ON APPROACHES FOR INTEGRATED COURSE OF ACTION DEVELOPMENT

by

Thomas Ian Saltysiak
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Master of Science
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DEDICATION

This is dedicated to my family whose support set the ground work for my education and allowed its realization. To my parents, Ann and John, who sacrificed much during my childhood to ensure their children had the best education and life experiences. To my wife, Jess, and children, Pax, John, and Ben, whose love, support, and sacrifice allowed me to pursue my education.

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I would like to thank the members of my advisory committee who, in a very real sense, allowed me to succeed in this process. Dr. Speller has mentored me on the non-military research areas of organizational culture and leadership. This broadening proved invaluable in my research as I brought in concepts from civilian business and engineering arenas and applied them to military planning. Dr. Nash's ability to explain complicated concepts and his patience and dedication to students are assets to this doctorate program. He spent many hours of his time tutoring and mentoring myself and my peers on mathematical optimization. This allowed us not only to understand the basic ideas but also to grasp the underlying concepts. In 2003, Dr. Loerch convinced a young captain that with hard work he could obtain a masters in systems engineering even though he had never had a course in probability, linear algebra, or differential equations. If not for that conversation, I would not be here today, and Dr. Loerch has served as a constant source of guidance and mentorship ever since. Finally, I would like to thank Dr. Levis who has enabled my success in so many ways. From the first time I attended his architecture class, I saw the power and potential of the underlying concepts for military command and control. I was fortunate that he agreed to be my advisor and guided me down a path that combined real world need with my background and skills. His keen guidance allowed me to go into a relatively unexplored research area while ensuring it was scoped in a meaningful and accomplishable way. He had the foresight to encourage me to work with the United States Strategic Command to gain value insights into the real world problem area. His tireless efforts, providing feedback and mentorship, any time of day and day of the week, allowed me to complete the dissertation process within the rigorous timeframe placed on active duty military officers.

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LIST OF ABBREVIATIONS

Air Defense Assets/Artillery	ADA
Bayesian Networks	BN
Causal Strengths	CAST
Center-of-Gravity	COG
Collaboration Evaluation Framework	CEF
Colored Petri Net	CPN
Command and Control	C2
Command Interpretation	CI
Course of Action	COA
Critique, Explore, Compare, Adapt	CECA
Decision Support System for Coalition Operations	DSSCO
Diplomatic, Information, Military and Economic	DIME
Effects-Based Operations	EBO
Global Positioning System	GPS
Influence network element	INE
Information Exchange Requirement	IER
Information Fusion	IF
Joint Intelligence Preparation of the Operational Environment	JIPOE
Joint Operation Planning and Execution System	JOPES
Military Decision Making Process	MDMP
Naturalistic Decision Making	NDM
Network-centric Warfare Maturity Model	NCWMM
North Atlantic Treaty Organization	NATO
Observe, Orient, Decide, Act	OODA
Operational Net Assessment	ONA
Planning Under Time Pressure	PUT
Processes, People, and Systems	PPS
Recognition-Primed Decision	RPD
Response Selection	RS
Service Oriented Architecture	SOA
Situation Assessment	SA
Stimulus-Hypothesis-Options-Response	SHOR
Systemic Operational Design	SOD
Task Processing	TP
Timed Influence Net	TIN
United Kingdom	UK

ABSTRACT

ON APPROACHES FOR INTEGRATED COURSE OF ACTION DEVELOPMENT

Thomas Ian Saltysiak, Ph.D.

George Mason University, 2012

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Integrating and synchronizing the effects of functional components is an important military principle. This is true across all types of military operations. Currently, functional component planning is often separated into multiple parallel processes. There is no agreed upon methodology for determining when and what type of information is shared between these parallel processes. Component courses of action are developed separately with limited information sharing. Once developed, courses of action are compared to determine if one component's actions negatively impact another's actions, commonly called de-confliction. The de-confliction process may or may not be completed within the time available.

Current approaches to improving planning integration have largely focused on increasing information and knowledge sharing between components. It was accepted that enabling knowledge sharing would lead to greater levels of integration. However, what is needed is a common understanding of the combined effects of each component's

potential actions. This requires components to adjust implicitly their understanding of the operational environment based on shared knowledge. Without explicit acknowledgement of this process goal and common conceptualization, and with no efficient process to achieve it, there has been limited success with planning integration. Although effective knowledge sharing is necessary to increase integration, it is not sufficient. This is especially true in time constrained military planning in which the efficiency of the planning process is vital. Current planning and operational design activities produce all the knowledge necessary for each component to conceptualize the environment. However, there is no established process for agreement on a common inter-component conceptualization.

The proposed approach to integrated planning, named Co-design, is focused on common conceptual model creation early in the planning process. Current planning and operational design activities were analyzed to determine the minimum elements of knowledge sharing and agreement needed to enable common conceptualization. An approach was then developed to enable agreement on these elements in discrete steps in a logical order. The approach was designed to complement the current workflow of planning and design activities.

The feasibility of this approach is demonstrated through a combination of planning process modeling and course of action performance modeling. The amount and timing of inter-component knowledge sharing and agreement is modeled in the process model. In turn, these interactions determine the level of commonality in component conceptualization. Course of action performance modeling is driven by the components' conceptualization of the environment and inter-component effects. An understanding of positive and negative inter-component effects leads to better performing courses of action. The proposed Co-design approach demonstrates that there are other necessary aspects for improvement of military planning integration beyond increasing information sharing. Courses of action developed using a common conceptual model are shown to have a much greater level of integration.

CHAPTER ONE

INTRODUCTION

1.1. Background

Military commanders always seek to maximize the effects of their organization's components by properly arranging them in time and space to achieve integration. The speed and complexity of modern warfare have only magnified the difficulty in achieving integration (Alberts and Hayes, 2003). This challenge is well documented and variously referred to as the need for: synchronization, synergy, unified action, coordination, and/or collaboration in military planning and military command and control (C2) in general. Many recent military policy and strategy documents make reference to the necessity of integration and related concept as a method to mitigate rising complexity and the challenge of diverse mission requirements (Department of Defense, 2005). Reports and critiques of shortcomings in modern military operations also point to integration as a concern that has yet to be fully addressed (Department of Defense, 2010; St Laurent, 2007). A great deal of research and development emphasis has been placed on integration. These efforts have focused on increasing information sharing and enabling knowledge sharing between organization components (Louvieris et al., 2008). Even as knowledge sharing barriers diminish, the challenge of efficiently building common knowledge in time constrained military planning remains (Clark and Moon, 2001). New approaches to military planning and the supporting command and control architectures will be necessary to maximize the benefit provided by new capabilities of knowledge sharing.

The objective of this research is to put forth an approach to military planning which will increase integration between cooperating organizational components, which are termed domains, in the resulting courses of action (COAs). The approach involves investment of additional time early in the planning process to develop a common conceptual model of the operational environment between domains. This approach is contrasted with traditional approaches of separate domain COA development and subsequent de-confliction (iterative adjustment of domain COAs to remove activities that have severe negative impact on the other domains' effectiveness). To demonstrate the feasibility of the proposed approach, a modeling methodology was developed which relates planning process approach to the resulting performance of developed COAs.

1.1 Motivation

Planning integration has been a challenge throughout military history. This challenge has been exacerbated by the current information intensive asymmetrical global security environment. This new security environment means information can travel much further and quicker, adversaries and neutral parties are more diverse and less predictable, and task forces and coalitions are unique to each operation. Civil-military actions such as humanitarian relief and peace keeping require unprecedented levels of cooperation with non-military organizations. All these factors put additional strain on the traditional methods for coordination between military organizations. These methods include establishing clear coordination procedures through training and institutional learning, developing common communication system standards for increased information sharing, and use of organizational liaisons. In addition to updating and improving these traditional methods, new inter-organizational processes will be needed to meet these integration challenges.

1.2. Problem Statement

Current Command and Control (C2) enterprise processes and supporting systems cannot produce integrated COAs within the desired timeframes for planning. This is a result of the combination of environmental challenges described above and failure to update doctrinal planning processes to address the increasing need for integration. Time-constrained crisis action planning results in COAs which are not fully integrated, adding more risk to military operations. Lack of methods to discover and agree upon cross-domain effects makes mutual adjustment between domains very difficult. Commanders are often required to perform COA integration in an ad hoc manner during decision making as a result of C2 process inadequacies.

The systems portion of any architecture is necessarily based on the operational concept and organizational procedures. There is little variation in general planning processes as they relate to inter-organizational integration. The focus for considering alternative designs for C2 planning architectures is currently on the systems architecture. This lack of fundamentally different functional/operational architecture design choice severely limits the scope of considered alternatives.

1.3. Hypothesis

There are other options for improvement of military planning integration beyond increasing information sharing. The current approach of developing separate domain conceptualizations and related COAs first, then beginning a process of integration is inefficient. Consequently, *it is possible to design integrated COAs within the timeframe currently used in mission planning by applying a method based on building a common conceptualization first. The resulting integrated COAs will be more effective.*

1.4. Original Contribution

This research demonstrates a new approach to the C2 planning process which emphasizes integrated planning. A framework is articulated for the logical and efficient construction of a joint understanding of the operational environment between disparate domains (common conceptual model). This effort illustrates that the proposed process is sound and can be used in a complex, real-world military C2 environment. A new paradigm for C2 planning architectures is presented as an important design alternative for consideration.

1.5. Document Organization

This dissertation is presented in six chapters. The first chapter introduces the subject area and background, as well as the problem statement, motivation, hypothesis, and contributions. Chapter two examines inter-organization military planning and explores the related areas of information and knowledge sharing, organizational conceptualization, and human decision making. The following chapter defines integrated planning, its goals, and current and potential methods for integration improvement. This chapter also proposes a method for integrated COA development, what is required, and how it was conceived. Chapter four describes an approach for modeling planning. The modeling approach relates the planning process to the integration level of domain conceptual models and the performance of the resulting COAs. Chapter five presents an application of the research results and their analysis. The final chapter summarizes this effort and recommends future work.

CHAPTER TWO

RELATED WORK

2.1. Organizational Communication and Decision Making

2.1.1 Information and Knowledge Sharing

This research area is extremely broad, potentially covering the fields of management, organizational communication, psychology, sociology, knowledge management (KM), information technology, and others. The focus here is on a general understanding of the relationships between how organizations share information and knowledge and the effects on decision making. This focus aligns well with themes in knowledge management (Chen et al., 2006). Knowledge management is a relatively new research discipline (1990s). There remains debate on the direction and basic definitions of the field (Jashapara, 2005). As a result there are no commonly agreed upon definitions or general models. The one concept that is generally accepted (with slight variations in definitions) is that of the delineation of data, information, and knowledge. The commonly held definitions are represented here according to Zins (2007):

Data are the basic individual items of numeric or other information, garnered through observation; but in themselves, without context, they are devoid of information. Information is that which is conveyed, and possibly amenable to analysis and interpretation, through data and the context in which the data are assembled. Knowledge is the general understanding and awareness garnered from accumulated information, tempered by experience, enabling new contexts to be envisaged.

It is also widely held that advances in information technology have made inter-organizational data and information sharing readily available but knowledge sharing remains a significant challenge. Context sharing and knowledge explicitness are two of many challenges to inter-organizational knowledge sharing (Nonaka and Takeuchi, 1995). Even though this is a very difficult problem, there is research which provides insight into the characteristics organizations must have to improve knowledge sharing. The most basic requirement for knowledge sharing is the ability to share data and information. As mentioned, knowledge is derived from information which is derived from data. Data and information sharing challenges have most likely been overcome between organizations which have worked or plan to work together. It may still be a obstacle however for organizations which are cooperating for the first time as the result of a contingency such as a natural disaster or newly formed military coalition (Holsapple, 2002).

Organizations which can share data and information can potentially also share knowledge. The ultimate knowledge sharing situation is to avoid the requirement to transfer knowledge by creating, managing, and using the knowledge together throughout the planning process (Holsapple, 2002). This is the goal of integrated planning discussed later. Short of this ideal situation, the knowledge must be transferred in some manner between organizations. This transfer must be supported by processes, people, and systems (PPS). Each of these three requirements is necessary to achieve the desired level of knowledge transfer. Various researchers have different models and/or definitions for the extent to which this knowledge transfer between organizations is an integrated process. They can be generalized into the following levels (the top three levels are not necessarily distinct as there may be overlap) :

0. No data/information sharing capability

1. Data and information are shared; no PPS for knowledge sharing; some knowledge might be retrievable by the receiving organization

2. Data and information are shared; knowledge is shared by personal (manual) interactions through established personnel training and procedures

3. Knowledge is shared through PPS (heterogeneous systems with a common ontology)

4. Knowledge is shared through PPS (homogenous system)

5. Collaborative planning - knowledge is inherently shared because it is created, managed, and used in concert.

One example of an organization's knowledge sharing maturity model in the military context is the Network-centric Warfare Maturity Model (NCWMM). This model was developed by Alberts and Hayes (2003) to represent achieved level of interoperability, and is shown in Fig. 1. They argue that interoperability emerges from a set of characteristics; simply enabling shared awareness or collaborating with technology will not achieve interoperability. It requires a change in the entire organization, the processes, the approach to information, and the technology. Their model is defined by the following levels:

Level 0 requires limited interoperability and information sharing. The interoperability that exists is based upon IERs (Information Exchange Requirements) developed from existing organizations, processes, and systems. Level 1 requires that more entities are able to share information. Level 2 requires sufficient interoperability for entities to participate in collaborative environments and processes. Level 3 requires that entities be interoperable not only in the information domain, but also in the cognitive domain, so that shared awareness can be achieved. Level 4 requires interoperability in the social domain so that actions can be dynamically self-synchronized.

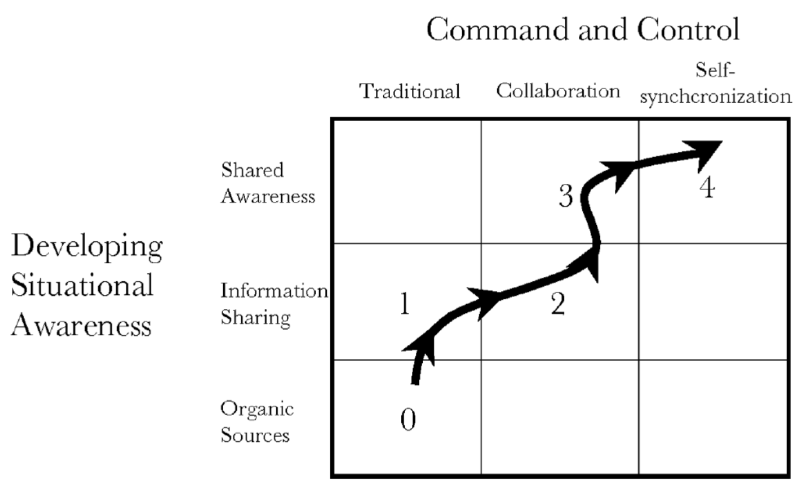


Figure 1 Network-centric Warfare Maturity Model (Alberts and Hayes 2003)

Lindsey (2006) uses a model previously researched in analysis of communications to model knowledge transfer in his analysis of knowledge sharing barriers. This model is useful because it coalesces ideas from other knowledge transfer research into one simple model. The key ideas it captures are encoding and decoding, noise, and feedback. The model, shown below in Fig. 2, shows that knowledge must be encoded by the sender, transmitted through some channel, and decoded by the receiver. Each of these phases can introduce noise (errors, miscommunication) and require time to complete. The time required for data and information transfer is dropping to zero with modern information systems. However, the challenges to knowledge sharing described above mean that cognitive encoding and decoding can take significant amounts of time in inter-organizational processes.

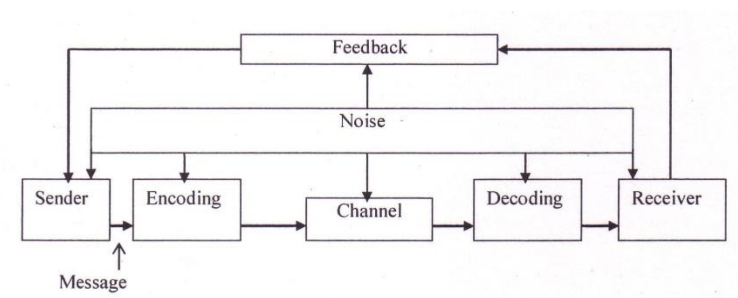


Figure 2 The Communications Model of Knowledge Transfer (Lindsey 2006)

The context of knowledge and cognitive encoding/decoding are associated with the related concept of mental models. Each individual or organization conceptualizes the situation or problem at hand in a mental model (also termed conceptual model). Each entity has its own unique conceptualization of the environment. Data and information are used to produce organizational knowledge of a situation. Through organizational processes, this knowledge is used to create a conceptual model of the operational environment for which planning is taking place (Perry, 2004). This relationship is shown in Fig. 3. Sharing of data/information is a requirement before sharing of knowledge can be considered. Likewise, knowledge sharing is necessary but not sufficient for conceptual model sharing. The generic term "elements" is used for information/data, knowledge, and conceptual models components.

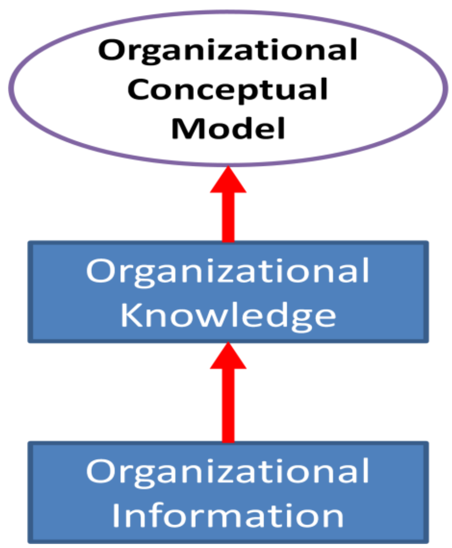


Figure 3 Organization Information, Knowledge, and Conceptual Models

Much of the focus of knowledge management and related areas has been on lowering the barriers to knowledge transfer. Ontologically based, enterprise information systems and service oriented architecture (SOA) based approaches are some of the many efforts to address knowledge sharing challenges. There is significant focus on these areas of research. Less focus has been applied to the organizational processes necessary to take full advantage of new knowledge sharing capabilities as they come to fruition.

2.1.2 Decision Making

Decision making is a complex subject involving rational, cognitive, social, information/knowledge, and other areas. The key areas focused on for this effort are: the bounded rationality of military decision making and the complexities of collaborative decision making. Many of the military problem solving and planning processes are built on the assumption of rational decision making. In the theory of rational decision making, decision makers choose an option which maximizes a value or pay-off function. This is a logical approach to decision making but achieving optimally comes with a heavy burden of required information and decision making resources. Rational decision making requires: information to assess all choices and consequences, identification of an exhaustive set of choices and consequences of those choices, a value function which supports rank ordering all consequences, and resources to analyze all the information prior to decision. Clearly many real life decision making situations do not support these requirements. In 1957 Hebert Simon formalized the idea of bounded rationality:

The alternative approach employed in these papers is based on what I shall call the principle of bounded rationality: The capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose *solution is required for objectively rational behavior in the real world — or even for a reasonable approximation to such objective rationality.*

Bounded rationality is evident in the actual application methods of military planning, even if not reflected in the overall rational decision making structure of the approaches (Grant, 2009). Limitations on planning time and resources drive military planners to consider only several or just one option in many cases. Planning time limitation discussions are expanded below because of their importance. Incomplete and uncertain information is another aspect in which military planning situations do not support full rational decision making. There is clearly an inconsistency here. Prescriptive military process models are largely based on rational decision making concepts. But military leaders operating in the constrained real world environments experience bounded rationality and employ expert decision making techniques. This dichotomy is evident in the ongoing debate on military planning doctrine between naturalistic decision making and rational decision making approaches, discussed in the next section.

In many military planning situations time is a critical factor. In time sensitive planning situations, a trade-off must always be considered between planning time and plan quality/integration. This is summarized well in the United States Army's new field manual on operations: "Taking more time to plan often results in greater synchronization; however, any delay in execution risks yielding the initiative—with more time to prepare and act—to the enemy" (Headquarters Department of the Army, 2010). In planning situations where time is less important, time inefficient processes of inter-domain adjustment can be used. In the more rigorous time constrained environment, full inter-domain de-confliction may not be possible within the time allowed for planning. For a new approach to be considered for use in time sensitive planning, it must not significantly increase the required time for planning.

Collaborative decision making is an extremely complex undertaking in realistic situations. The challenges described above in sharing information, and knowledge, as well as the assumption of rational decision making, are just a few aspects. Even if perfect situational awareness and knowledge sharing are achieved, there are still the process and cognitive requirements of collaboration which add to the already significant burden of time sensitive planning. Choices must be made as to when, what type, and with what tools collaboration will take place in support of planning goals. Studies have demonstrated that not all collaboration and collaboration tools increase planning effectiveness in terms of performance or planning time. Freeman and Serfaty (2002) have shown that not all collaboration is beneficial. Work by MacMillan et al. (2004) has shown that collaboration inherently raises the amount of necessary communication required to accomplish planning tasks. Since communication takes resources (time and cognitive attention), it can degrade other planning activities. Therefore, it is important that processes use the minimum number of coordination and collaborative activities required to accomplish the desired level of integration.

