDAP_B**. We identify the local causes for these two programs and then determine whether interdependency issues exist among them. In other words, we observe whether any of these "poorly performed" programs propagate their performance effects to the other program causing the other programs to perform poorly as well, in section 3.3.

3.2 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 use the DAES reports of individual programs to analyze their performance from a local perspective. We observe that the DAES reports capture the performance issues of a programs local domain. We focus on four performances issues recorded in the DAES reports, namely, cost, schedule, performance and funding.

3.2.1 Understanding the local causes for MDAP_A to perform poorly

We study a total of forty 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 understand how effective the APB and Contract forecasting are to mitigate the pertinent problems by (i) recording the instances where the forecasting was effective as well as where it was not ineffective and (ii) identifying the issues that caused the predictions to slip. We then analyze the issues for deeper understanding and categorization.

We present our analyses in tabular format for three parameters: cost, schedule and funding in sections 3.2.1.1, 3.2.1.2 and 3.2.1.3 respectively. Since **MDAP_A** did not have any performance issues we focus on the cost, schedule and funding issues.

3.2.1.1 MDAP_A Cost Analysis

The following table (Table: **MDAP_A** Cost Analysis using DAES report from 2006 - 2010) captures cost related issues for the program.

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	**Issue 1:** hardware building **Issue 2:** hardware design **Issue 3:** logistics issue
Month: September 2007: Issue: Contract - Red APB - Yellow Mitigation Forecast: 8 months	Month: May 2008 Status: Contract - Yellow APB-Green	**Issue 1-3:** resolved **Issue 4:** Contractor unable to forecast cost.
Month: May 2008 Issue: Contract - Yellow Mitigation Forecast: 8 months	Month: July 2008 Status: Contract - Red Note: After 5 months the contract issue turns into critical	**Issue 4:** Contractor unable to forecast cost. **Issue 5:** Schedule delay increased contract cost.
Month: July 2008	Month: November 2008	**Issue 4:** Contractor unable

Issue: Contract - Red Mitigation Forecast: 4 months	Status: Contract - Red	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

Table: **MDAP_A** Cost Analysis using DAES report from 2006 - 2010

Lessons Learned: While this table suggests that there are some instances where the forecasting turned out to be effective, we observe and focus on the instances where the cost related forecasting was not effective. We identify two local issues namely (i) contractors inability to forecast cost and (ii) schedule delay leading to increased contract cost which appear to recur and leading to increased program costs.

3.2.1.2 MDAP_A Schedule Analysis

The following table (Table: MDAP_A Schedule Analysis using DAES report from 2006 - 2010) captures schedule related issues for the program.

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	**Issue 1:** remains **Issue 2:** Software testing, delivery and other waveform issues
Month: October 2007 Issue: APB - Yellow Mitigation Forecast: 1 month	Month: November 2008 Status: APB - Green	**Issue 1:** resolved **Issue 2:** resolved
Month: March 2008 Issue: APB - Yellow Contract - Yellow Mitigation Forecast: 8 months	Month: November 2008 Status: APB - Red Contract - Red	**Issue 3:** Hardware testing and performance failure **Issue 4:** 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	**Issue 3:** Hardware testing and performance failure **Issue 4:** 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	**Issue 3:** Hardware testing and performance failure **Issue 4:** 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	**Issue 4:** Execution delay in contractor's schedule & lack in funding **Issue 3:** 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	**Issue 4:** Execution delay in contractor's schedule & lack in funding **Issue 3:** Hardware testing and performance failure

Table: **MDAP_A** Schedule Analysis using DAES report from 2006 - 2010

Lessons Learned: While there are some instances for which the forecasting turned out to be effective, we observe and focus on the instances where the schedule related forecasting was not effective. We identify two local issues namely (i) hardware testing & performance failure and (ii) execution delay & lack of funding that appear to recur and lead the program towards schedule delay.