A model that has been effectively used to examine interactions between decision makers is the five-stage interacting decision maker model (Levis, 1993). The model builds upon the classic decision making theory model of two stages, situation assessment and response selection (March and Simon, 1958; Mintzberg et al., 1976) by considering the additional stages for interacting with other decision makers and decision support systems. The five stages are: situation assessment (SA), information fusion (IF), task processing (TP), command interpretation (CI), and response selection (RS). In the situation assessment stage, decision makers create their assessment based on input from the environment or other decision makers. This assessment can be shared with other decision makers. Decision makers that receive shared information can fuse it during the information fusion stage. The fused information can be used in the task processing stage to select an approach to response selection. The command interpretation stage accounts for restrictions to response selection placed on decision makers by superior decision makers. In the final stage, a response is selected which can be an organizational output or an input to another decision maker. This model is shown in Fig. 4.

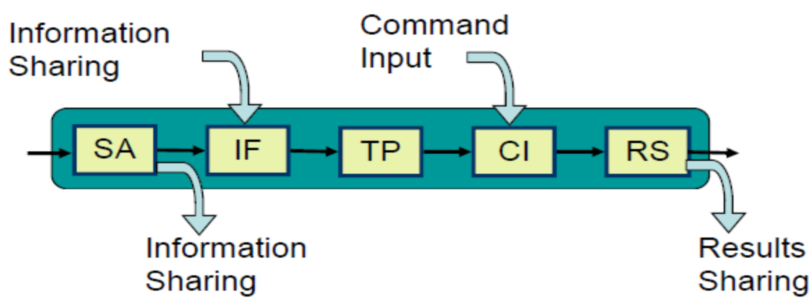


Figure 4 The Five-Stage Interacting Decision Maker Model (Levis, 1993)

2.2. Planning and Design

2.2.1 Military Planning

The United States Department of Defense has a doctrinal planning approach which serves as the basis for most organizational approaches in the United States Military. It can be characterized as an analytic and procedural approach. This is in contrast to emerging alternatives based on naturalistic decision making. The modern analytic and procedural method is generally recognized to have started with the Prussian General Staff in the late 19th century (Herwig, 1998). It was heavily influenced in the mid 20th century by the rational analysis models of psychologists Herb Simon and Allen Newell (Newell and Simon, 1972). Most modern western military doctrinal planning approaches are based on these ideas. The intuitive decision making approach stems from psychological research into the way people actually approach decision making and emerged in the late 1990s led by Klein and others (Klein, 2008). There is ongoing debate on the merits of each approach and combinations of the two (Bryant, 2007).

Most western militaries have planning doctrines based on the analytic and procedural approach and have not changed to reflect intuitive decision making ideas. The United States Army's planning doctrine, for example, has changed little since 1984 (Paparone, 2001). These approaches are generally depicted as a series of sequential steps or stages, often with output from one step serving as input to later steps. In general, the processes are very detailed. For example, the United State Joint Operational Planning doctrine has 7 top-level steps, each with many sub-steps (Chairman of the Joint Chiefs of Staff, 2006), and the United States Army Military Decision Making Process (MDMP) has

7 steps and 40 sub-steps (Headquarters Department of the Army, 2010). The strength of these processes is the systematic and deliberate way that they address the planning problem. However, their widely acknowledged weakness is the length of time required for such deliberate planning (Nawoichyk, 2008). It is also generally acknowledged that in practice these approaches are significantly modified. Although depicted as sequential, steps are often conducted in parallel or iterated as more detail emerges or situations change. In addition, the process is often reduced as a result of time constraints by eliminating or abbreviating steps (Bryant, 2007).

There is a great deal of similarity between the approaches used by the various branches of the United States Armed Forces and between the US, NATO, and Commonwealth (United Kingdom and Canada) allies. Figure 5 shows several western military planning approaches. It is generally true that when considered from a functional perspective, these various planning processes perform the same functions. The functions take place in different sequences and are delineated into various steps but provide the same overall functionality. In general, all the approaches accomplish these functions, usually referred to as the Observe, Orient, Decide, Act (OODA) loop (Boyd, 1976):

- Gather and analyze available information including directives and guidance from superiors
- Formulate one or more courses of action
- Compare or analyze course(s) of action
- Select and implement a course of action

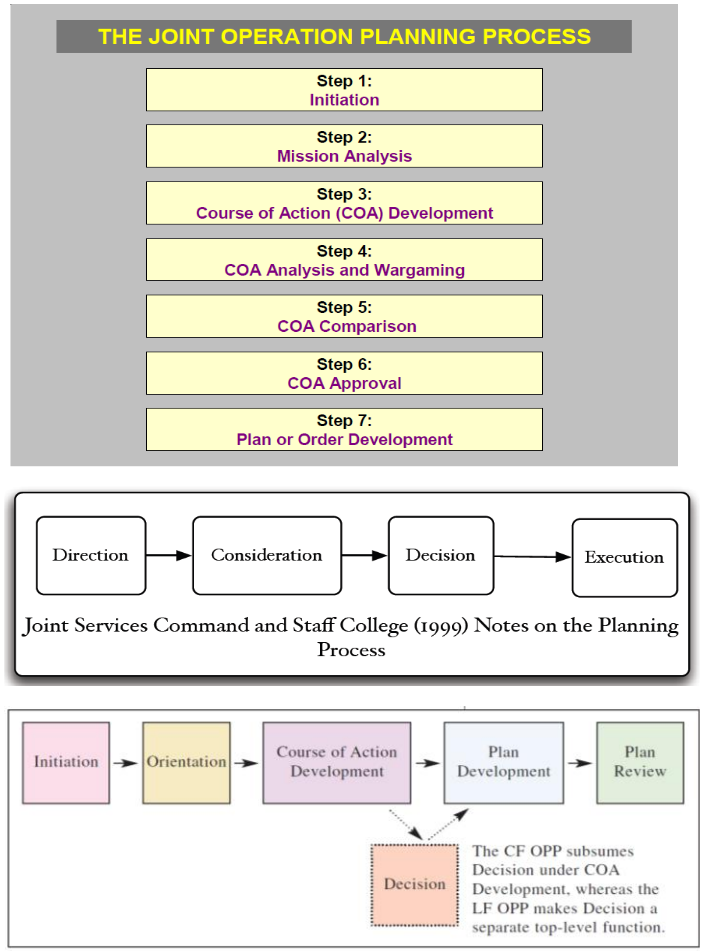


Figure 5 Planning Processes (From top to bottom: United States, United Kingdom, Canada)(Chairman of the Joint Chiefs of Staff, 2006)(Bryant, 2007)

There are two primary alternative approaches: the intuitive decision making approach and hybrid approaches which combine rational and intuitive approaches. The intuitive decision making approach has been mentioned as an alternative which more closely matches the way humans make decisions. The intuitive approach to decision making (and therefore planning) emerged as a result of research into Naturalistic Decision Making (NDM) in the late 1980s/early 1990s. Researchers observed that humans did not follow rational decision making theory approaches when making real decisions (people do not form multiple alternatives and compare them according to utility and probability theory). By observing how people actually made decisions in real situation over many studies, Klein and his colleagues developed the Recognition-Primed Decision (RPD) Model. In this model, a decision maker recognizes patterns from experience and has an intuitive idea on what decision to make. This intuitive idea is then mentally simulated to identify potential pitfalls. If necessary, the decision is modified or replaced completely with a new idea. This process continues until a decision or course of action which satisfices (meets minimum requirements; a term used in NDM contexts) is found (Klein, 2008). After researching applications of NDM ideas in military settings for a decade, Klein and associates extended the RPD to military planning with the Recognition Planning Model (RPM) (Ross et al., 2004). Several military planning researchers have suggested that traditional approaches can be used when there is adequate time for deliberate planning and the RPM or a hybrid (Vowell, 2004) can be used when time is critical (Nawoichyk, 2008).

There are several suggested hybrid approaches that combine aspects of analytic and procedural models with RPM ideas. Bryant (2007) suggests streamlining the Canadian Forces Operational Planning Process by applying RPM techniques to their existing methods which are similar to the US Army MDMP. He proposes keeping the analytic process, but reducing the initial course of action analysis, selecting only one potential course of action, and tightly integrating planning and execution. These are all ideas from the RPM approach. Thunholm (2005) proposes a separate model, the

Planning Under Time Pressure (PUT) model, which also incorporates many RPM ideas but with a key difference. In the PUT model, there is an additional step of analysis of the mission/situation before the commander can be expected to intuit a feasible course of action. This is essentially adding mission analysis to the RPM model which Klein argued is often unneeded. The PUT model breaks the overall planning process down into three steps: 1) What must be achieved? 2) How can it be achieved? 3) How should it be achieved? This breakdown provides a simple but useful delineation of the functional components of any planning process.

Prescriptive process models provide several important background components for this research. A new approach must include the same basic functional components of planning processes as contained in the prescriptive models. It should also be acknowledged that organizations have significant investments in current processes in terms of information systems and personnel training. A new approach which reuses current processes where permissible will be more easily adopted by real world organizations. In addition, including the commander in the approval of an early conceptual model of the environment could help realize many of the benefits suggested by intuitive decision making paradigms. The commander's creation of a conceptual model of the environment is called operational design, or simply design, and is discussed in the following section.

2.2.2 Military Design

In contrast to the procedural nature of the prescriptive planning process, models of operational design are more of an intuitive visualization process as shown in Fig. 6.

Operational design, or just design, is the commander's process of framing and understanding the problem, a necessary component of which is the visualizing of a framework of the operational environment. This has clear overlaps with the common conceptual model of the environment required for integrated planning. Design is a difficult concept to understand even for experienced military professionals (Grigsby et al., 2011). Two United States Military definitions are presented here:

Design is a methodology for applying critical and creative thinking to understand, visualize, and describe complex, ill-structured problems and develop approaches to solve them (Headquarters Department of the Army, 2010).

Operational Design — the process of developing the intellectual framework that will underpin all plans and their subsequent execution (Chairman of the Joint Chiefs of Staff, 2006).

The analogy of an architect and an engineer cooperating to build a house can be used to understand the interactions of the design and planning processes respectively. The architect takes the requirements and creates a vision of the house based on creativity and experience. This vision is communicated to the engineer who must turn it into a reality consistent with all the real world constraints. There is frequent interaction between the architect and engineer as constraints and discovered problems impact realization of the design vision. The vision evolves over time as a reaction to real world events but also the architect ensures that construction does not stray from the vision (United States Army War College, 2008).

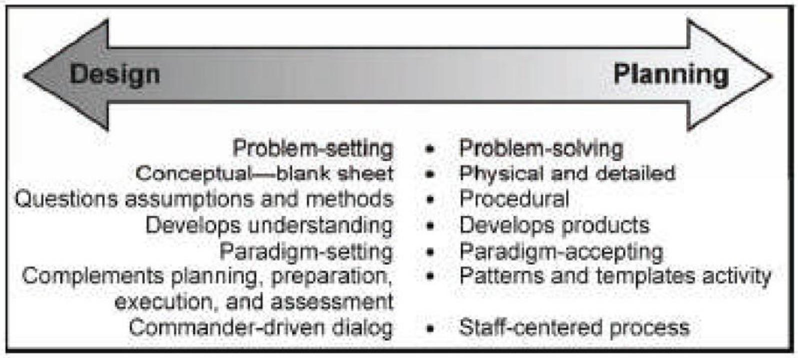


Figure 6 The Continuum of Design and Planning (United States Army War College, 2008)

While there is only one concept of operational design and how the design process (driven by the commander) interacts with the planning process (executed by the staff), there are several alternative frameworks for organizing and representing operational design. The design framework presented in the United States Military planning manuals is Center-of-Gravity (COG) analysis. Alternative frameworks include: Effects-Based Operations (EBO), Operational Net Assessment (ONA), and Systemic Operational Design (SOD).

According to the United States Military joint planning doctrine, :

[The COG] is a source of moral or physical strength, power, and resistance — what Clausewitz called "the hub of all power and movement, on which everything depends . . . the point at which all our energies should be directed." A COG can be viewed as the set of characteristics, capabilities, and sources of power from which a system derives its moral or physical strength, freedom of action, and will to act. The

COG is always linked to the objective. If the objective changes, the center of gravity also could change. (Chairman of the Joint Chiefs of Staff, 2006)

COG analysis is a framework which assists planners in relating the main sources of friendly and enemy power with their goals, capabilities, and potential weaknesses. COG analysis includes identification of friendly and enemy centers of gravity and three related critical factors: critical capabilities, critical requirements, and critical vulnerabilities. Critical capabilities enable the center of gravity to perform its desired functions and thereby accomplish its goals. Certain resources, conditions, and means are required for a critical capability to be realized; these are termed critical requirements. Critical requirements that can be affected by an adversary or which are deficient in the first place are called critical vulnerabilities (Chairman of the Joint Chiefs of Staff, 2010). As part of operational design, decision makers use the COG/critical factors framework to envision an operational concept which efficiently defeats the enemy COG. Concepts are designed to take advantage of enemy critical vulnerabilities while protecting friendly critical capabilities. This approach minimizes operational risk (Cardon, 2010). Any proposed planning approach should take advantage of the similarities between the operational design process and the integration requirement to construct a common conceptual model of the operational environment

2.2.3 Non-military Fields

If we consider military planning in a generic sense, it is a problem solving and design process. Inter-organization military planning is then related to group problem solving, cooperative work, and concurrent/distributed design processes. Research in these non-military fields then provides some insight into approaches for integration. Emerging research in these areas indicates there is a connection between agreeing on a common conceptual model and the integration level of the resulting product. Research in psychology of team and group cooperation and decision making has shown that common or overlapping mental models of the tasks and methods are a prerequisite for effective performance (Serfaty and Kleinman, 1990; Cooke et al., 2000). Several researchers in cognitive psychology have put forth work more directly related to this research in that they have created and experimented with models of expert decision makers in time sensitive cooperative planning. These are discussed further in Section 2.2.4.2. Much of the recent work in cooperative design and concurrent engineering identifies building a common conceptual model of a problem as a crucial step in various methodologies for improving the integration of the results (Schmidt, 1994; Détienne, 2006). Others have demonstrated specific analytical approaches to improvement cross-organization coordination and workflows (Huang et al., 2010; Ping Jiang et al., 2008). Although they do not explicitly discuss a cross-organizational conceptual model, the frameworks they propose are essentially accomplishing the same function, which is to establish a model that effectively unifies participants' understanding of how their part affects the common outcome. Another focus area in coordination design is the management of design task interdependencies (Malone and Crowston, 1994). Still other efforts have focused on the crucial role of conflict resolution and techniques for negotiation and agreement in collaborative engineering and design (Lu and Cai, 2001; Lu et al., 2007). In all, these efforts highlight the potential promise of collaborative approaches for increased integration and challenges such as conflict resolution and agreement.

2.2.4 Modeling Planning, Design, and Integration

2.2.4.1 General C2 Models

The Observe-Orient-Decide-Act (OODA) loop is the best known conceptual C2 model. It was conceived during the Korean War to model the decision cycle of fighter pilots by Col. John Boyd (Wikipedia, 2011). The main concept behind the model, that the adversary with the shortest decision cycle will win the contest, is still a major tenet of military art. The OODA model was adopted as a general model of the decision making process and popularized in business as well as strategic and operational level military contexts (Grant and Kooter, 2005) . The OODA model is shown in Fig. 5, and consists of the following steps:

- Observe - Gathering information and data from external sources
- Orient - Processing gathered information and assessing the situation
- Decide - Choosing a course of action based on assessment
- Act - Implementing the chosen course of action

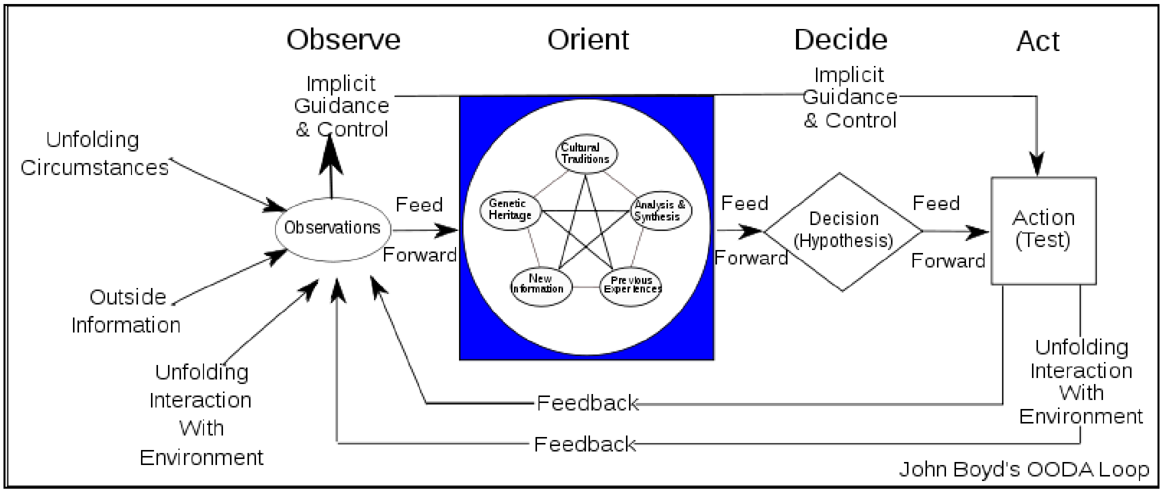


Figure 7 OODA Loop (Wikipedia, 2011)

Similar models were developed around the same timeframe: the Stimulus-Hypothesis-Options-Response (SHOR) model by Wohl (1983) and the five step Sense-Process-Compare-Decide-Act model from Lawson (1981). The resemblance of these models coupled with the large number of OODA adaptations and successor models (Modular-OODA, Team-OODA, Cognitive OODA, etc.) demonstrate the general applicability of the OODA and similar concepts (Guitouni et al., 2006). While OODA is focused on the decision cycle, the Critique, Explore, Compare, Adapt (CECA) model explores the cognitive aspects of creating and updating conceptual models of the situation/environment which is implicit but not emphasized in the "orient" phase of OODA (Bryant, 2003).

The OODA processes can be expanded into more detailed activities. This expansion enables mapping of more detailed C2 processes to the general phases of the

OODA model. This allows separating the functions of generating options (COA development) from evaluating options (COA analysis) as an example that can be applied to planning (Fewell et al., 2005). An example of an expanded OODA loop model is shown in Fig. 8.

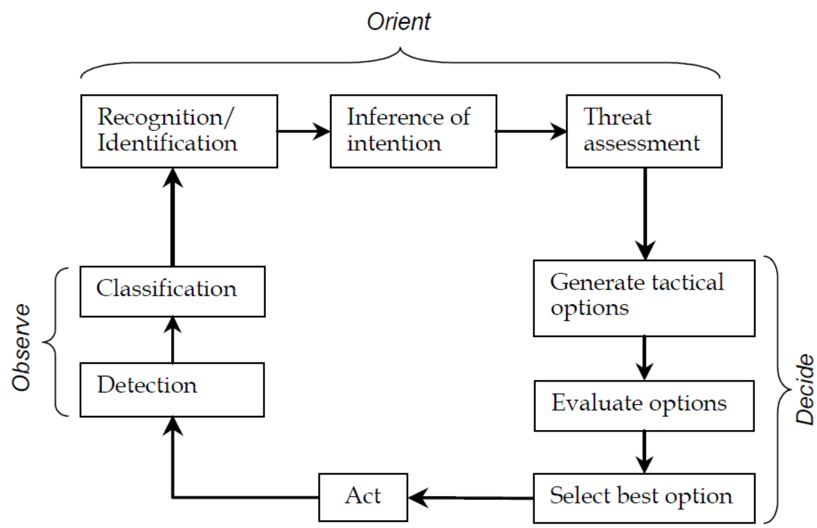


Figure 8 Expanded OODA Loop Model (Fewell et al. 2005)

The general applicability of OODA and similar C2 models is demonstrated by their frequent and continued use for government, business, and military application for nearly sixty years (Guitouni et al., 2006). Any general model used in the development of a new planning approach should be consistent with the concepts in these models.

2.2.4.2 Integration Models

There are no known general models of a strategic/operational level integrated planning process but there are related models. There are models of military planning integration which address some integration aspects. The goal of the integrated COA is a cross-domain COA which best meets the commander's selection criteria. The understanding of how well a COA meets the commander's criteria and the underlying aspects which effect how well a COA meets the criteria are termed option awareness (Drury et al., 2009). Klein et al. have expanded this definition based on Endsley's (2000) levels of situation awareness to create the three levels of option awareness shown below. Clearly the goal of an integrated planning process would be to allow all participants the highest level of option awareness permissible during each phase of the COA development and selection.

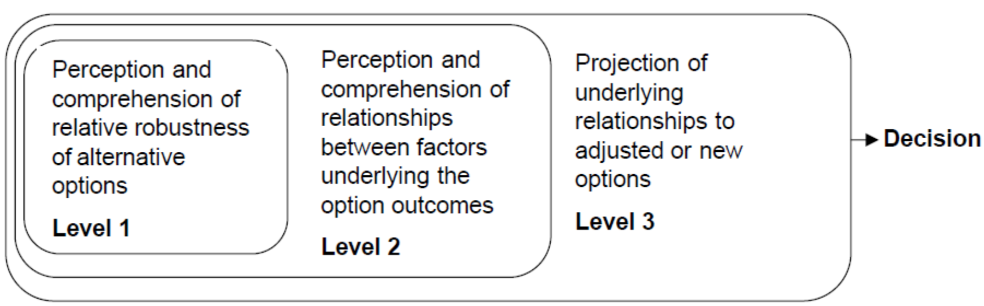


Figure 9 Endsley's Levels of Situation Awareness (G. L Klein et al. 2010)

In Klein et al. (2010) the authors present the COAction process for tactical decision making. They demonstrates effective joint option awareness for situations with a relatively small decision space and decision makers having access to a decision support tool which modeled the interaction effects between domains. Several key aspects in this study were pre-determined for the decision makers: the goal and measure of performance, the set of actions, the probability of states of nature, the interactions between actions for each domain, and a method for expressing the joint options results. In more complex situations such as realistic strategic/operational level military planning, each of these aspects will have to be determined and agreed upon by involved parties during planning, if joint option awareness is to be achieved. For this concept to work, a process must be identified to build option awareness during the COA development process using appropriate information exchanges and mutual decision making steps.

In the Collaboration Evaluation Framework (CEF) research, Klein and Adelman (2005) demonstrate through experimentation Thompson's concept of collaboration methods becoming more resource intensive as they progress from standardized to planned to mutual adjustment (Thompson, 1967). In experiments with tactical level military planning scenarios, it was shown that changing collaboration tasks approaches from mutual adjustment to planned or standardized lowered the communication and cognitive resource costs. Mutual adjustment collaboration tasks were changed to less costly approaches by developing process routines/rules and method/systems that encourage common conceptual agreement (Klein et al., 2008). This would indicate that building a common conceptual model lowers the resource cost of integrating COAs.

2.2.4.3 Analytical Process Models

There are many prescriptive and/or procedural process models for military planning and design as explored above. There are relatively few analytical models of military planning and design processes. One model of planning process is "Formal specification and state space analysis of an operational planning process" by Mitchell et al. (2007). This research effort describes a systematic approach for constructing a CPN model of an operational level military planning process which models process steps, information flows, and staff utilization. The described techniques can be used to efficiently build discrete event models of other strategic or operational level planning processes including integrated planning. Another effort examined the functional flow of activities performed during actual operational level planning as contrasted with doctrinal process models (Bruyn et al., 1987). It was determined that many processes were abbreviated as a result of planning time constraints.

As stated above, CPN models have been used to model military planning processes. CPN and related business process modeling techniques have been used extensively to research and model processes across a large number of fields: business (Lohmann et al., 2009), biology (Reisig, 2011), information systems (Van Dongen et al., 2009), and many others. Petri Nets have properties that provide several advantages for process modeling: mathematical basis, a large body of theory, executable nature, hierarchical, and inherent visualization (Girault and Valk, 2003).

Carl Petri first developed Petri Nets in 1962. Petri Nets are bipartite directed multi-graphs. Bipartite refers to the two types of nodes: places and transitions. Nodes are connected with directed arcs and there can be multiple arcs between the same two nodes. Arcs are not allowed between two nodes of the same type. Tokens reside in places and are consumed and created with the execution of transitions. Places with arcs to transitions are called input places while places with arcs from transitions, output places. Input places represent pre-conditions, required resources, or input data. Output places represent output data, produced information, or available resources. Transitions models represent processors, events, tasks, or jobs. Tokens in places represent available resources or conditions met. An example Petri Net execution is shown in Fig. 10. The left side shows the net prior to transition (T1) execution. The token present in P1 means necessary information or resources are available, or preconditions have been met. The right side shows post execution where the precondition are no longer met but the post condition are now satisfied.

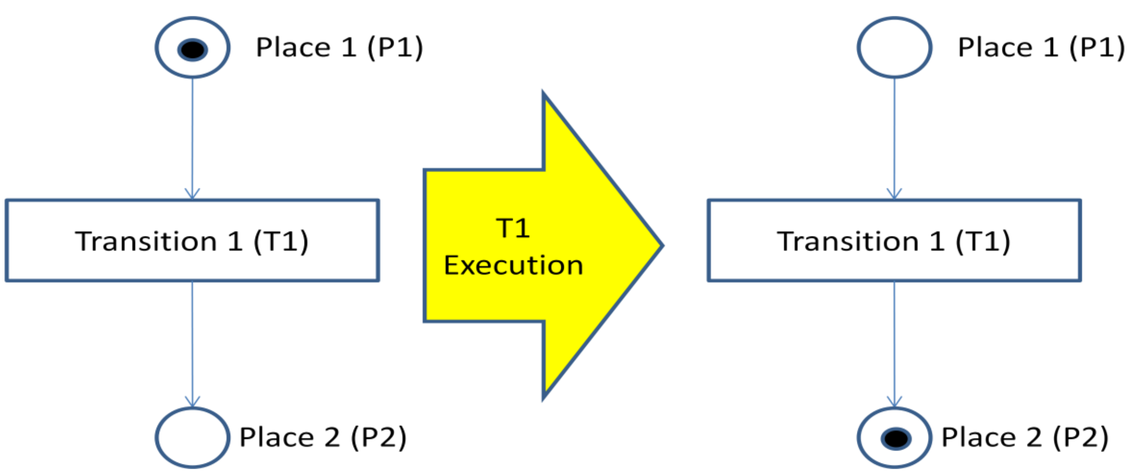


Figure 10 Example Petri Net Execution

Detailed descriptions of CPN application into many problem types are available in (Jensen and Kristensen, 2009).

2.2.4.4 Analytical Models of Planning Results

There are many examples of analytical methods used to enhance military planning. The majority involve COA creation/discovery, performance analysis, and/or comparison. Several approaches are rather specific in the applicability to portions of military planning or certain situations/levels of war. Aberdeen et al. (2004) demonstrate the use of algorithmic approaches developed in the field of artificial intelligence to efficiently solve an operational planning problem formed as a Markov decision process. This could be used in COA development from a planning and scheduling perspective where resource cost, duration, and likelihood of success are known. Kewley and Embrechts (2002) present a fuzzy-genetic decision optimization approach for determining a final population of high-performance plans (COA) after a genetic algorithm search. In this approach, the commander specifies his preference for battle outcome which is then converted to genetic algorithm search parameters using fuzzy ordinal preference. Their methodology uses a high resolution combat simulation and is therefore only directly applicable to tactical planning in its current form. One approach uses a 2-person zero sum gain game theory model for COA comparison. Its research contribution is the heuristic for determining the military worth of a standard COA for use in the payoff matrix (Cantwell, 2003). Zhang et al. (2001) present a framework for modeling an operational level military planning using Colored Petri Nets (CPNs). Using state space analysis and simulation, they demonstrate the model's ability to answer important planning questions (readiness for enemy action in their example).

A second group of analytical approaches has more direct application to this research. These modeling paradigms can all be used to model the interactions that occur in the common conceptual model of the environment which is a requirement for integrated planning. The mathematical model in each case could be used as the modeling language to quantify the interactions expected between actionable events in the operational environment. One approach, by Thuve (2006), uses differential and difference equations to model all the interactions in a systems-of-systems approach to modeling the operational environment. This research was focused specifically on the Effects Based Operations (EBO) framework for operational design but the basic methodology could be extended to other frameworks. There is a body of related research which involves modeling of military strategic COAs which include Diplomatic, Information, Military and Economic (DIME) factors using influence networks and CPNs. Wagenhals et al. (1998) initially demonstrated the modeling of strategic level COA with influence networks. Influence networks were valued for the ability to represent the complex interactions of DIME component at the strategic/operational level. This research further illustrated the timing effects of COA actions by converting the influence network to a timed CPN and estimating the delay associated with each actions' effects. This research was then extended by inclusion in Decision Support System for Coalition Operations (DSSCO) to support COA development and analysis in a coalition environment (Lee W. Wagenhals et al., 2001). Concurrently, (Falzon et al., 2000) proposed a process for using an influence network to model COAs using a COG framework based decomposition. Later Levis (2010) summarized these concepts and the algorithms that were developed to allow analysis of the time-sensitivity of COAs without manual conversion to timed CPNs.

Timed Influence Nets (TINs) are well suited for modeling COA conceptualization and performance. Influence nets and timed influence nets are probabilistic belief networks with similarities to Bayesian Networks (BN). Unlike BN, TINs assume independence between causal influences which greatly simplifies the process of parameter elicitation by avoiding the requirement for developing extensive tables of conditional probability. The tables are instead constructed through the Causal Strengths (CAST) algorithm (Chang et al., 1994). In situations where probability estimates are subjective, such as in strategic/operational course of action development, this assumption is appropriate. Previous research has demonstrated the effectiveness of TINs in operational and strategic level course of action development and modeling (Wagenhals et al., 1998).

TINs are depicted as a network of nodes and directed arcs. The influence nodes represent random variable with two states, true or false. These nodes are chosen because they are events of interest in the situation being analyzed. Arcs represent causality. They show the influence of the source, or parent, node on the destination, or child, node. Arcs can be either promoting, shown with a pointed arrow, or inhibiting, shown with a round head on the arc. Nodes without parents are used to model potential actions of actors in the situation being modeled. Nodes without children are often the target or goal node(s) that represent the most important event(s) of interest.

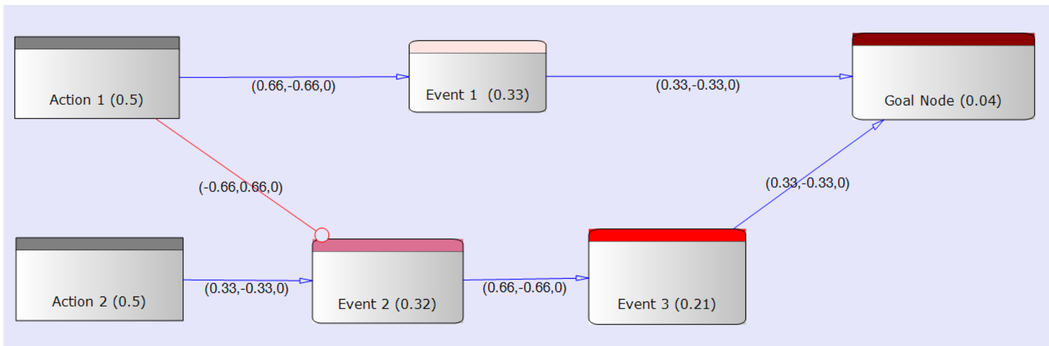


Figure 11 Influence Net Example

A simple influence net example is shown in Fig. 11. This example was created using the Pythia TIN software tool. There are two actions, three events of interest, and the goal node. In this case every arc is a promoting arc except the arc from Action 1 to Event 2. The promoting arc from Action 1 to Event 1 indicates that if Action 1 is true the likelihood of Event 1 increases. However if Action 1 is true the inhibiting arc to Event 2 decreases its likelihood. The numbers seen on the arcs indicate the strength of the influence. The strength of the influence of Action 1 on Event 1 is twice the magnitude of the influence of Action 2 on Event 2. The software tool can update the conditional probability of all nodes after the probability of the activity nodes is specified. In this case, with the probability of both actions set to 0.5, the probability of the goal node being true is 0.04.

This chapter has examined research work related to this effort. Previous work on knowledge flow and cooperative decision making between organizations was considered. Efforts on planning and design were also summarized. These include both civilian and military approaches and methodologies to measure and model them. The following chapter discusses more specifics on integrated planning: definitions, requirements, and approaches.

CHAPTER THREE

APPROACHES TO PLANNING INTEGRATION

3.1 Defining Integration

The term integration has many meanings depending on the domain and context, as do the related terms synchronization and synergy. Much of the difficulty in defining management or organizational integration stems from the fact that there are a great many inter-related fields that use these terms in different variations. Some of the many related theoretical areas and concepts are: organizational theory, military command and control theory, enterprise integration, enterprise resource planning, knowledge management, supply chain integration, information technology integration, system of systems architecture development, business process improvement, and collaborative planning systems. For this effort, integration is any effort that more closely aligns two concepts or processes. The level of integration is a state that can range from completely unrelated to fully integrated.

There is also no accepted definition for integrated planning or integrated COAs in military contexts. The definition of related terms according to United States military doctrine is shown below (Chairman of the Joint Chiefs of Staff, 2008):

Integration — The arrangement of military forces and their actions to create a force that operates by engaging as a whole.

Command and control — The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. Also called C2.

Synchronization — The arrangement of military actions in time, space, and purpose to produce maximum relative combat power at a decisive place and time.

Unified action — The synchronization, coordination, and/or integration of the activities of governmental and nongovernmental entities with military operations to achieve unity of effort.

Unity of effort — Coordination and cooperation toward common objectives, even if the participants are not necessarily part of the same command or organization.

Integrated command and control is not defined in any official United States Government documents. However, in the Air Force Research Laboratory solicitation announcement for research into this area, the concept is described broadly as follows (Department of the Air Force, Air Force Materiel Command, Rome Research Site, 2010):

Meeting the demands of assigned missions requires unprecedented amount of coordination and synchronization of military resources across all organizations and all echelons of command in all levels of war. It is command and control that provides the *means by which a commander synchronizes and/or integrates force activities in order to achieve the commonly recognized objectives in one unity of effort. These activities require key decisions within the strategy, planning, scheduling and assessment phases of the command and control process. These decisions are made by humans and are supported by computer technology so it is in these areas that information technology contributes the most to ameliorating human capabilities and transforming how the Air Force commands and controls.*

Based on the above description of the concept, the key ideas for integrated C2 are:

- The complexities of modern military operations require unprecedented levels of coordination and synchronization
- Coordination and synchronization are required horizontally (between organization at the same hierarchical level but potentially different domains) and vertically (between different echelons)
- Successful use of this paradigm results in unity of effort; horizontal and vertically

Based on this understanding of the concept of integrated C2, **an integrated COA is a COA in which all participating entities act as one organization in pursuit of a common goal.** For this research a more precise definition is used. A domain COA is a set of actionable events and associated execution times chosen by a domain. When there are multiple domains cooperating toward a common goal, there are interaction effects between domains (some actions maybe more or less effective based on the actions of another domain). If the actionable events of all cooperating domains are selected to realize positive interaction effects and avoid negative interaction effects, then the combined COA is integrated. In other words, **an integrated COA is one in which no higher estimation of performance can be obtained by changing the actions taken and action timing in each involved domain COA**.

3.2 Requirements for Planning Integration

In order to conduct integrated planning, a common understanding of the operational environment is needed. This common model allows a dialog during COA development as to the mutual effects of various actionable event choices and execution times between domains. A process must be articulated that builds this common conceptual model during the planning process. The process must include a concept for information sharing and joint decision making that does not significantly slow the process and is not dependent on a particular DSS or analytical model. The process should emphasize sharing and agreeing on only what is necessary to build a common conceptual model of the operational environment. As much as possible, the process should build the common understanding of the environment as extension of processes that are already accepted activities of planning. To be used for integrated COA development, the common conceptual model must include: 1) Goals and metrics, 2) Adversary and environment potential actions, 3) Domains' potential actions, and 4) System structure (variables, interactions, and constraints). The model must enable an understanding of how well a COA meets the commander's criteria and the underlying aspects which affect how well a COA meets the criteria during its selection (provide option awareness).

3.3 Current Approaches

United States military planning doctrine does not explicitly define a methodology for inter-domain planning integration (Chairman of the Joint Chiefs of Staff, 2006; Chairman of the Joint Chiefs of Staff, 2001). The importance of planning integration is articulated but no specified approach is suggested. The traditional method for producing an integrated COA is to develop and approve domain COAs and then begin the time consuming process of mutual adjustment coordination to obtain the best performing (criteria determined by the commander) integrated COA. This process clearly breaks down in a time constrained environment where the integration level of the COA is ultimately determined by the time available for mutual adjustment coordination. This is the reality of current US military planning processes shown in Fig. 12. The figure also shows the information time lag associated with concurrent planning processes. As a result of the encoding and decoding delays discussed in Section 2.1.1 shared information from adjacent domains can arrive after relevant decisions are made. The process block entitled "Informal design coordination" represents the process of coming to some level of common agreement on a conceptual model of the operational environment. This must take place to have a meaningful dialogue on COA changes that increase overall inter-domain effectiveness.

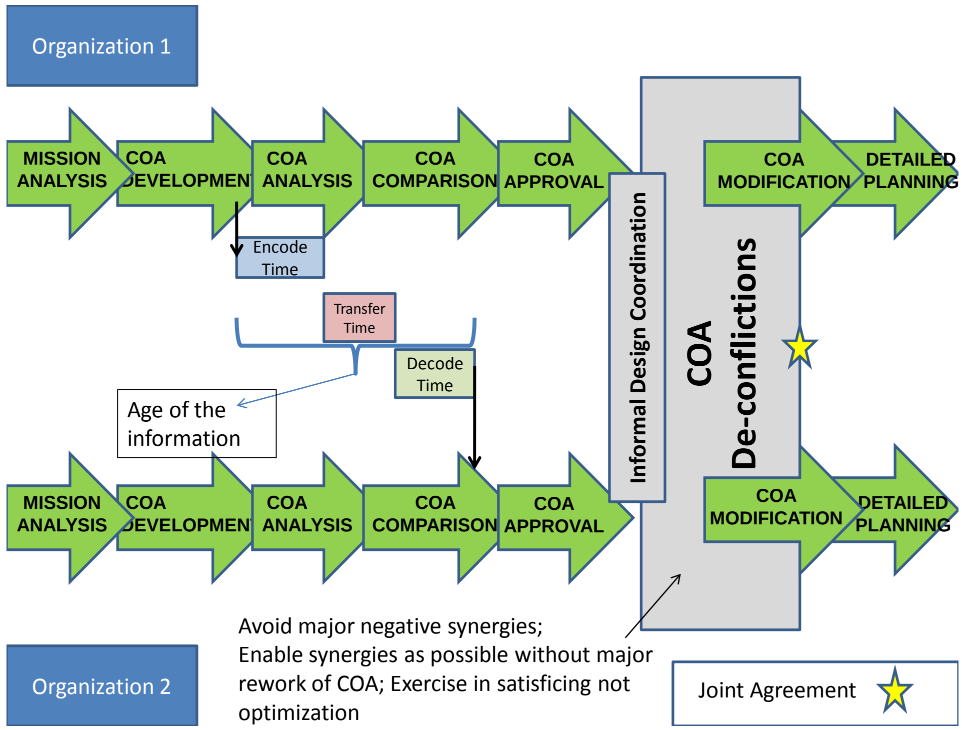


Figure 12 Current Planning Approach

3.4 Conceptual Models

During military planning each domain is building a conceptual model of the operational environment. Organization information, knowledge, and conceptual models are evolving during the planning process until decisions are made by the commander to approve specific aspects at certain points. Based on this understanding of how the operational environment works, each domain will choose a COA which best meets the commander's and/or higher authorities' specified criteria.

There are two primary considerations in developing processes to increase inter-domain COA integration: what is shared (conceptual models, knowledge, or information), and when in the process this sharing is attempted, as shown in Fig. 13.

The choice of when in the process to share elements affects whether or not the specific element has been approved by the domain commander. In addition, for conceptual models and knowledge, there is the choice of whether or not and when to attempt inter-domain agreement on a specific element.