3.2.1.3 MDAP_A Funding Analysis

The following table (Table: **MDAP_A** Funding Analysis using DAES report from 2006 - 2010) captures funding related issues for the program.

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	<u>**Issue 1:**</u> WPN Fund cut
Month: May 2009 Issue: APB - Red Contract - Red Mitigation Forecast: 4 months	Month: September 2009 Status: APB - Green Contract - Green	

Table: **MDAP_A** Funding Analysis using DAES report from 2006 - 2010

Lessons Learned: While there are some instances for which the forecasting turned out to be effective, we observe and focus on the instances where the funding related forecasting was not effective. We identify one local issue namely Weapons Procurement Cut that appears to recur and lead the program towards experiencing funding related problem (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 identify the following observations that appear to be responsible for APB cost and schedule breach of **MDAP_A**:

O1: 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.

O2: MDAP_A suffered greatly due to budget cuts. The program did not receive required amount of funding from Government (Congressional committee), which delayed the schedule, and as a consequence cost increased.

3.2.2 Understanding the Local Causes for MDAP_B to Perform Poorly

We study a total of 44 available DAES reports for **MDAP_B** between 2006 and 2010. We first understand the effectiveness of APB and Contract forecasting to mitigate the pertinent problems. We do this by recording the instances when the forecasting was effective as well as when it was not ineffective. We then seek 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 sections 3.2.2.1, 3.2.2.2 and 3.2.2.3 respectively. Since **MDAP_B** did not have any performance issues we focus on cost, schedule and funding issues.

3.2.2.1 MDAP_B Cost Analysis

The following table (Table: **MDAP_B** Cost Analysis using DAES report from 2006 - 2010) captures cost related issues for the program.

Current Status	**Status at the predicted month**	**Causes**
Month: February 2007 Issue: APB - Yellow Mitigation Forecast: 3 months	Month: May 2007 Status: APB - Yellow	<u>**Issue 1:**</u> require procurement funding
Month: May 2007 Issue: APB - Yellow Mitigation Forecast: 1 month	Month: June 2007 Status: APB - Yellow	<u>**Issue 1:**</u> require procurement funding
Month: June 2007 Issue: APB - Yellow Mitigation Forecast: 2 months	Month: August 2007 Status: APB - Yellow	<u>**Issue 1:**</u> require procurement funding <u>**Issue 2:**</u> 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	**Issue 1:** require procurement funding **Issue 2:** contractor cost increased
Month: October 2007 Issue: Contract - Yellow Mitigation Forecast: 8 months	Month: June 2008 Status: Contract - Yellow	**Issue 1:** require procurement funding **Issue 2:** contractor cost increased
Month: June 2008 Issue: Contract - Yellow Mitigation Forecast: 8 months	Month: February 2009 Status: Contract - Yellow	**Issue 1:** require procurement funding **Issue 2:** contractor cost increased
Month: February 2009 Issue: Contract - Yellow Mitigation Forecast: 8 months	Month: October 2009 Status: Contract - Yellow	**Issue 1:** require procurement funding **Issue 2:** 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	**Issue 1:** require procurement funding **Issue 2:** contractor cost increased

Table: MDAP_B Cost Analysis using DAES report from 2006 - 2010

Lessons Learned: While there are some instances for which the forecasting turned out to be effective, we observe and focus on the instances where the cost related forecasting was not effective. We identify two local issues namely (i) lack in procurement funding and (ii) increased contract cost that appear to recur and lead the program towards cost increase**.**

3.2.2.2 MDAP_B Schedule Analysis

The following table (Table: **MDAP_B** Schedule Analysis using DAES report from 2006 - 2010) captures schedule issue for the program.

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	**<u>Issue 2:</u>** 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

Table: **MDAP_B** Schedule Analysis using DAES report from 2006 - 2010

Lessons Learned: While there are some instances for which the forecasting turned out to be effective, we observe and focus 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**.

3.2.2.3 MDAP_B Funding Analysis

The following table (Table: **MDAP_B** Funding Analysis using DAES report from 2006 - 2010) captures funding related issues for the program.