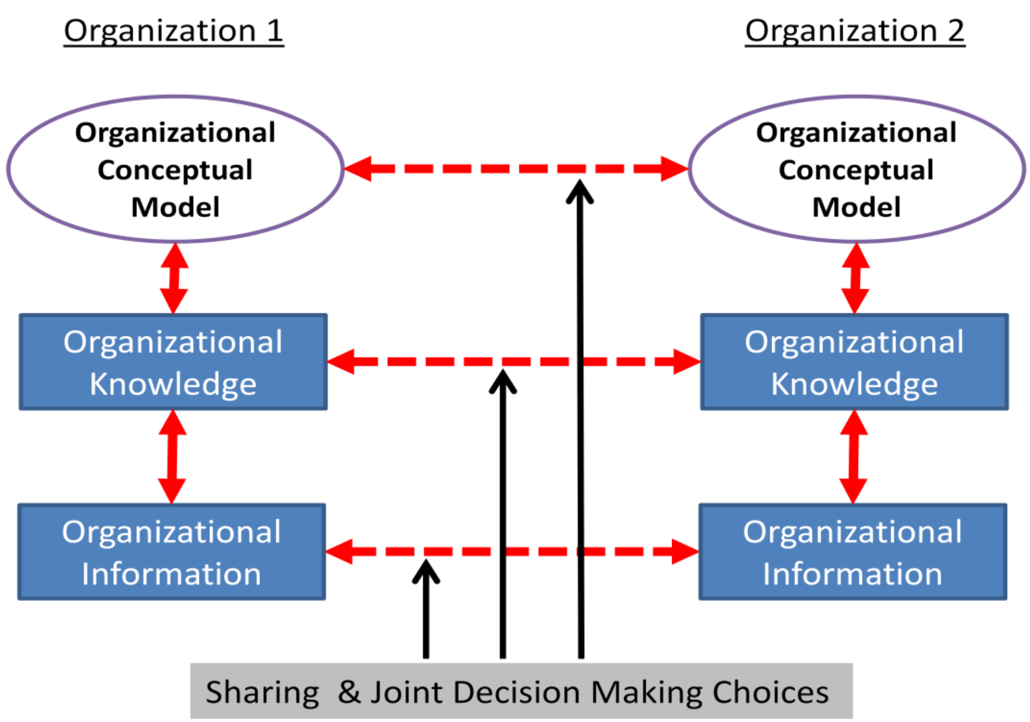


Figure 13 Element Sharing and Joint Decision Options

3.5 Co-Design

Separate domain conceptual models make integration very difficult and a common model increases integration. Therefore, the goal is clear: a process that will facilitate common conceptual model creation during military planning without significantly increasing the time required. The proposed approach is based on creating a common conceptual model of the operational environment among all domains prior to developing COAs. Important to the overall concept is the acknowledgement that the domains seek to establish a common conceptual model. Although information and knowledge sharing is required, this is the means and not the end. Current approaches toward integration are based on increasing knowledge sharing: Commanders are sharing knowledge with other commanders, Commanders are communicating knowledge to their staff, and Staffs are sharing knowledge with other staffs. The exchange of knowledge implicitly and slowly adjusts domain conceptual models, but COAs that are initially based on domain conceptual models and then de-conflicted create the burden of changing domain conceptual models after they have been formed. In contrast, the proposed approach is based on integrating the necessary components of domain conceptual models before beginning to develop courses of action.

The proposed approach is centered on consensus building between domains during the operational design process and related planning activities. This approach is therefore termed "Co-design," as it describes a cooperative operational design process among domain participants. Five stages were developed to incrementally build the common conceptual model during mission analysis. This allows domains to agree on essential conceptual model elements one increment at a time to simplify consensus building. The five stages and the conceptual model component delineation were chosen to align with existing concepts in operational design. The five steps, termed design coordinations, are: Step 1. Objective(s) and metric(s), Step 2. Key Influencers of objective(s), Step 3. Adversary and environment potential actions, Step 4. Organizations' (Domains') potential actions, and Step 5. System structure (interactions, constraints, synergies). These five steps are envisioned as enabling joint conceptual model creation. To these, three more design coordinations are added to facilitate the overall integrated COA development process: Step 0. Agreement on Coordination Approaches (if not specified by previous agreement), Step 6. Develop Integrated COA Actions, and Step 7. Establish COA Action Timings. The entire process between two domains is shown in Fig. 14. Higher headquarters guidance and its potential effect on any point in the process are explicitly shown.

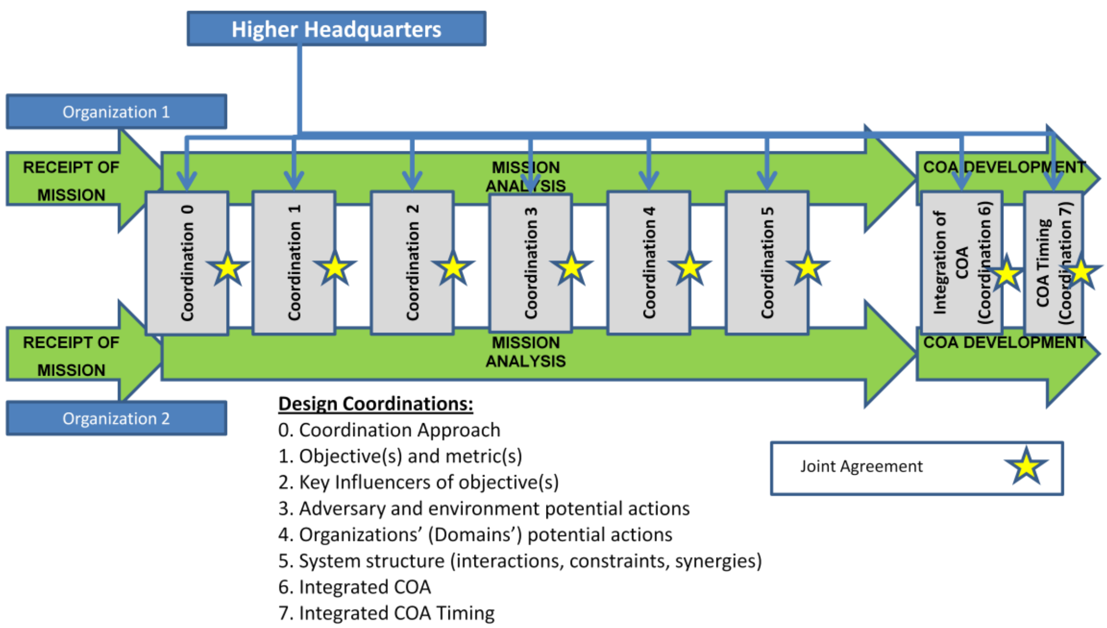


Figure 14 Proposed Approach

An attempt was made to lower the potential implementation burden of the new approach through use of existing planning and design processes as much as possible. First the necessary components of a common conceptual model to allow integrated COA creation were identified. These components were then related to the conceptual model components which are commonly created by commanders during operational design. In turn, the necessary inputs for each component of the commanders' design from standard military planning process activities were determined. An example of this information/knowledge relationship is shown in Table 1. This example specifically uses the JOPES process planning model and the COG approach to operational design, but equivalent concepts could be used from alternative prescriptive models.

Table 1 Planning Activity Inputs to Design Coordination

JOPES Activity	JOPES Output/Input to Design Coordination	Design Coordination	Design Coordination Output	Equivalent Doctrinal Design Concept
Analyze Commanders Mission and Intent	Proposed Mission and Intent	1. Objective(s) and Metric(s)	Joint Objectives and Metrics	The Desired Effect on the Enemy Center of Gravity and Means to Measure it
Determine Own Military End State Objectives and Initial Effects	End State and Objectives			
Determine Own and Enemy's Centers of Gravity and Critical Factors	Enemy Center of Gravity	2. Key Influencers of Objective(s)	Joint Key Influencers of Objectives	Critical Factors that Affect the Enemy Center of Gravity
JIPOE	Potential Enemy Actions	3. Adversary and Environment Potential Actions	Joint Adversary and Environment Potential Actions	Effects which the Adversary will Attempt to Achieve on the Friendly Center of Gravity
Determine Specified Implied and Essential Tasks	Potential Tasks	4. Organizations' (Domains') Potential Actions	Domains' Potential Actions	Effects which Coalition Capabilities can Achieve
Conduct Initial Force Structure Analysis	Potential Capability to Conduct Actions			
JIPOE	Effects of Potential Enemy and Environment Actions	5. System Structure (Interactions, Constraints, Synergies)	Interactions, Constrains, and Interaction Effects of the Common Conceptual Model	Constraints on Coalition Actions; The Interactions of Coalition and Adversary Effects
Determine Facts Status Conditions	Facts on Effects			
Determine operational limitations	Operational Constraints			
Develop assumptions	Assumptions on Effects and Interactions			
determine own military end state objectives and initial effects	Operational Effects			

Chapter Three has considered integrated planning in detail. First integrated planning and integrated COAs were defined. This was followed by a consideration of what is required to achieve integrated planning. Then, current approaches toward integrated planning were discussed. Finally, a new approach was proposed which focuses on early integration of conceptual models. The following chapter presents the research approach for modeling the planning process, the planning results, and how they are connected.

CHAPTER FOUR

MODELING THE PLANNING PROCESS

The feasibility of the proposed approach can only be explored with a modeling paradigm that relates the planning approach with the time required and the estimated performance of the resulting COAs. To achieve this, a two part modeling approach was used: a discrete event model of the planning process and a timed influence network (TIN) model of the domain conceptual models and resulting COAs. Based on the chosen planning approach with its associated coordination activities, the process model provided an estimate of the time required to complete the planning approach. The TIN provides both a model of the domain's conceptualization of the operational environment and a probability of goal achievement, or mission accomplishment, based on a chosen COA. The structure of the timed influence net used by each domain to choose a COA was determined by the planning process (coordination approach) used in the process model. This overall modeling approach is shown in Fig. 15.

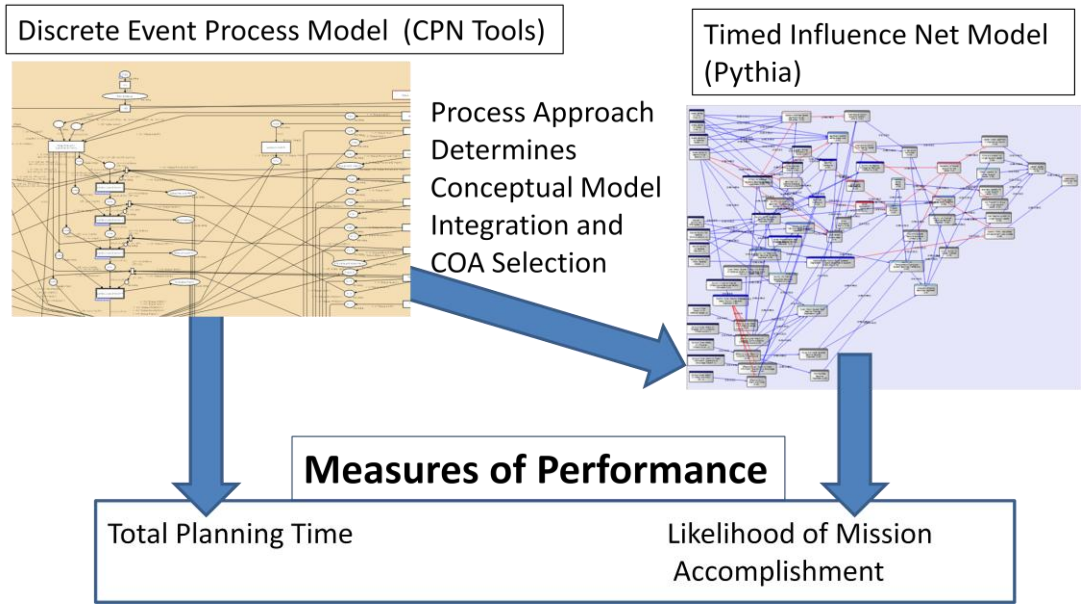


Figure 15 Modeling Approach

4.1 Process Modeling

4.1.1 Process Model Structure

As described in Section 2.2.3, one of the strengths of CPN is their hierarchical nature. Using this capability, extremely large models can be organized in a manageable way. The planning process model is organized into four hierarchal levels as shown in Fig. 16.

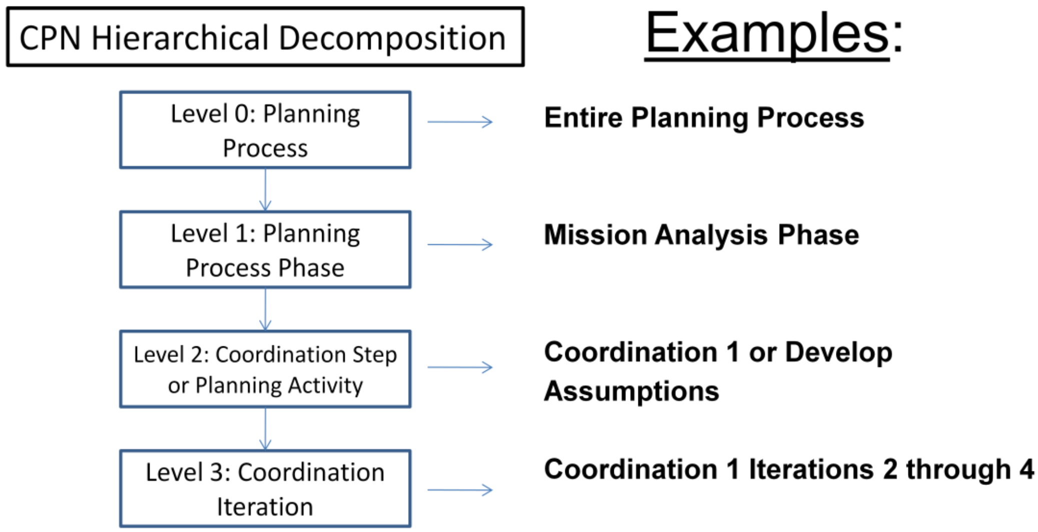


Figure 16 Planning Process Model Hierarchical Decomposition

The focus of this research is on methods for COA development. It is sufficient to focus on the military planning phases from initiation through COA approval to examine different approaches to COA development. Figure 17 shows the Level 0 decomposition of the process model with six planning phases: Mission Analysis, COA Development, COA Analysis, COA Comparison, COA De-confliction, and COA Approval. The COA De-confliction phase is not explicitly described in current planning approaches. The activities of this phase must be conducted to mitigate negative cross-domain effects, as described in Section 3.3. The token generator is not a planning phase, but rather is a modeling device that is described later. Three process phases are modeled in detail to examine the differences in the proposed approach and current methods: Mission

Analysis, COA Development, and COA De-conflictions. The remaining phases are the same for all approaches and are not modeled below the planning phase level.

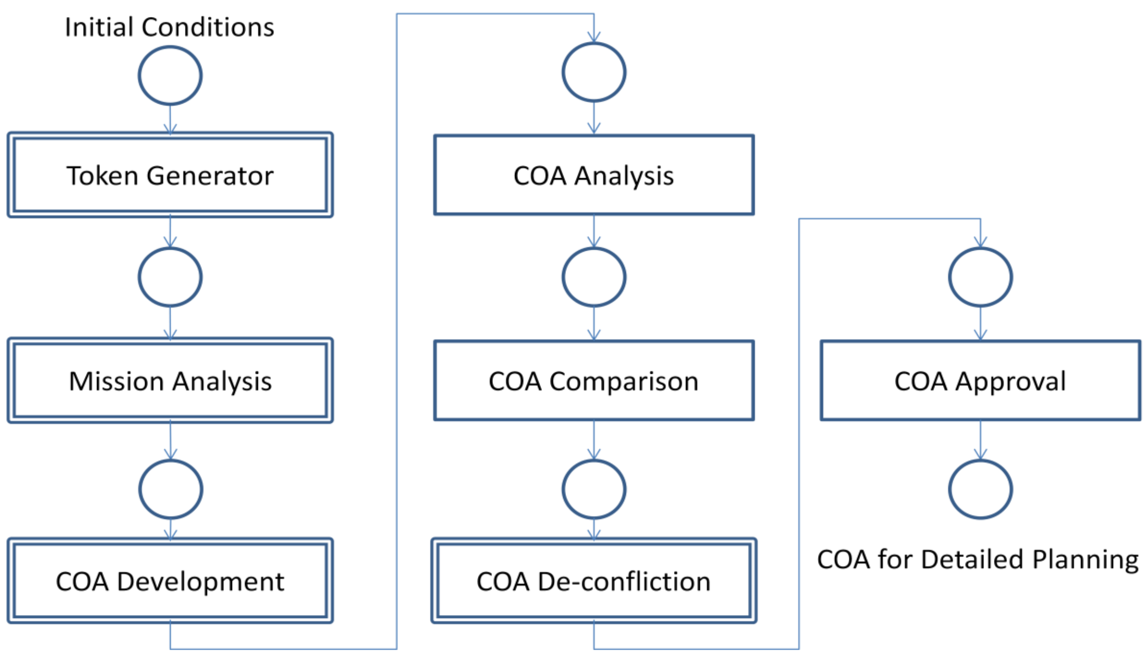


Figure 17 Planning Phases

Activities in each planning phase are generally modeled as activities in series, with some exceptions. Each domain conducts these activities separately. Coordination activities occur concurrently with domain planning activities when all the input requirements for each coordination are met. In the example shown in Fig. 18, a generic Coordination 1 requires as input information output from Planning Activity 2 from both domains before proceeding.

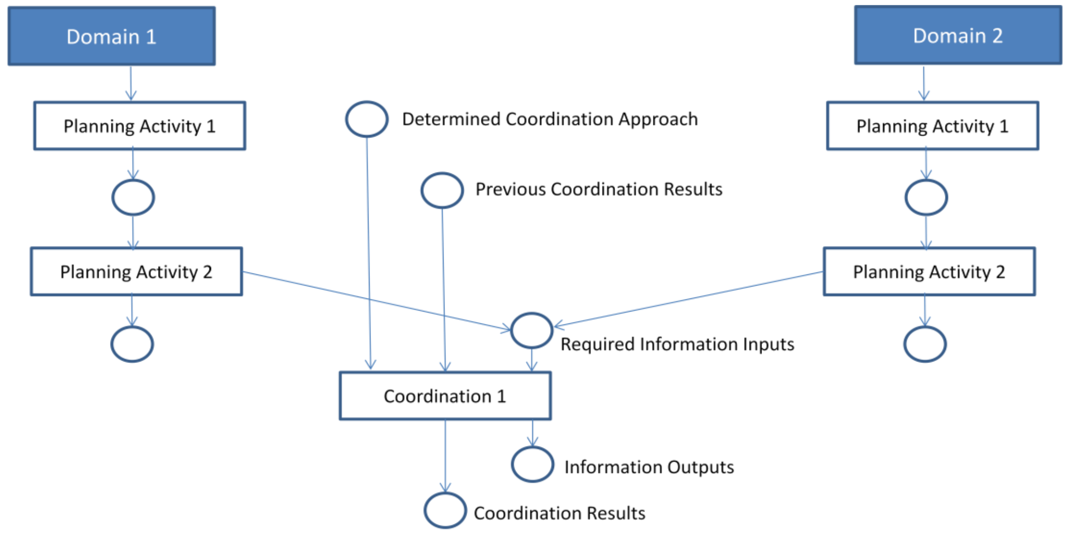


Figure 18 Coordination Inputs and Outputs

Activities in each planning phase were determined from descriptions of the JOPES process in United States Joint Doctrine Manuals JP 5. For example, the list of activities modeled in the Mission Analysis phase are shown in Table 2.

Table 2 Mission Analysis Phase Modeled Activities

Planning Activities Modeled in the Mission Analysis Phase
Conduct Joint Intelligence Preparation of the Operational Environment (JIPOE)
Receive or Determine Coordination Policy
Determine Facts, Status, and Conditions
Analyze Commanders Mission and Intent
Determine Specified, Implied, and Essential tasks
Determine Operational Limitations
Develop Assumptions
Determine Own Military End State Objectives and Initial Effects
Determine Own and Enemy's Centers of Gravity and Critical Factors
Determine Initial Commanders Critical Information Requirements
Conduct Initial Force Structure Analysis
Conduct Initial Risk Assessment
Develop Mission Statement
Develop Mission Analysis Brief
Mission Analysis Commander Approval
Prepare Initial Staff Estimates
Publish Commanders Planning Guidance and Initial Intent

All these Mission Analysis activities are conducted in series except Conduct JIPOE and Receive or Determine Coordination Policy, which are conducted concurrently with the remaining activities. Coordination activities, whether design coordination or de-confliction steps, are modeled in the same way. As described in the generic case above, the determination is made as to what information requirements are necessary to begin each coordination. In addition there will be an input that determines the coordination approach. This approach may have been dictated by a higher headquarters, determined by the domain prior to initiating planning, or determined during planning by domain consensus. In the development of the Co-design approach, the information requirements for each design coordination were determined. Similarly, the information requirements for de-confliction include each domain's conceptual model and chosen COA. Examples of how design coordination and de-confliction steps are modeled at the level 2 hierarchical level are shown in Fig. 19 and Fig. 20.

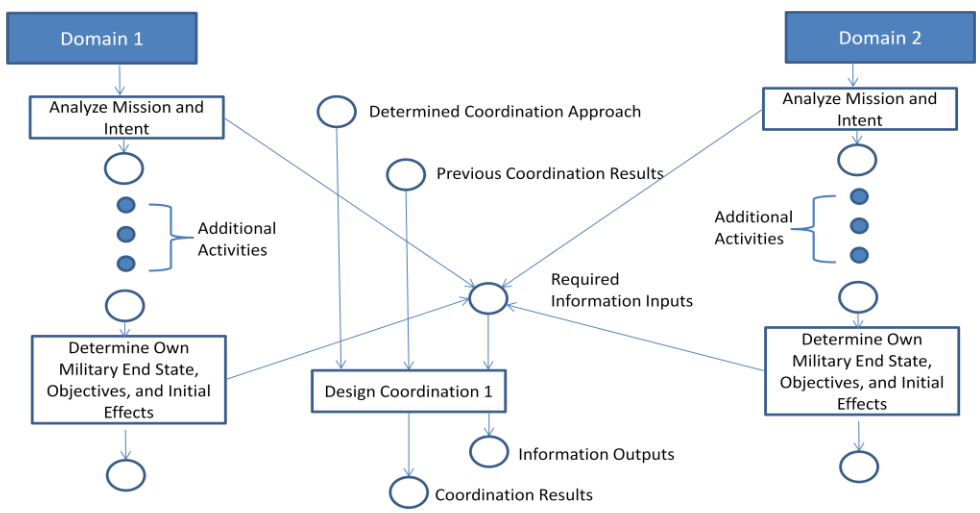


Figure 19 Example Design Coordination Inputs and Outputs

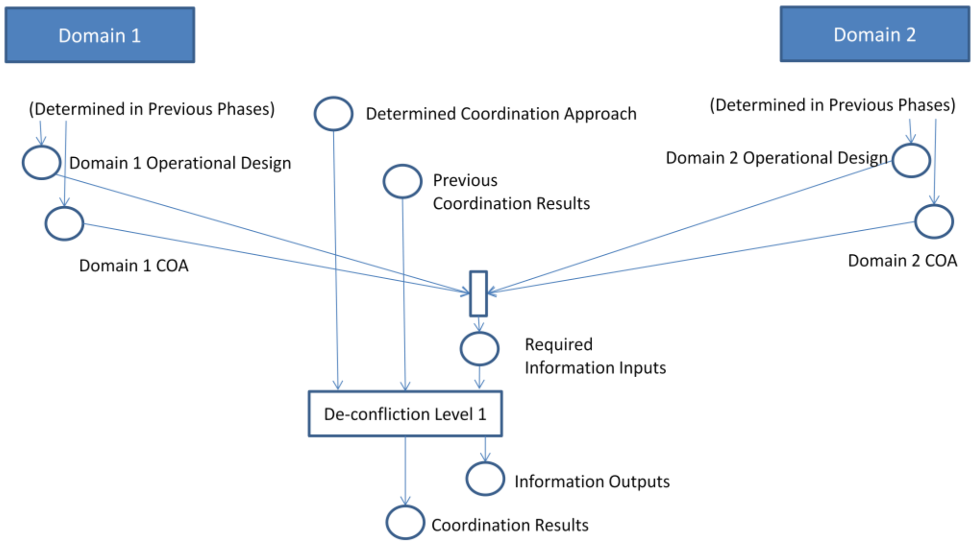


Figure 20 Example De-confliction Inputs and Outputs

This hierarchical level shows the input and output of coordination. Modeling of the processes inside the coordination activity is discussed in the following section.

4.1.2 Coordination Modeling

4.1.2.1 Iterative Consensus Model

The five stage interacting decision maker model (Levis 1993), described in Section 2.1.2, was extended to model iterative consensus building. Successive iterations were modeled by replicating the decision making organizations. These successive decision making organizations receive as input the results from that domain's previous decision and then, during the information fusion stage, gain understanding of the other domain's decisions and willingness to continue consensus building. In the response selection stage, decision makers not only make a selection for the decision at hand but also determine whether they are willing to begin/continue consensus building. If any decision maker elects not to continue then the decisions will become final regardless of whether consensus has been obtained. Figure 21 demonstrates this process with two organizations and one iteration of consensus building.

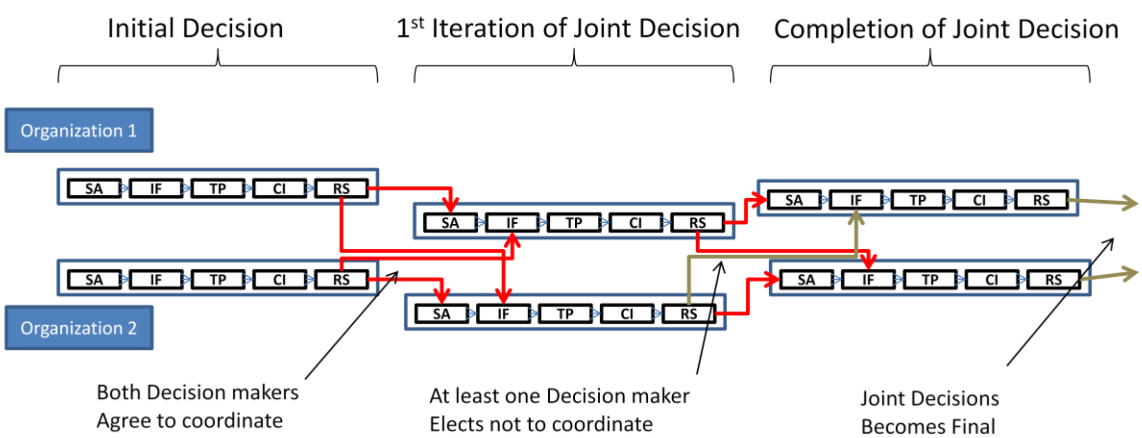


Figure 21 The Iterative Consensus Building Modeling Approach

The coordination process structure is the same for all modeled coordination activity. The only exception is that the command interpretation stage is only used if there is appropriate command guidance.

4.1.2.2 Coordination Model Implementation

The iterative consensus building processes are modeled in hierarchical levels 2 and 3 of the planning process model. The first iteration of joint decision making is modeled in level 2 and further iterations are modeled in level 3. The level 2 model, shown in Fig. 22, initializes model variables (2) based on the coordination approach (1) and models the effect of higher command guidance on the decision process (3). The level 2 model also allows the coordination step to be skipped entirely (6). This is used to ensure only the coordination steps associated with the chosen planning approach are conducted during model execution. If all domains agree to conduct consensus building (4), then the decision information and process parameters are passed to the level 3 iteration model (5). Regardless of whether an iteration is conducted, decision results are consolidated and passed back to the level 1 process model (7).

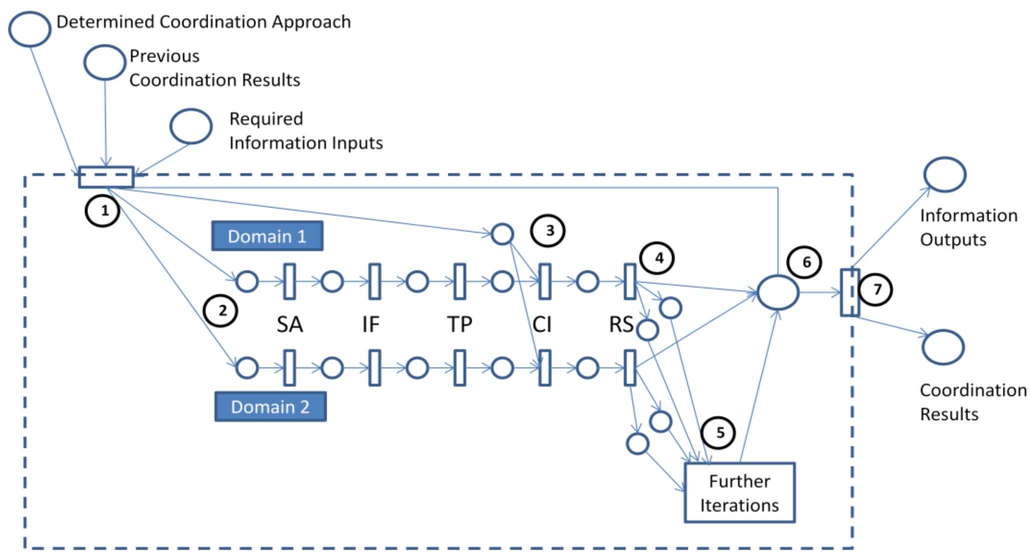


Figure 22 Level 2 Coordination Model

The final level of the model implements successive iterations of consensus building after the first. This portion of the process model executes repeated iterations until one or more variables reach a value specified as stop criteria. The stop criteria are determined by the agreed upon coordination approach. The number of iterations required to achieve full consensus for each type of coordination is a parameter examined in the subsequent analysis. The number of iterations is modeled as stochastic with a Gaussian distribution. The expected value and variance are the experimental parameters with variance set to zero for the deterministic case. When the process stops, joint decisions become final regardless of whether consensus has been reached.

The level 3 model is shown in Fig. 23. If consensus building is agreed to by all domains, previous decision information and iteration parameters are accepted as input from the level 2 model (1). Domains conduct their decision process. In the information fusion (IF) stage, domains may account for other domains' previous decisions. If any domain has declined further iteration, then the process will continue but ends after response selection. In the response selection stage, decision makers make a selection (3) and determine whether they are willing to continue consensus building (unless it has previously been determined that consensus building is to end). If consensus building is ending, all selections become final and information is passed out to the level 2 model (4). If another iteration is to be conducted, decision results serve once more as inputs to the same process (2).

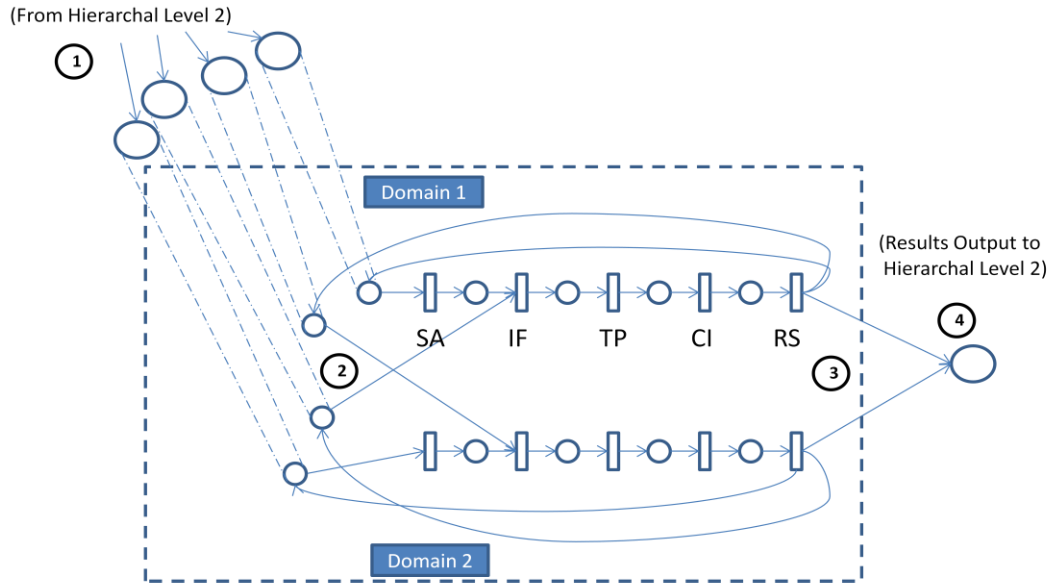


Figure 23 Level 3 Coordination Model

4.1.3 Process Model Execution

During execution of the planning process model, all planning activities are conducted by each domain. Coordination, including de-confliction, activities are only conducted if they are associated with the planning approach being modeled. Ten potential coordination activities were added to model interactions in the proposed approach and traditional de-confliction methods. Each of these coordination activities takes the necessary input from the domain planning activities, models the consensus building between the domains (modeling approach described above), and outputs the results back into planning activities. Four separate approaches were modeled: the proposed approach, traditional de-confliction level 1 (level difference explained below), traditional de-confliction level 2, and no coordination. Table 3 shows the ten potential coordination activities and the approaches with which they are associated. Coordination Step 0 may or may not be required depending on whether the involved domains have previously agreed on the coordination approach parameters to be used.

Table 3 Coordination Steps for Each Approach

Coordination Step	Planning Approach			
	Co-Design	De-confliction Level 2	De-confliction Level 1	No Coordination
0. Coordination Approach	✓	✓	✓	
1. Objective(s) and metric(s)	✓			
2. Key Influencers of objective(s)	✓			
3. Adversary and environment potential actions	✓			
4. Organizations' (Domains') potential actions	✓			
5. System structure	✓			
6. Integrated COA	✓			
7. Integrated COA Timing	✓			
8. De-confliction Type I		✓	✓	
9. De-confliction Type II		✓		

The element of time can be applied to Petri Net models in several ways. In the process model for this effort, the time delays are associated with transitions representing planning or coordination activities. The delays can be deterministic or stochastic. All time delays in the model use a Gaussian distribution with expected value and variance as experimental parameters. The variance is set to zero for the deterministic case. The process model was designed to capture the total time required for planning. Each experimental simulation of the planning process captures the time required to execute all planning and coordination activities. In addition, times for specific subsets of activities can be captured such as the time required for a specific coordination step.

When all parameters are deterministic, only one computational experiment is required for each of the four approaches. When process times or iterations required for consensus are made stochastic, many separate experiments are used to generate results for statistical analysis. The token generator modeling artifact easily generates initial data (tokens) based on input parameters for experiments with hundreds or more executions of the entire planning process.

4.2 Conceptual Modeling

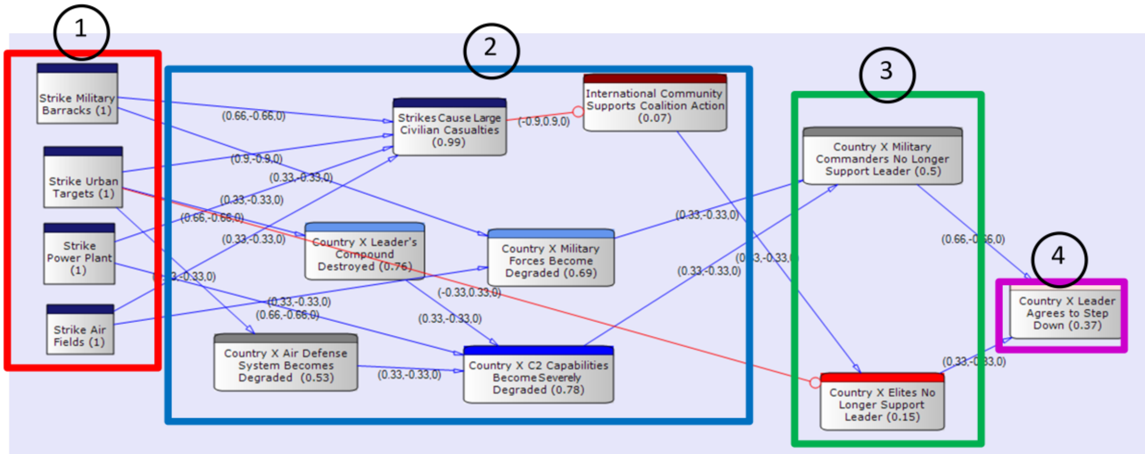
The conceptual model is the domain's current understanding of the operational environment and how participant actions, including the timing of actions, interrelate. As described, this is similar in many ways to ideas in operational design. Conceptual modeling was accomplished using TINs, which were described in Section 2.2.4.4. TINs were used to model both domain conceptual models and course of action performance estimates. In this modeling approach, the conceptual model is modified based on interactions with other domains during the planning process. In order to more clearly explain these concepts, a simple example is described. This example includes two domains, kinetic strike and cyber attack components. For this example scenario the common goal of the domains is encouraging the dictator of Country X to step down after the loss of his international legitimacy.

4.2.1 Structure

The conceptual model has up to three components: nodes, relations, and constraints. Nodes include actionable events and other potential events in the conceptualization of the operational environment. Relations are the causal relationships understood between events. There can also be constraints. Constraints are not explicitly displayed in the TIN. Explicit constraints will be stated in a description accompanying the TIN in the form of a rule. Rules can be in any format. Examples are: "If a strike is conducted on military barracks, then a strike on urban targets cannot be conducted," or "Only two strikes are possible within a five day period." There are also implicit constraints such as strikes which are not possible given the coalition capabilities.

Nodes can be divided into three general categories: actionable events, effect events, and goal/objective. Effect events are further delineated in this effort into standard enemy/environment effects, strong cross-domain effects, and key influencers of the goal/objectives. From a modeling perspective, there is no difference between key influencers and other effects. They are classified separately only for their relation to concepts from operational design. Strong cross-domain effects are a subset of standard enemy/environment effects which will be further explained in the following section.

An example of a strike domain conceptual model is shown in Fig. 24. The conceptual model includes the understood potential actions, the envisioned intermediate effects of those actions, and the impact of all event likelihoods on the probability of objective success. In this example four potential actions are conceived. Strikes can be conducted on military barracks, urban targets, power plants, and air fields. The causal relationships between those actions and enemy/environmental effects are depicted with eight nodes (exclusive of actions and objective) and numerous influence links. In this case, the strike domain has determined that important events include the case when certain capabilities of Country X become severely degraded, a large civilian casualty event, and international support. As can be seen, all strike actions increase the likelihood of large civilian casualties, but some more than others. Striking urban targets has a stronger influence on the probability of a large civilian casualty event than striking air fields. The events that directly affect the objective are the key influencers. They represent a key decision in that domain's operational design process: "Which events most influence the objective?" The strike domain has determined, in this case, that the support of military commanders and Country X elites have the most influence on the leader deciding to step down.



1. Kinetic Actionable Events
2. Standard Enemy/Environment Effects
3. Key Influencers of the Objective Node
4. Objective Node

Figure 24 Example Kinetic Strike Domain Conceptual Model

Domain conceptual models, as all models, are by definition incomplete. Limits on process time and human cognitive ability mean that only a subset of potential actions and events can be considered. Military commanders and planning staff are experts and have strategies to deal with the limits on planning. An important strategy is focusing on the expected key aspects for the given situation. Potential actions, events and/or relationships can be divided into four groups with the inclusion of two attributes: knowledge and importance. Actions, events, and relationships in the domain's model are, of course, known to the domain. In addition, they have been determined to be important or non-trivial. There are known actions, events, and relationships which the domain has purposely left out of the model because they are not practical or expected to have little effect. There are also possible actions, events, and relationships which are unknown to the domain. These unknown elements may or may not be important to the domain, if they were known. A previously unknown element may also raise the importance of a known element. For example, a known action may be considered of little importance because the known influences and related effects of that action are trivial. If a new relationship is discovered in which that action has a significant influence on a key event, then than action may now be considered important and added to the domain's conceptual model. For example, the strike domain planners may consider the effect of religious leaders support on Country X's leader to be trivial. If new information contradicts this assumption, then loss of religious leader support may be added as an event with influence on the objective node. Gaining knowledge of new elements from other domains is described in the next section.

4.2.2 Creation and Modification

As described in previous sections, domains create a conceptual model of the environment during Mission Analysis. This occurs as a result of the staff planning activities and the related operational design activities. Based on the approach used, these conceptual models may be integrated across domains or remain domain centric. If a domain centric model is created, it can be expanded later during a de-confliction process to include actions from other domains and their effects. One domain centric model was described in the previous section. The other domain in the example scenario, the cyber attack domain, would have an equivalent model as shown in Fig. 25.

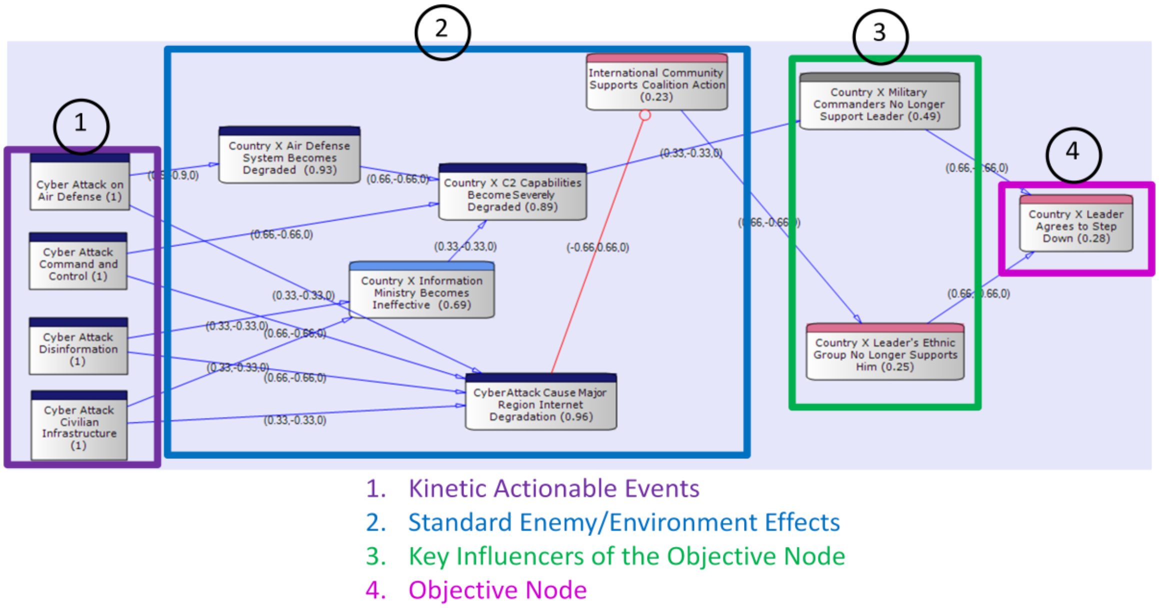


Figure 25 Example Cyber Attack Domain

This domain model has the same types of elements and goal node as the previous example. The domain's understanding of the environment is unique. Actions are based on the domain. The effects and key influencers have some elements which are the same and some that are different. The similarities and differences are purposeful. This is done to model each domain's unique perspective on the same operational environment. The differences in key influencers represent different conceptualized approaches to meet the same objective. All domain models are a subset of a complete inter-domain model. In this modeling approach, the elements contained in the domain models have the same values as the complete model. In other words, there are no "errors" introduced such as different causal strengths on the same link in different conceptual models. In the example, the cyber attack domain model contains actionable events associated with the cyber domain. It has a set of enemy/environment effects which is also more oriented to the cyber domain, but with some overlap with the strike model such as common events on international support for coalition operations. The cyber domain has one key influencer node that is the same as the strike domain, "Country X Military Leaders No Longer Support Leader," and one which is unique, "Country X Leader's Ethnic Group No Longer Supports Him." This difference models the domain-specific approaches to the problem domains will envision in the absence of a methodology to use to a common, integrated approach.