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	**<u>Issue 1:</u>** require procurement funding
Month: May 2007 Issue: APB - Yellow Contract - Yellow Mitigation Forecast: 1 month	Month: June 2007 Status: APB - Yellow Contract - Yellow	**<u>Issue 1:</u>** require procurement funding
Month: June 2007 Issue: APB - Yellow Contract - Yellow Mitigation Forecast: 2 months	Month: August 2007 Status: APB - Yellow Contract - Yellow	**<u>Issue 1:</u>** 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	**<u>Issue 1:</u>** 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	**Issue 2:** R&D shortfall driven by overall technical and schedule issues **Issue 3:** 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	**Issue 2:** FY 12-15 R&D shortfall driven by overall technical and schedule issues **Issue 3:** Hardware testing issue to increase program cost

Table: **MDAP_B** Funding Analysis using DAES report from 2006 - 2010

Lessons Learned: While there are some instances for which the forecasting turned out to be effective, we observe and focus on the instances where the funding related forecasting was not effective. We identify three local issues namely **(i) requirement of procurement funding (ii) R&D shortfall driven by overall technical and schedule issues and** (iii) 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 make the following observations about what is responsible for APB cost and schedule breach of **MDAP_B**:

O3: Lack in procurement funding is the most beleaguering issue for **MDAP_B** for its observed cost and funding problems

O4: 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 motivates us to investigate the interdependent region between **MDAP_A** and **MDAP_B** to identify possible cascading effects.

3.3 Phase 3: Study the non-local reasons for poor performance by analyzing the SAR

In the following we provide summary of findings that has been revealed from the study of DAES reports for **MDAP_A** and **MDAP_B,** in an effort to understand the non-local issues:

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: **MDAP_A** and **MDAP_B** local issue summary for 2006-2010

This table indicates that while contractor's ineffective forecasting and schedule delay (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 short-fall 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 prepare 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 indicates that a comparative analyses of SAR files for the programs of **MDAP_A** funding network provides insight about the joint space and hence useful for us to indentify the non-local issues. SAR captures the yearly APB breach status, %PAUC, cost and funding data; hence it is suitable for quantitative analyses.

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: **MDAP_A** 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

Table: **MDAP_B** SAR Funding Summary ($BY) for the period 2004-2010

In the above two tables, we focus on the parameter "delta" which captures the difference in the amount of required and received funding for the respective year. For **MDAP_A** we notice that from 2009 to 2010 the %PAUC has increased while delta turned out to be positive. On the other hand, for **MDAP_B**, from 2009 to 2010, delta retains 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** do 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, is suggestive of 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.

3.4 Observations from the Performance Reports based Analyses

In subsection 3.2 and 3.3 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. Following are the summary of observations from this process:

O1: 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.

O2: Programs are observed to be suffered greatly by budget cut. Sometimes it does not receive required amount of funding from Government (Congressional committee), which delays the schedule, and as a consequence cost increases.

O3: Lack in procurement funding is another cause that leads to cost and funding problems.

O4: 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.

O5. Analyses of SAR files, on the other hand, offer some insight about the interdependency of the programs.
O6. The observed instance of possible cascading effect in the **MDAP_A** network (in section 3.3) motivates us to design an automated scheme that would be able to identify and predict the likelihood of cascading effects.