4.2.3 De-conflicted Models

Domains will choose a COA based on the conceptualization of how their chosen actions will affect the enemy/environment events and ultimately the objective. This is discussed further in the following section. COAs based on domain centric (non-integrated) conceptual models may contain actions which are very detrimental to desired effects other domains are attempting to achieve. In traditional military planning approaches, these domain COAs will be de-conflicted after they are developed and approved. During de-confliction, domains will share their planned actions and conceived effects. The goal of de-confliction is to eliminate or adjust actions and effects which have a significant negative impact on other domains. While de-confliction is focused on actions and effects and not explicitly on conceptual model integration, some conceptual model adjustment must occur. When domains share their intended actions at the beginning of the de-confliction process, other domains must conceptualize the effect those actions will have on the operational environment. The process of de-confliction raises the potential importance of actionable events and causal interactions which were previously unknown, not understood, or discounted. De-confliction is therefore modeled as slowly evolving domain conceptual models to incorporate knowledge of the actions and effects of other domains.

The process modeling of de-confliction was described in previous sections. Here the effects on the conceptual model are explained. De-confliction is broken into two levels. The first level of de-confliction involves conceptualizing all the potential actions and effects of the adjacent domains. Each action and effect in the first level of de-confliction was previous known by at least one domain. Through the process of iterative discussion and negotiation on which actions cause negative effects, each domain slowly gains understanding of the others' actions and effects. If there is sufficient time for level one de-confliction to come to completion, each domain has a conceptual accounting for all domain actions and effects. For the example problem, the resulting model is shown in Fig. 26.

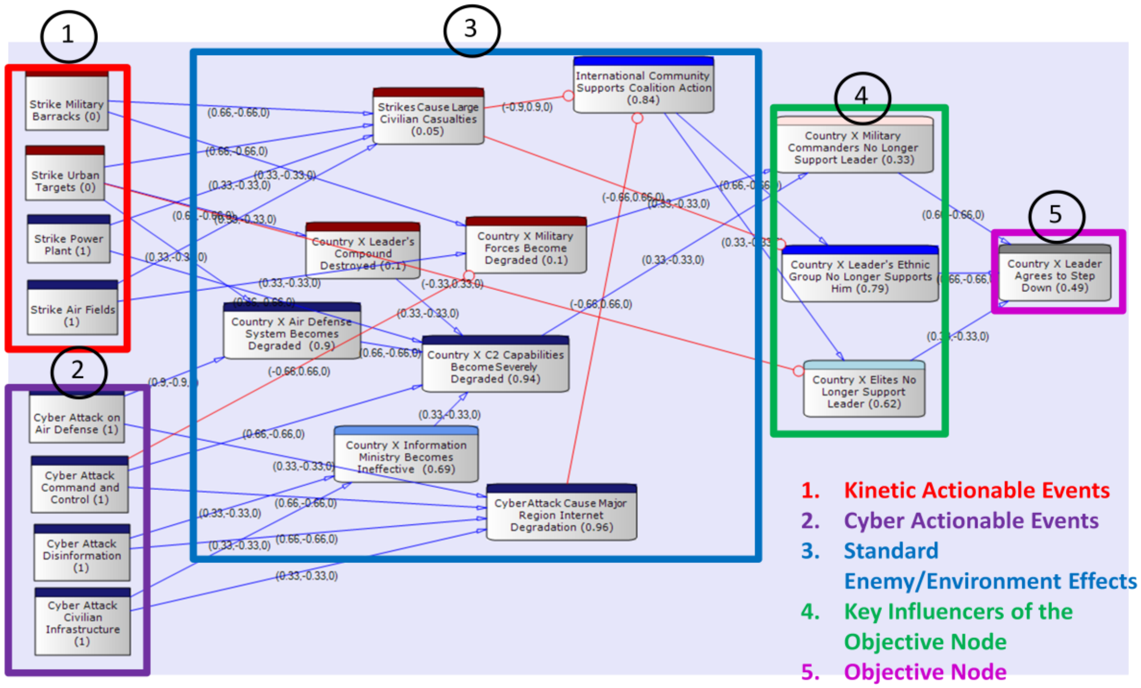


Figure 26 Example De-conflicted Level One Conceptual Model

Once level one de-confliction has been completed, a second level of de-confliction can be attempted. Level two de-confliction models the domains going beyond de-conflicting actions and events previously conceived by one or more domains. In level two, de-confliction domains consider potential negative cross-domain effects not previously comprehended which may be more evident now that domains can conceptualize each other's actions and effects. In the example, once the domain comprehends the level one de-conflicted model, they might realize that strikes on the power plants could cause collateral power outages in areas where they were not intended. Depending on the timing, these power outages could severely inhibit friendly cyber attacks. These non-obvious and potentially significant cross-domain effects model the results of higher levels of integration which are not being achieved in current planning approaches. Since the focus of de-confliction is avoiding negative cross-domain effects, positive cross-domain effects will not emerge. The fully level two de-conflicted model for the example is shown in Fig. 27 with two negative cross-domain effects having been determined.

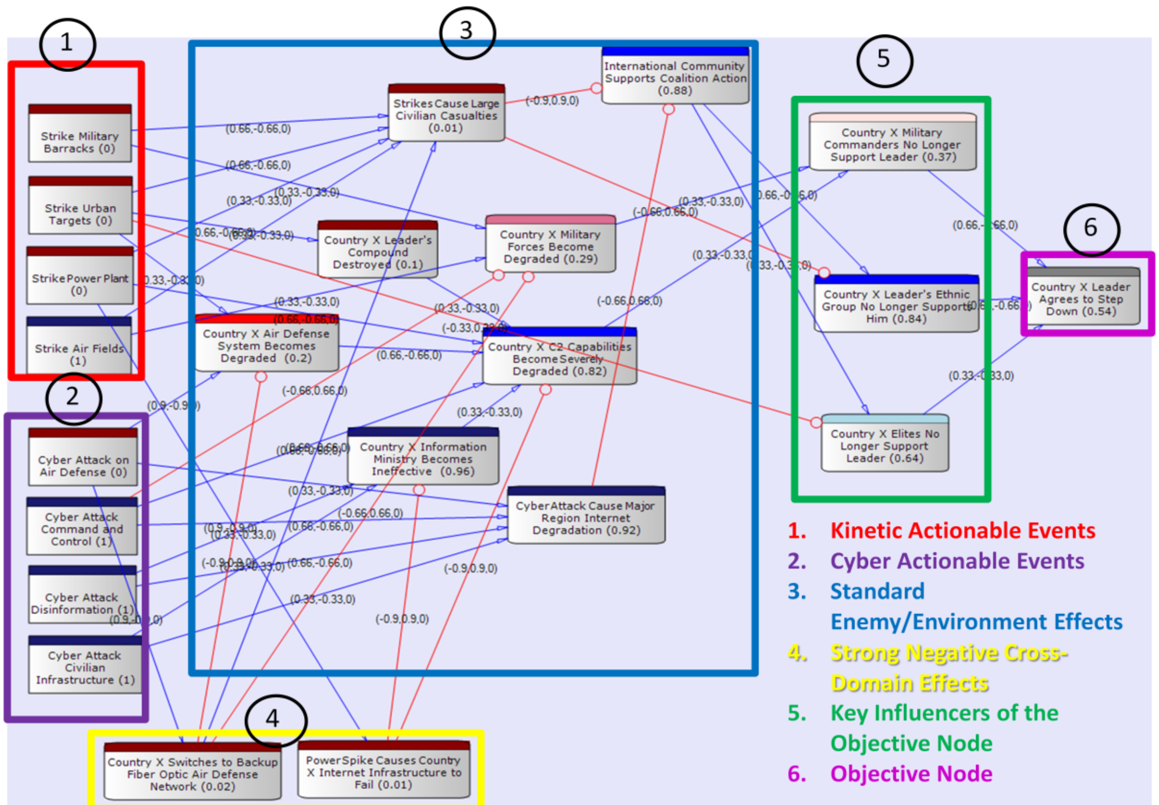


Figure 27 Example De-conflicted Level Two Conceptual Model

4.2.4 Integrated Models

The integrated conceptual model is the result of the Co-design process. As illustrated in previous sections, this process builds a common conceptual model with consensus from all domains. Unlike de-confliction, this approach encourages conception of cross-domain approaches to achieving effects. It is expected that positive cross domain effects will be determined using this method. As shown in Fig. 28, the integrated conceptual model is similar to the level two de-conflicted model but with the addition of positive cross-domain effects. As with negative cross-domain effects, these elements model the impact of higher levels of integration. These effects can only be understood through integrated conceptualization of the environment. In the example, both strikes on military barracks and cyber disinformation attacks are not particularly effective as separate activities. However, if they are combined in a targeted campaign on individual leaders, the effect could be magnified. Consider a Country X military leader being eliminated in a targeted strike. The next leader in the chain of command then receives information from a cyber attack indicating the coalition knows his boss has been eliminated, knows his location, and has access to all his communications. This could be much more effective in getting military leaders to stop supporting Country X's leader than perceived unrelated and random kinetic and cyber attacks.

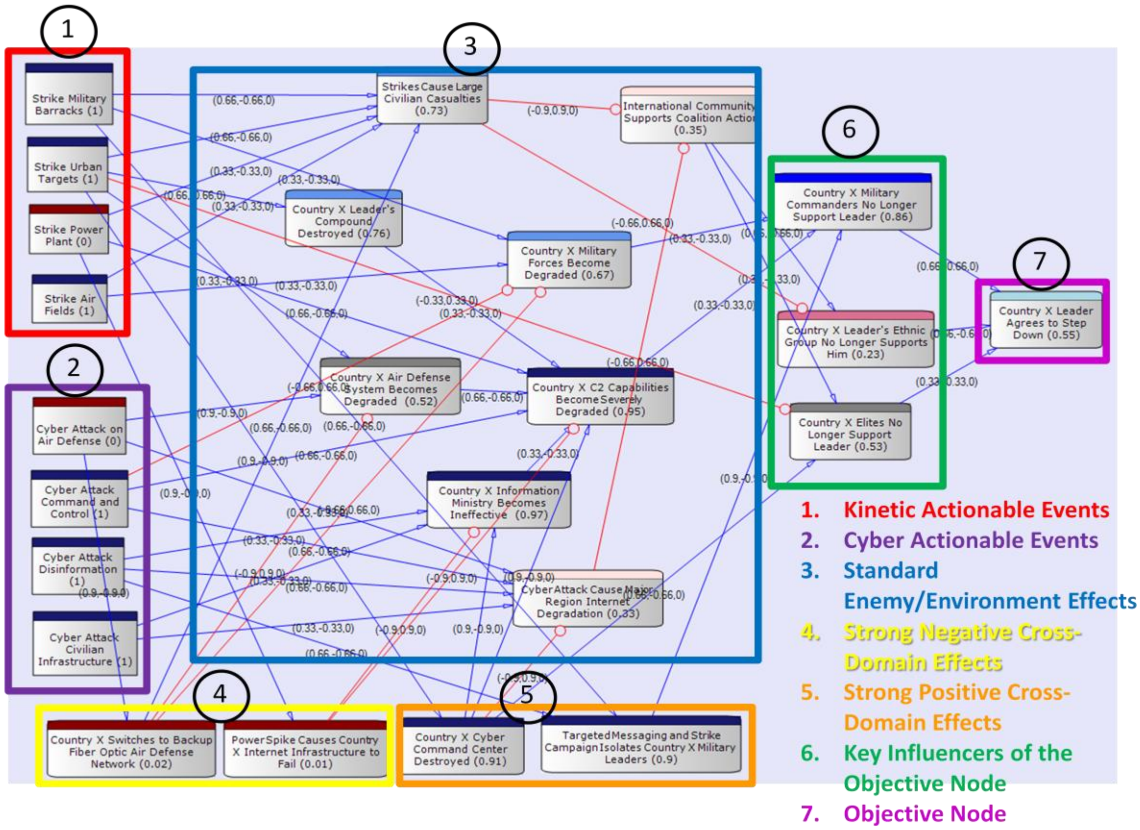


Figure 28 Example Integrated Conceptual Model

4.3 Relating Process, Conceptualization, and Results

The TIN models are used to represent how each domain perceives the operational environment. The TIN models are also used to determine the performance of the selected COAs. The integrated conceptual model represents the correct model of the operational environment. The strong cross-domain effects are real effects in the operational environment. The emphasis on integration is an attempt to capitalize on these types of effects. Domains will choose a COA based on the conceptual model they have obtained, as determined by the planning approach. The performance level of the COA will be determined using the integrated conceptual model. Actions potentially have real cross-domain effects which are not understood by those planners with conceptual models that have a lower level of integration.

COAs chosen from conceptual models with little or no integration will have poor performance. In the example, if the strike domain chooses a COA from the domain conceptual model, every action appears to increase the likelihood of achieving the objective except striking urban targets. Striking urban targets increases the likelihood of large civilian casualties which diminishes international support. In the true integrated model however, striking urban targets greatly increases the likelihood of destroying Country X's Cyber Command Center making all coalition cyber attacks much more effective. This offsets the increase in potential civilian casualties because more effective cyber attacks can in turn make kinetic attacks more effective and less likely to cause collateral damage. Similarly, striking power plants appears to be a good action in the strike domain conceptual model. As mentioned previously, this can cause power outages which severely degrade coalition cyber activity.

The assumption is made that each domain chooses actions to maximize the probability of goal node success based on their current conceptual model. As described above using the domain centric model from Fig. 24, the strike domain would choose the following COA: Strike Military Barracks - True, Strike Urban Targets - False, Strike Power Plant - True, and Strike Air Fields - True. Without the knowledge of strong cross-domain effects, this is perceived to be the highest performing COA for the strike domain.

When applied to the true model, the COA performs very poorly. For the example scenario, Table 4 shows the actions that would be chosen by each domain based on the integration level of the conceptual model and the resulting true performance (T = True, F = False).

Table 4 Example COAs and Performance

	Conceptual Model Integration Level			
	None	De-conflicted Level One	De-conflicted Level Two	Integrated
Actionable Events	Chosen COA			
Strike Military Barracks	T	F	F	T
Strike Urban Targets	F	F	F	T
Strike Power Plant	T	T	F	F
Strike Air Fields	T	T	T	F
Cyber Attack on ADA	T	T	F	F
Cyber Attack on C2	T	F	F	F
Cyber Dis-information	F	F	F	T
Cyber Attack on Civilian Infrastructure	F	T	T	F
	True Performance of COA			
Probability of Leader of Country X Stepping Down	0.13	0.32	0.38	0.68

Chapter Four has presented the modeling methodology for this research effort. First, an overview was provided which explained how a planning process model coupled with a model of the operational environment can be used to measure the effect of process on performance. The process model was then detailed, including the model structure and execution. The modeling approach for inter-domain coordination was also described. After this, the approach for conceptual modeling of the operational environment was presented. Finally, the methodology for relating the amount of coordination during planning to the performance of the resulting COAs was demonstrated. The following chapter presents a realistic operational level military case study and analyzes the results of modeling this case study.

CHAPTER FIVE

RESULTS AND ANALYSIS

5.1 Case Study

In order to examine the potential differences in planning approaches a case study was developed. The case study operational scenario is similar to the example used in explanations in Chapter Four. The scenario was made more realistic with the inclusion of three domains and a more complicated operational environment. The size and level of detail of the TIN representing this scenario was similar to models used by the George Mason University Systems Architecture Lab in war games conducted with United States Military Officers. In the first part of this section, the TIN for the case study is detailed. The second part describes the scenario parameters for the process model.

5.1.1 Conceptual Model

The operational scenario for the case study is similar to the example in Chapter Four. A coalition military operation is being considered to encourage the dictator of Country X to relinquish power and agree to a peaceful transition. Potential coalition capabilities were divided into three domains: kinetic, cyber, and space capabilities. The key influencer and goal structure were also made more robust. In addition, the enemy, environment, and strong cross-domain effect nodes/links were made more realistic with a total of over 50 modeled events and numerous links. Unfortunately more realistic models such as this are difficult to display. In order to show the entire model the resolution must be lowered to the point where the node names are unreadable. The entire integrated model is shown in Fig. 29. Although the node names are unreadable it can be seen that the model is structurally similar to the example described in Chapter Four, except for the addition of a new domain. Each node is given a number to allow more compact representation. The numbers are shown in parenthesis after the node name in the description. A brief description of the actionable events, goal/key influencer nodes, strong cross-domain effect nodes, and a subset of the enemy/environment nodes is provided below. The complete list of nodes and their connecting arcs is provided in Appendix A.

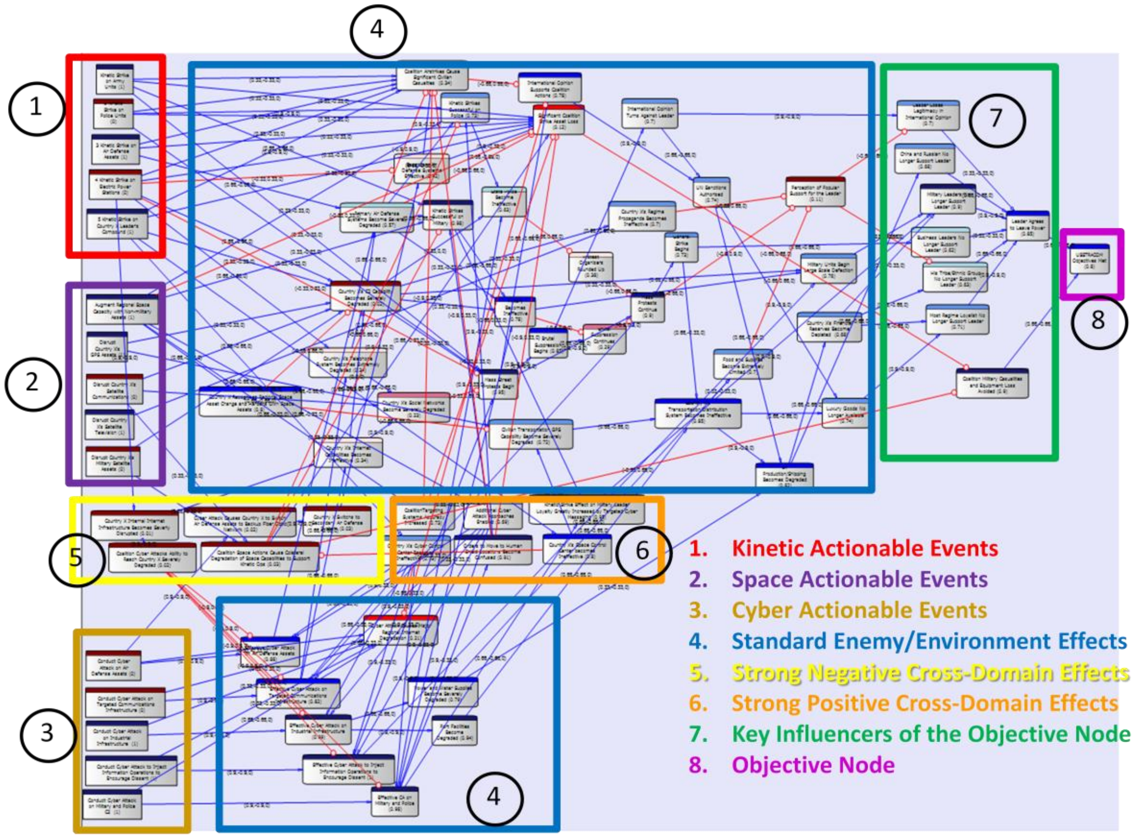


Figure 29 Case Study Integrated Conceptual Model

5.1.1.1 Domains and Domain Actions

The kinetic strike domain represents military capabilities such as aerial bombardment, missile and rocket strikes, and naval gunfire. This domain can have devastating physical effects on adversary military and non-military capabilities. These physical effects are not always delivered with the intended precision and control, which creates the potential for civilian casualties and collateral infrastructure damage. Kinetic strikes also have the significant psychological effects which may be intended or unintended as well as being obvious or non-obvious in advance of the strike.

As described in Chapter Four, each domain may have a domain centric conceptual model of the operational environment. The kinetic strike domain conceptual model is shown in Fig. 30.

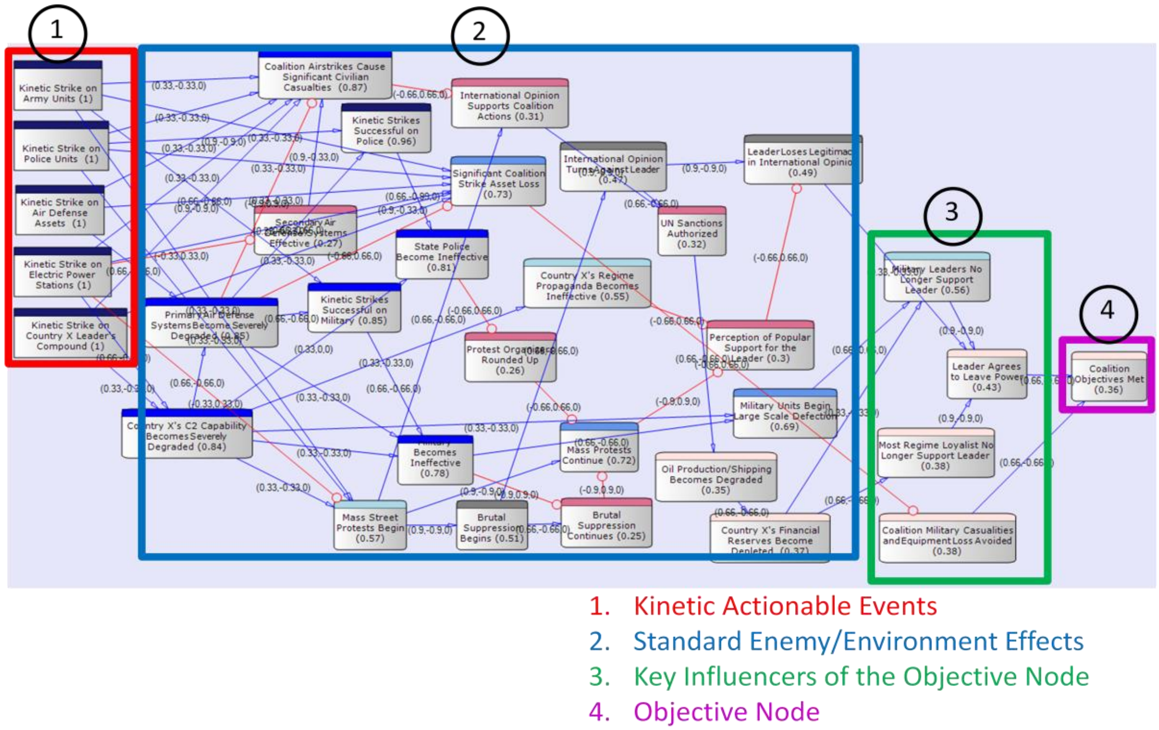


Figure 30 Case Study Kinetic Domain Centric Model

As before, this model contains only kinetic domain actionable events, a subset of the enemy and environment nodes and key influencer nodes, and the identical goal node in relation to the complete integrated model. Regardless of the integration level of the conceptual model, the actionable events remain the same. The actionable events for the kinetic domain are:

Kinetic Strike on Army Units (1) - Coalition strikes on army units increases the likelihood that the Country X military will become ineffective.

Kinetic Strike on Police Units (2) - Coalition strikes on police units increases the likelihood that the Country X police will become ineffective; police ineffectiveness has different causal effects than the military one.

Kinetic Strike on Air Defense Assets (4) - Coalition strikes on air defense assets increases the likelihood that the Country X air defense will become ineffective; primary and secondary air defense effectiveness affect the results of further kinetic strikes.

Kinetic Strike on Electric Power Stations (5) - Coalition strikes on power stations increase the likelihood that a number of Country X capabilities will become degraded including air defense and C2.

Kinetic Strike on Country X Leader's Compound (65) - Coalition strikes on the leader's compound can increase the probability of various Country X capabilities to become degraded; all kinetic strikes increase the likelihood of large scale civilian casualties, the strike on the leader's compound more so because of its urban location.

The space domain includes all coalition capabilities involving military and civilian satellites and ground stations, and kinetic and non-kinetic methods to degrade or protect those capabilities. Space capabilities include global positioning, intelligence gathering, communication, command and control, and others. The space domain can use coalition assets in attempts to bolster friendly capability as well as degrade adversary capabilities. The space domain centric conceptual model for the case study is shown in Fig. 31.

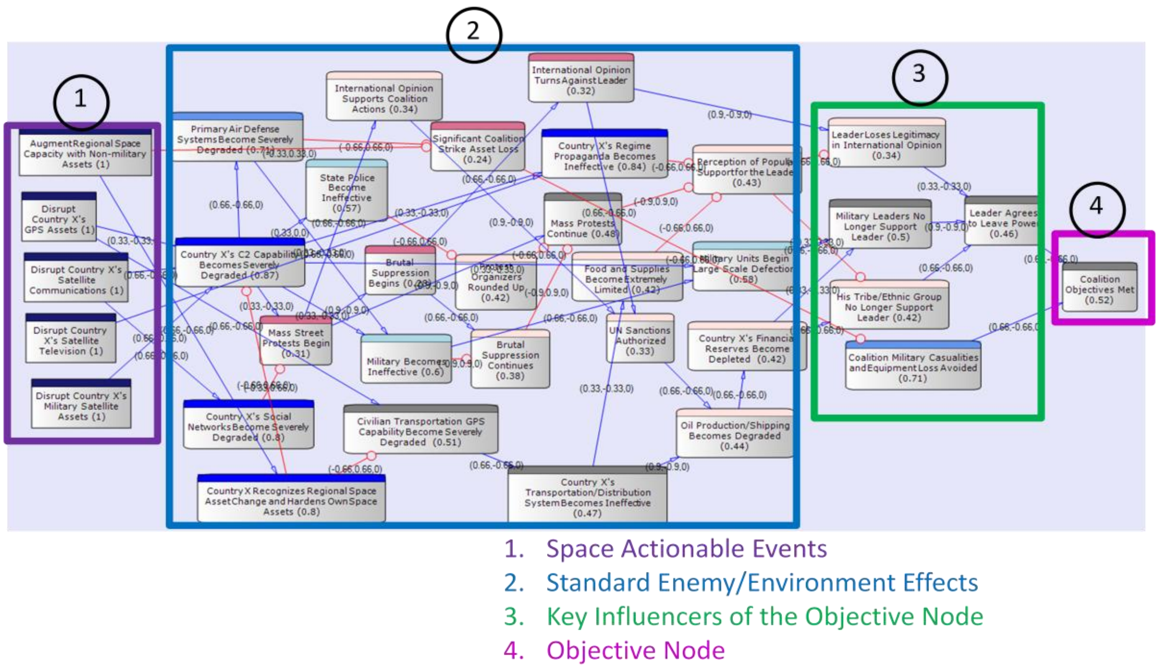


Figure 31 Case Study Space Domain Centric Model

The space actionable events for all conceptual models are:

Augment Regional Space Capacity with Non-military Assets (66) - The capacity of coalition military space assets can be augmented with leased civilian capacity; this increases the probability of success of certain coalition actions but also increases the likelihood of Country X being alerted to potential coalition activity.

Disrupt Country X's GPS Assets (6) - Space assets are used to degrade Country X's global positioning systems; this promotes the likelihood of both civilian and military GPS dependent systems becoming degraded.

Disrupt Country X's Satellite Communications (7) - Space assets are used to degrade Country X's communication systems; this promotes the likelihood of both civilian and military communication disruption; it can affect the regime as well as opposition.

Disrupt Country X's Satellite Television (8) - Space assets are used to degrade Country X's satellite television system; it increases the probability that regime propaganda will not be effective.

Disrupt Country X's Military Satellite Assets (9) - Space assets are used to degrade Country X's military satellite system – it increases the probability that regime command and control will not be effective.

The cyber domain includes coalition offensive and defensive capabilities involving global networks of information systems. These capabilities can be used to degrade or protect other domain capabilities that rely on information systems. They can also be used to conduct information or psychological operations. As with kinetic attacks, there is also the possibility of collateral damage in cyber operations. Attacks may cause unintended degradation of enemy, friendly, or neutral party capabilities. The cyber domain centric conceptual model is shown in Fig. 32.

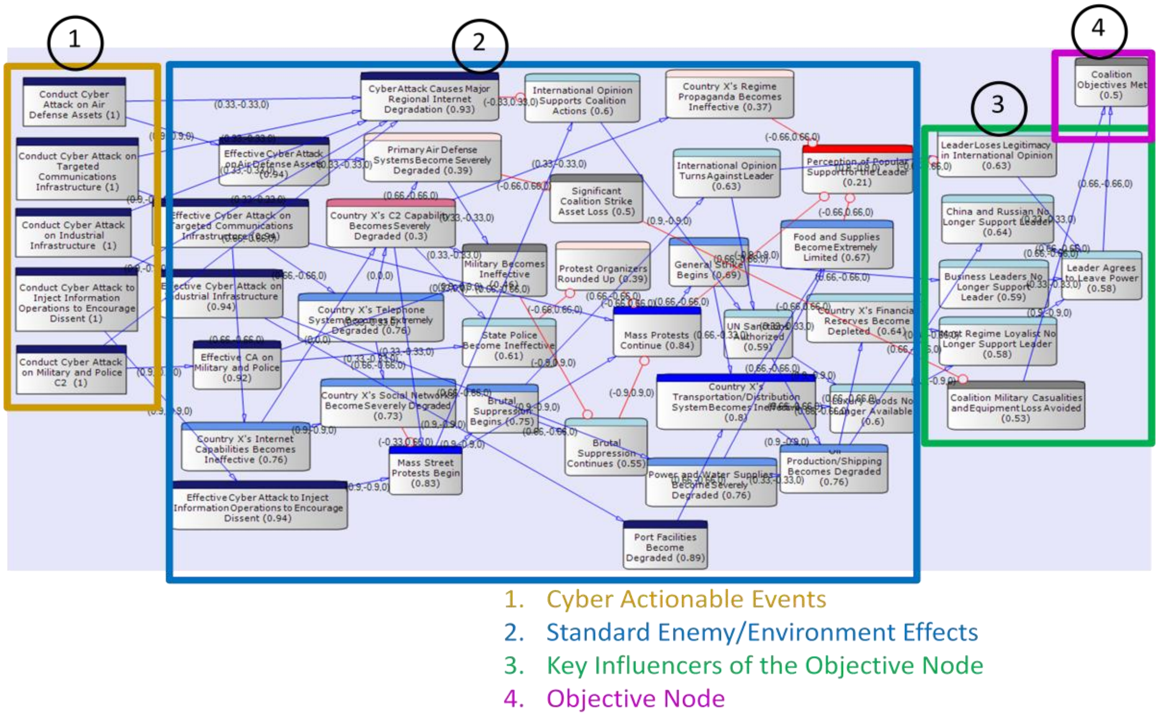


Figure 32 Case Study Cyber Domain Centric Conceptual Model

The actionable events for the cyber domain include:

Conduct Cyber Attack on Air Defense Assets (10) – a Cyber attack affecting air defense systems; it can cause Country X to switch to a secondary air defense system.

Conduct Cyber Attack on Targeted Communications Infrastructure (11) – a Cyber attack would increase the likelihood of degrading military and civilian capabilities.

Conduct Cyber Attack on Industrial Infrastructure (13) – a Cyber attack which increases the probability of Country X transportation and basic infrastructure systems failing.

Conduct Cyber Attack to Inject Information Operations to Encourage Dissent (14) - Cyber attacks to enable information operations through Country X's information systems; they have causal effects on both military and civilian events.

Conduct Cyber Attack on Military and Police C2 (48) - Cyber attacks on military and police C2 will increase the probability of their C2 effectiveness becoming degraded.

5.1.1.2 Goal and Key Influencers

The theme of the goal and key influencers for the case study scenario is similar to the example in Chapter Four with one important difference. The goal was modeled as a combination of the Country X leader stepping down and a new key influencer, "Coalition Military Casualties and Equipment Loss Avoided," which models the requirement for the coalition to avoid losses. With this more complicated structure, COAs must now balance the influences on the Country X leader with maintaining coalition capability. This scenario models the military and political realities that actions chosen must not lead to catastrophic results which would threaten the viability of the coalition.

Additional influences on the leader's decision to step down have also been added to increase the realism of the model. Six influences on the leader are modeled, of which two are international/external to Country X and four represent domestic influences. The complete set of influencers and goal node is shown in Fig. 33. This figure is zoomed in on the goal node portion of the complete integrated model.

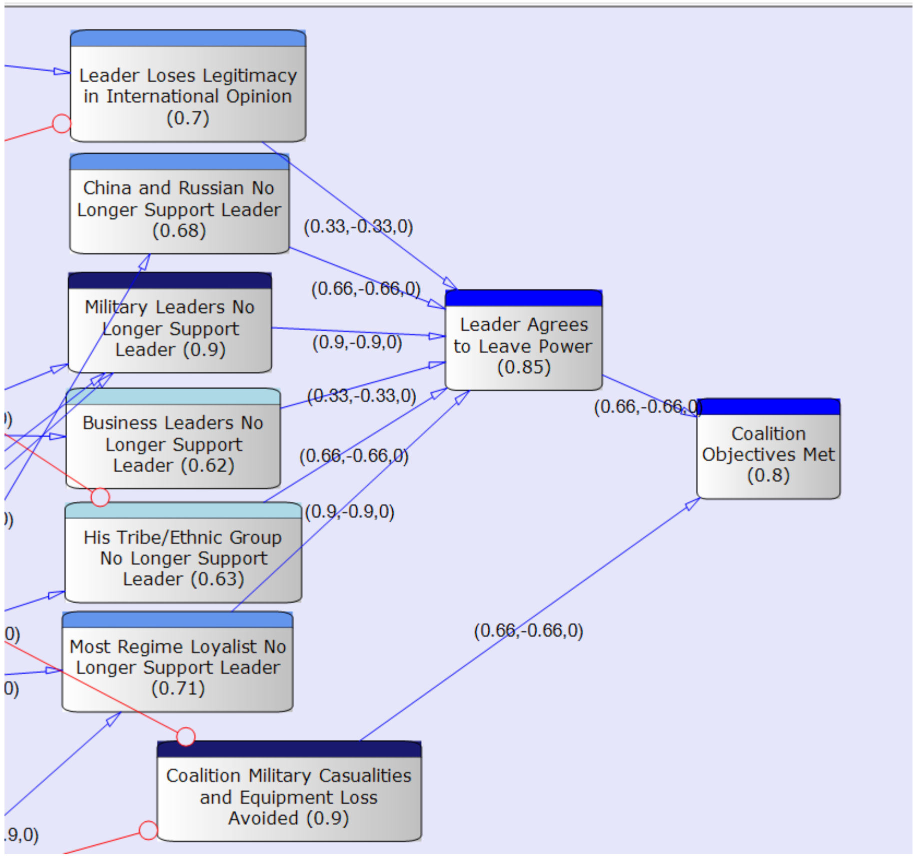


Figure 33 Case Study Key Influencers and Goal Node Portion of the Integrated Model

Of the six influences on the leader's decision, support of the regime loyalists and the military have the strongest influence. The leader's ethnic group and the support of China and Russia (with United Nations Security Council veto power) have the second strongest influence. Weaker influence on his decision making is exerted by the international opinion of his legitimacy and the support of business leaders. The complete set of key influencers and goal are:

Leader Loses Legitimacy in International Opinion (30) - Loss of legitimacy is influenced by international support for the coalition, perception of popular support for the leader, and brutal suppression of popular uprisings.

China and Russia No Longer Support Leader (31) - Ending of support from China and Russia is influenced by the availability of Country X's oil.

Military Leaders No Longer Support Leader (32) - Military leaders ending support for the leader is promoted by loss of military capability and defection of military organizations.

Business Leaders No Longer Support Leader (33) - The support of business leaders is under the causal influence of general strikes (labor strikes).

His Tribe/Ethnic Group No Longer Support Leader (34) - Tribe/ethnic groups support is influenced by perception of popular support and financial reserves becoming depleted.

Most Regime Loyalists No Longer Support Leader (35) - Regime loyalists are influenced by the availability of luxury goods and the depletion of financial reserves.

Leader Agrees to Leave Power (0) - The leader's decision to step down is most influenced by the six events listed above; the relative strength of the influences is described in the preceding paragraph.

Coalition Military Casualties and Equipment Loss Avoided (51) - Loss avoidance is influenced by significant air craft loss and loss of cyber capabilities.

Coalition Objectives Met (50) - Coalition objectives being met are equally influenced by the leader agreeing to step down and also maintain coalition military capability.

5.1.1.3 Enemy and Environment Effects

There are a large number of enemy and environment effect nodes and relations in the model. A summary and representative examples are described here. The full set is detailed in Appendix A. In general, the enemy and environment effect nodes are key events that can be affected by domain actions and together have effects on key influencers. In the case study scenario, these nodes mainly model when adversary capabilities change, infrastructure fails, or domestic/international public opinion reaches a crucial point. Example nodes include:

Secondary Air Defense Systems Effective (63) - Country X has a secondary air defense system based on fiber optic (not radio) communications.

Coalition Airstrikes Cause Significant Civilian Casualties (3) - The likelihood of this event is promoted by effective air defense systems, human shields, and increased numbers of kinetic strikes; likelihood is reduced by increased targeting system accuracy.

Kinetic Strikes Successful on Police (45) - Successful strikes on police decrease the likelihood that police will be successful in rounding up protest organizers.

International Opinion Supports Coalition Actions (47) - International support is influenced by civilian casualties and disruption of regional internet capabilities; the probability of support influences the likelihood of United Nations sanctions.

Significant Coalition Strike Asset Loss (53) - Significant strike assets loss is promoted by air defense system and human shield effectiveness and inhibited by targeting systems accuracy and increases in coalition C2 capacity.

5.1.1.4 Strong Cross-domain Effects

Again strong cross-domain effects are intended to model the benefits of higher levels of integration. These effects may also not be obvious to planners using a domain centric approach. Only with the understanding of how multiple domains can approach the problem can these effects be conceptualized. They are divided into those which have negative effects on other domains, and those which have positive ones. For the case study the negative cross-domain effects are:

Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops (52) - Attempting to degrade Country X's military and communication satellites may cause Country X or third parties to alter their space asset posture; this could require hardening of coalition space assets which could degrade support to kinetic operations.

Country X Switches to Secondary Air Defense System (62) - This node is caused by node 54, described below; together they represent cyber attack on air defense triggering a change in Country X’s air defense status.

Cyber Attack Causes Country X to Switch Air Defense Assets to Backup Fiber Optic Network (54) - In combination with the effect of Node 62, a cyber attack on air defense can have the unintended consequence of causing a switch to a secondary system which is more difficult to counter.

Country X Internal Internet Infrastructure Becomes Severely Disrupted (55) and Coalition Cyber Attacks Ability to Reach Country X Severely Degraded (56) - Together these two effects can severely degrade the effectiveness of all coalition cyber actions; the likelihood of this increases as a result of kinetic strikes on power stations which can have unintended collateral effects on other parts of Country X's power grid.

The positive cross-domain effects are separated because they are the results of integrated planning approaches. The positive effects for the case study are:

Coalition Targeting Systems Accuracy Increased (71) - Augmenting the coalition regional space capacity increases the likelihood of this event; increased capacity allows more detailed targeting data to be updated more frequently.

Country X's Space Control Center becomes Ineffective (67) and Country X's Cyber Control Center becomes Ineffective (68) - Attacking Country X leader's compound increases the likelihood that co-located centers will become ineffective; this is an example of an effect that would only be understood using an integrated approach; Ineffective control centers increase the probability of coalition space and cyber activity success.

Orders to Move to Human Shield Locations Become Confused (70) - Country X regime uses human shields to discourage attacks on key assets; disrupting military and police C2 through cyber attacks in conjunction with kinetic strikes can greatly decrease the application and effectiveness of human shields.

Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging (73) - This synergistic effect was detailed in 4.2.4.

Additional Cyber Attack Approaches Enabled (72) - Augmenting the coalition regional space capacity increases the likelihood of additional cyber attack approaches being available for the coalition.

5.1.2 Process Model Parameters

The case study scenario includes a 48 hour planning time for three domains to develop COAs and present them to a higher level commander. The process model described in Chapter Four was used to model the case study planning process. All activities and coordination steps were modeled as presented except for the addition of the third domain. Each of the three domains conducts separate parallel planning activities. Coordination processes can only be initialized when the required input from all three domains is available.

Parameter settings drive the process model. The parameters are shown in Table 5. The process approach used for planning drives the coordinations which will be conducted as described in Chapter Four. Parameters two through five set the expected times and variance level of all planning and coordination activities. Parameters six through eight prescribe the number of expected iterations required to complete each coordination type. Those same parameters also control variance in the required number of iterations.