4. A decision-theoretic model for MDAP network

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 6 months") that yields 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 which can allow managers to 1) 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 problem occurrences 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 multiagent system and decision-making in a MDAP network is viewed as a multiagent 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 will make 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 in 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 decentralized partially observable MDP (DEC-POMDP) in literature (Bernstein, Givan, Immerman, Zilberstein, 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 taken by all the agents. The complexity, however, of this decentralized control model is NEXP-hard (Bernstein, Givan, Immerman, Zilberstein, 2002) and hence it is computationally intractable. In our previous work (Cheng, Raja and Lesser, 2012) we make 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 multiagent system is that each agent plays a best-response to the strategy of every other agent: this is called a Nash Equilibrium. We apply this technique to the MDAP domain. We define 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
$\mathcal{S} = S_1 \text{ x } S_2 \text{ x} \ldots\ldots \text{ x } S_n$ is a finite set of factored world states, where S_i is the state space of agent i.
$\mathcal{A} = A_1 \text{ x } A_2 \text{ x} \ldots \text{x } A_n$ is a finite set of joint actions, where A_i is the action set for agent i.
$\mathcal{T}: \mathcal{S} \text{ x } \mathcal{A} \text{ x } \mathcal{S} \rightarrow \mathcal{R}$ 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. $R_i : S \text{ x } A \rightarrow \mathcal{R}$ provides agent i with an individual reward $r_i \in R_i(s, a)$ for taking action a in state s.

We make this a stochastic DEC-MDP by defining a solution as a stochastic policy for each agent. A stochastic policy of an agent i 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.

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[1] A DEC-MDP is a DEC-POMDP with joint full observability (Bernstein, Givan, Immerman, and Zilberstein, 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 bubble refers to resolvable issue and Red bubble refers to critical issue. But if there is no issue then the feature is represented by Green bubble. Number of bubbles starting from the current month indicates the number of months during which the issue will sustain. We assign the Green, Yellow and Red bubbles weights of 0.0, 0.1 and 1.0 respectively. Hence, in the feature value the count of Yellow bubbles will appear at the right side of the decimal point and that the count for Red bubbles will appear 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 next consecutive 4 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 "Acquisition Baseline Program" section of DAES reports. The following two parameters (LR1 and LR2) capture the change in %PAUC and Schedule on 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 calculate 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.

5. 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 subsections 5.2 and 5.3 respectively. We believe that by addressing these issues, the accuracy of the proposed decision-theoretic model would be enhanced.

5.1 Significance of the Data set
The available data that we used for in-depth study of the **MDAP_A** funding network offers significant insight about each individual program as well as 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 has been taken to resolve the issues. Analyses of monthly forecasting on the program features help us to identify the root cause of the program or its absence, which in effect lead 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 helps us for comparative quantitative analyses and to gain insight about the cascading effects.

5.2 Structure of the Data

- We note that none of the performance reports directly capture the interdependent regions.
- Although the PE documents provide set of programs that shares common funding source, it does not provide a comparative status of the programs.
- The DAES reports show the data interdependency, but 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 up “funding summary” table for both the programs based on base year dollar. 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 better understanding of the issues and mitigation measures, while others do not. There should be a uniform standard to prepare this document.

5.3 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. While 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 complete report. Some DAES reports provide partial information (contains only the risk summary page), hence 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.

6. Conclusions & 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 section 2, our analyses of these disparate yet intrinsically related data indicate 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 have also noticed that while the available data provides useful information about the MDAPs, it is challenging to integrate and understand this data coherently such that network dependencies can be revealed accurately.

In section 3, 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 have shown that local mitigation efforts while 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 short fall. This observation, even if it may not be conclusive, is suggestive of cascading effects between neighboring MDAPs. Our study of **MDAP_B** in 2009 and 2010 led us to address two questions: (i) why would the procurement funding requirement increase in 2009 and 2010? (ii) what is the reason for **MDAP_B** not receiving its requested amount of funding that resulted in funding short-fall condition for two consecutive years? While 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 section 4, we first argue why a decision-theoretic model based on MDPs would be a good candidate to isolating cascading risks for the MDAP network. We then show 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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9. Biographical Information

Anita Raja is an Associate Professor of Software and Information Systems at The University of North Carolina at Charlotte and 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 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.

Mohammad Rashedul Hasan is a Ph.D. candidate in 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.

Mary Maureen Brown, Professor of Public Administration, University of North Carolina at Charlotte; Senior Fellow, the Center for Excellence in Municipal Management at George Washington University; and Visiting Scientist, 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.