Table 5 Process Model Parameters

Process Model Parameters
1. Approach to be used ("New Approach", "Current Approach", "Current Approach Level 2", or "No Coordination") 2. Traditional activities in the JOPES process through the COA Approval phase a. Base (expected) times b. Mu to sigma ratio (for stochastic modeling using the normal distribution; controls the variance) 3. Activities in coordination type I (Co-design) a. Base (expected) times b. Mu to sigma ratio (μ/σ) c. Iterative time reduction percentage (if used) d. Minimum activity time (if iterative reduction is used) 4. Activities in coordination type II (Level 1 de-confliction) a. Base (expected) times b. Mu to sigma ratio c. Iterative time reduction percentage d. Minimum activity time 5. Activities in coordination type III (Level 2 de-confliction) a. Base (expected) times b. Mu to sigma ratio c. Iterative time reduction percentage d. Minimum activity time 6. Iterations required to complete coordination type I a. Variance for required iterations (type I) distribution 7. Iterations required to complete coordination type II a. Variance for required iterations (type I) distribution 8. Iterations required to complete coordination type III a. Variance for required iterations (type I) distribution

The mu to sigma ratio (μ/σ) is the ratio of the expected value to the standard deviation. This allows one ratio to be used to adjust the variance of a set of activity times with different magnitudes without causing skewing of the variance. For example, the expected time for the activity "Conduct JIPOE" is 60 minutes and for "Receive or Determine Coordination Policy" is 10 minutes. If the mu to sigma ratio is 0.2 then the standard deviation for "Conduct JIPOE" will be 12 minutes and for "Receive or Determine Coordination Policy" is 2 minutes. If the mu to sigma ratio is 0.5 then the standard deviation for "Conduct JIPOE" will be 30 minutes and for "Receive or Determine Coordination Policy" is 5 minutes.

The expected activity time values used were based on subject matter expert opinions from a current United States military command which conducts strategic and operational level planning. These estimates are presented in Table 6. It can be seen later in this chapter that the full planning process with de-confliction can take more than 48 hours. It would seem counter-intuitive that based on the planning activity time estimates the current approach including de-confliction can take longer than 48 hours when the time estimates are based on a 48 hour process. In other words, the apportionment of time from the 48 hours period for de-confliction is less than that required for full de-confliction. This is purposeful based on the feedback that under current processes, full de-confliction is rarely achieved and time constraints often result in partially de-conflicted COAs.

Table 6 Planning Activity Expected Time Estimates

Process	Time in Minutes
Conduct JIPOE	60
Receive or Determine Coordination Policy	10
Determine Facts, Status, Conditions	60
Analyze Commander's Mission and Intent	60
Determine Specified Implied and Essential Tasks	90
Determine Operational Limitations	60
Develop Assumptions	60
Determine Own Military End State, Objectives and Initial Effects	90
Determine Own and Enemy's Centers of Gravity and Critical Factors	90
Determine Initial Commanders Critical Information Requirements	60
Conduct Initial Force Structure Analysis	90
Conduct Initial Risk Assessment	90
Develop Mission Statement	60
Develop Mission Analysis Brief	90
Mission Analysis Commander Approval	60
Prepare Initial Staff Estimates	60
Publish Commanders Planning Guidance and Initial Intent	60
Update Coordination Policy	10
Develop Ops Concepts	90
Identify Major Tasks	60
Place Tasks in Temporal Order	60
Determine Capabilities Required	60
Develop Task Organization	60
Identify Decision Points	60
Identify Branch Plans and Sequels	60
Estimate Time Required to Reach Mission Success or Termination	60
Identify Theater Reserve Requirements	30
Identify High Value Targets	60
Conduct Operational Risk Assessment	30
Develop COA Brief	60
COA Dev Commander Approval	30
COA Analysis	420
COA Comparison	420
COA De-confliction	180
COA Approval	60

Coordination activities, whether Co-design or de-confliction, are designed to model simple consensus building iterations. The entities upon which agreement is sought are relatively atomic for each coordination. It is expected that one iteration of the 5-stage decision maker model can take place in tens of minutes and multiple iterations will be required to achieve consensus. The expected times used in the case study for each coordination are shown in Table 1.

Table 7 Coordination Step Expected Time and Parameters

Decision Maker Stage	Design Coordination	De-confliction Level 1	De-confliction Level 2
	Time (Minutes)		
Situation Assessment	5	5	5
Information Fusion	5	5	5
Task Processing	5	5	5
Command Interpretation	5	5	5
Response Selection	5	5	5
	Percent Time Reduction per Iteration		
Situation Assessment	5	5	5
Information Fusion	5	5	5
Task Processing	5	5	5
Command Interpretation	5	5	5
Response Selection	5	5	5

Another parameter examined was that of increasing time efficiency in subsequent consensus building iterations. As the leaders involved become increasingly familiar with the joint decision for which consensus is sought, it is possible that later iterations will take less time. This was modeled with two parameters: a percentage decrease by iteration in the original expected activity time and a minimum activity time. For example if each stage of the 5-stage decision maker model is initially expected to take five minutes, later iterations can be expected to take less time until some minimum time is reached. If the iterative efficiency is set to 5% and minimum to two minutes, the second iteration activities would be expected to take four minutes and 45 seconds, the third iteration activities would be expect to take approximately four and a half minutes, and so on. If there are enough iterations to reduce the time to the minimum than all remaining activities would take two minutes.

In addition to the expected activity time and potential iterative efficiency, there are parameters settings the expected number of iterations required to reach consensus. The design coordinations and de-confliction level 2 are holistic processes. Consensus is being sought on entity or groups of related entities. In contrast, de-confliction level 1 has discrete components. Consensus is iteratively being reached on accounting for a portion of the other domain's conceptual models. For the case study, the expected iterations parameter was set to five for design coordinations and de-confliction level 2. The parameter for de-confliction level 1 was based on the difference in the number of enemy/environment effect nodes and key influence nodes between the domain centric model and the integrated model. For the case study scenario that difference was 25.

5.2 Results

The modeling results for various parameter setting are presented in this section. First the COA performance results are presented followed by the deterministic and stochastic process results. The overall results are a pairing of the total process time, or process time distribution, and the estimated combined COA performance. Both the process time and performance are determined by the planning approach as described in Chapter 4. Each computational experiment used the parameter values described in section 5.1.2 unless otherwise noted.

5.2.1 Performance Results

The approach an organization chooses during planning will determine the level of integration of its conceptual model with other domains. When a COA is selected it will be based on the current conceptualization of the environment. Poorly integrated conceptual models will not allow domains to account for strong cross-domain effects in the selection of COAs. This can result in COAs which perform poorly in the actual integrated model used to assess performance. This can be seen in Table 8. These results are based on the case study TINs described above. The integrated COA more than doubles the probability of achieving coalition objectives.

Table 8 COA Performance

Approach Used	Combined COA Type	COA Performance (Probability of Goal Node Being True) (Pythia Model)		
		Coalition OBJs Met	Coalition Losses Avoided	Leader Agrees to Leave Power
New Approach	**Integrated COA**	**0.802**	**0.9**	**0.85**
Current Approach Level 2	**De-conflicted Level 2**	**0.56**	**0.67**	**0.59**
Current Approach	**De-conflicted**	**0.394**	**0.45**	**0.43**
No Coordination	**Combined Domain COAs**	**0.28**	**0.32**	**0.295**

As long as the coordination processes are allowed to come to completion, the structure of these conceptual models and performance of resulting COAs will remain the same. Changing process model parameters affects only the process time, not the COA performance. This will not be true if overall process time is compressed sufficiently and coordination processes are at risk for not coming to completion.

The COAs, sets of actionable events, associated with each of the performance levels above are shown in Table 9 (T = true, or action taken; F = false). The rationale for the changing of action choices as conceptual models change is similar to those explained in Section 4.2. As cross-domain effects become evident, the influence, positive or negative, of certain actions can change significantly. For example, the space domain action "Augment Regional Space Capacity with Non-military Assets" appears to have a negative impact on probable success of coalition objectives when viewed from the space domain conceptualization. This is because that action increases the probability that Country X will be alerted to coalition space activities and counter them. However, once a more integrated conceptualization of the environment is developed, the potential benefits outweigh these concerns. The augmented capacity increases targeting accuracy for all kinetic strikes and provides additional approaches for all cyber attacks.

Table 9 COA Selections by Integration Level

Domain Actionable Events	Integrated COAs	De-conflicted Level 2 COAs	De-conflicted Level 1 COAs	Combined Domain COAs
Kinetic Strike on Army Units	T	F	F	F
Kinetic Strike on Police Units	F	F	F	F
Kinetic Strike on Air Defense Assets	T	T	T	T
Kinetic Strike on Electric Power Stations	F	F	T	T
Kinetic Strike on Country X Leader's Compound	T	F	F	F
Disrupt Country X's GPS Assets	T	T	T	T
Disrupt Country X's Satellite Communications	F	T	T	T
Disrupt Country X's Satellite Television	T	T	T	T
Disrupt Country X's Military Satellite Assets	F	F	T	T
Augment Regional Space Capacity with Non-military Assets	T	F	T	F
Conduct Cyber Attack on Air Defense Assets	F	F	T	T
Conduct Cyber Attack on Targeted Communications Infrastructure	F	T	T	F
Conduct Cyber Attack on Industrial Infrastructure	T	T	T	T
Conduct Cyber Attack to Inject Information Operations to Encourage Dissent	T	T	T	T
Conduct Cyber Attack on Military and Police C2	T	F	F	F

5.2.2 Deterministic Process Model Results

Using the process model parameters from Section 5.1.2, without variance on activity times or numbers of iterations required, the model produces the results shown in Table 10. These results are based on no assumption of iterative efficiency. In other words, the last iteration coordination will take just as long as the first. The table shows the total process time results paired with the performance results explained previously. All planning activities in absence of any inter-domain coordination take a total of 43 and a half hours. The proposed approach takes approximately 49 hours or one hour more than the target planning time. De-confliction approaches take approximately 55 and 57 hours respectively. The large number of iterations required for de-confliction level 1, which is necessary for level 2, accounts for the greater times.

Table 10 Deterministic Process Model Results

Approach Used	Combined COA Type	Process Times (CPN Model)		COA Performance (Probability of Goal Node Being True) (Pythia Model)		
		Minutes	Hours	Coalition OBJs Met	Coalition Losses Avoided	Leader Agrees to Leave Power
New Approach	Integrated COA	2945	49.1	0.802	0.9	0.85
Current Approach Level 2	De-conflicted Level 2	3435	57.25	0.56	0.67	0.59
Current Approach	De-conflicted	3310	55.1	0.394	0.45	0.43
No Coordination	Combined Domain COAs	2660	44.33	0.28	0.32	0.295

If the concept of iterative efficiency described above is applied to the deterministic process model, the results are shown in Table 11. Since the number of iterations is higher in de-confliction approaches, the iterative efficiency assumption clearly has a greater effect. With this assumption, all coordination approaches are close to the target time frame of 48 hours in the deterministic case. As a result, once stochastic variation is added, the process may or may not come to completion within the desire time frame, which is consistent with feedback from operational level military planning exercises.

Table 11 Deterministic Modeling Results with Iterative Efficiency

Approach Used	Combined COA Type	Process Times (With Iteration Efficiency) (CPN Model)		COA Performance (Probability of Goal Node Being True) (Pythia Model)		
		Minutes	Hours	Coalition OBJs Met	Coalition Losses Avoided	Leader Agrees to Leave Power
New Approach	Integrated COA	2847	47.45	0.802	0.9	0.85
Current Approach Level 2	De-conflicted Level 2	3018	50.3	0.56	0.67	0.59
Current Approach	De-conflicted	2910	48.5	0.394	0.45	0.43
No Coordination	Combined Domain COAs	2660	44.33	0.28	0.32	0.295

5.2.3 Stochastic Process Model Results

There is a great number of combinations of process model parameters that can be applied to the stochastic version. The variance of the expected time for each type of activity can be separately adjusted (planning activities and the three types of coordination activities). Additionally the number of iterations required for completion of the three types of coordination can be varied. The sensitivity to these parameters is examined in 5.3. The results presented here are modeled with a similar moderate variation (standard deviation being 20% of the expected value) of all activity times and required iterations. Using the same expected values as the deterministic case, the results are shown in Table 12.

Table 12 Stochastic Modeling Results

Approach Used	Combined COA Type	Process Times (CPN Model)		COA Performance (Probability of Goal Node Being True) (Pythia Model)		
		Hours (Mean)	Hours (Std Dev)	Coalition OBJs Met	Coalition Losses Avoided	Leader Agrees to Leave Power
New Approach	Integrated COA	51.8	2.8	0.802	0.9	0.85
Current Approach Level 2	De-conflicted Level 2	59.6	3.1	0.56	0.67	0.59
Current Approach	De-conflicted	57.5	2.9	0.394	0.45	0.43
No Coordination	Combined Domain COAs	46	2	0.28	0.32	0.295

The structure of the process model is such that the value for any given computational experiment stochastic variable will be different for each domain. In other words, the value of the probabilistic time for the "Conduct JIPOE" activity will be different for each domain. This stochastic variation will increase the time for the overall process if the approach uses any coordination. Coordinations are modeled as requiring all input information before proceeding. Therefore the inter-domain delay will be the largest delay of all the activities producing inputs for a coordination. The mean total planning time of all approaches, except the no coordination approach, increases with activity time variability.

As with the deterministic case, the concept of iterative efficiency can again be applied. As shown in Table 13 with the iterative efficiency assumption, the mean process times are slightly over the target time of 48 hours with a standard deviation between one and two hours.

Table 13 Stochastic Modeling Results with Iterative Efficiency

Approach Used	Combined COA Type	Process Times (With Iteration Efficiency) (CPN Model)		COA Performance (Probability of Goal Node Being True) (Pythia Model)		
		Hours (Mean)	Hours (Std Dev)	Coalition OBJs Met	Coalition Losses Avoided	Leader Agrees to Leave Power
New Approach	Integrated COA	49.8	2.2	0.802	0.9	0.85
Current Approach Level 2	De-conflicted Level 2	52.7	1.9	0.56	0.67	0.59
Current Approach	De-conflicted	50.6	1.9	0.394	0.45	0.43
No Coordination	Combined Domain COAs	46	1.9	0.28	0.32	0.295

The results in Table 13 are using the set of parameters considered to best account for uncertainty in the parameter estimation. A medium variance is placed on all activity times, planning and coordinating, and the number of iterations required for complete coordination/consensus. In addition, a moderate iterative efficiency, of 5% per iteration, down to a minimum of two minutes was used. These same parameters are used in the subsequent sensitivity analysis.

Table 14 Time Spent in Coordination by Approach

Approach	Mean Time in Coordination		Standard Deviation in Coordination Time	
	Minutes	Hours	Minutes	Hours
Co-design	694	11.6	68	1.1
Current Level 1	280	4.7	8	0.1
Current Level 2	412	6.9	44	0.7

An important point can be observed here based on Tables 13 and 14. Table 14 shows the mean time spent in coordination activities for each approach based on 25 computational experiments. It can be seen that the mean time in coordination for the proposed approach is more than twice that of the traditional approach and almost twice the current approach Level 2. However, it is clear from Table 13 that the overall increase in process planning time is similar for Co-design and the traditional approach. Both approaches extend planning time by an approximate average of four to five hours compared to the no coordination approach. The reason for this is that the Co-design approach has an inherent time advantage over de-confliction approaches that take place after COA development. Coordination always takes time and other resources. However, much of the coordination time in the Co-design approach is concurrent with other planning activities during Mission Analysis and COA Development. In contrast, all de-confliction happens after traditional planning activities. As a result any time spent in de-confliction is added to the total process time in its entirety.

5.3 Analysis

The case study modeling results indicate there is a potential for significant performance gains through integration with only moderate increases in the planning time required. These results are based on key assumptions for both the process modeling and performance modeling. These assumptions are discussed here and examined in the subsequent sensitivity analysis.

The planning process times are primarily based on assumptions relating to three areas: planning and coordination activity expected times, expected number of iterations to achieve consensus, and iterative efficiency. Military planning activity times are difficult to estimate because of their situational dependence. Factors such as the difficulty of the military environment/mission, previous knowledge of the situation, number/type of domains involve, planning resources, and constraints can heavily influence activity times. Individual activity times may vary greatly. Activities may also overlap and/or be repeated. Subject matter experts on operational planning were queried to help estimate the activity time. Their input was that the situation dependence mentioned does change individual activity time greatly but the overall apportionment of time by planning phase is more constant. For example the total planning time could be divided: Mission Analysis 30%, COA Development 20%, and so forth. The recommended apportionments by phase were used in activity time estimation. Estimation of the consensus iteration numbers and efficiency are also difficult. In addition to situational dependence on the complexity of the military situation as above, these characteristics are also dependent on the PPS (process, people, and system from knowledge management, Chapter Two) of the interactions in consensus building. These include training and experience of the people, effectiveness of collaborative information systems, and processes for conflict resolution and negotiation. This uncertainty of estimated parameters was mitigated through a more wide ranging sensitivity analysis in this area and more variation on the parameters in the process model itself.

COA performance is based on the structure and influence strengths of the TINs. The intent of the case study scenario was to create a realistic example of an operational level military environment with multiple domains. In actual planning cases, the cause-effect relationships will be determined by subject matter experts. No claim is made that those modeled here are accurate in terms of real world causal relationships. However, although the modeled relationships may not be accurate to any current real world operational environment, similar events, links, and causal strengths are expected. The performance is most influenced by the strong cross-domain effects nodes. By design these nodes have a strong influence on the COA performance. Their existence in the integrated model creates the large performance difference between integrated COAs, which account for them, and less integrated COAs, which do not. It could be argued that strong cross-domain effects have less influence or do not exist. There is no known quantification of these types of effects. However, continued emphasis on integration indicates a general belief in the existence and significance of strong cross-domain effects. It might be the case that these cross-domain effects exist in some operational environments and not in others. In addition, the capabilities and limitations of the domains themselves might determine if strong cross-domain effects will be present in a specific planning situation. Although the strong cross-domain effects in the case study scenario may or may not be realistic, if these effects exist they will have significant performance implications for COAs. In actual planning situations, analysts and subject matter experts would choose different effects and causal relationships, but the impacts would be similar.

5.3.1 Effects of Time Compression

The purpose of this section is to explore the potential effects of time compression. As seen in the previous sections, all coordination process types have the potential to exceed the target planning time for the case study scenario of 48 hours. This raises the question: how would the performance of resulting COAs be affected if it is necessary to strictly adhere to a process time limit?

A key assumption in this portion of the research is that the times for planning activities cannot be compressed. The case study scenario is based on a crisis action planning situation with an approximate 48 hour timeline for COA approval. The planning activity time estimates are based on this situation. Crisis action planning is already a compressed/time sensitive situation therefore the assumption is made that the time estimate values already represent compressed times and cannot be further compressed. Only coordination activity times will be modified in the consideration of time compression.

Before considering the potential performance effects from time compression, some bounds can be examined based on the assumption above. Using only the process model, it is possible to determine the potential effects of coordination activity process time reduction on the total planning process time. Table 15 shows the effect of coordination activity expected time compression on the overall process time for each level of integration. Only the coordination phase expected activity times were changed for these computational experiments; all other parameters remain the same (identical to those used in the stochastic results with iterative efficiency, Section 5.2.2.). The table includes the mean process time and standard deviation results for set amounts of expected coordination activity time reduction. The high end point of a 95% confidence interval is also included. It is assumed that having the high end point of the 95% confidence interval less than the maximum planning time would be the ideal target for process time compression. Based on this initial analysis, the only combination of integration and compression level which could meet this target would be 40% compression of the integrated approach. Even at a compression level of 60%, the de-confliction approaches fail to meet this target.

Table 15 Coordination Time Compression Affect on Total Process Time

Integration and Compression Level	Mean Total Process Time		Standard Deviation		High End of 95% Confidence Interval	
	Minutes	Hours	Minutes	Hours	Minutes	Hours
Fully Integrated COA	2989	49.82	133	2.21	3015	50.26
20% Process Time Reduction	2887	48.12	130	2.16	2912	48.54
40% Process Time Reduction	2827	47.12	120	1.99	2850	47.51
Fully De-conflicted Level 2 COA	3160	52.67	115	1.92	3182	53.04
20% Process Time Reduction	3075	51.24	130	2.17	3100	51.67
40% Process Time Reduction	2995	49.91	135	2.25	3021	50.35
60% Process Time Reduction	2928	48.79	124	2.06	2952	49.20
Fully De-conflicted Level 1 COA	3038	50.64	113	1.88	3060	51.01
20% Process Time Reduction	2998	49.97	125	2.09	3023	50.38
40% Process Time Reduction	2932	48.86	133	2.21	2958	49.29
60% Process Time Reduction	2867	47.78	131	2.18	2893	48.21
No Coordination COA	2758	45.96	117	1.95	2781	46.34
Minutes in 48 Hours	2880	48				

The goal here is to model the effect of process time compression on the process outcome, performance of selected COA. In order to accomplish this, three relationships must be reflected in the modeling approach: 1) the effect(s) of time compression on the process, 2) the effects of process changes on the conceptualization of the problem or the decision making methods, and 3) the effects of conceptualization/decision making approaches changes on the selected COA (and resulting performance). Section 2.1.2 described the concept of bounded rationality in relation to military decision making. Limits on the resources for decision making require processes which are not fully rational. Time compression is one potential stressor which can further limit the rationality of the decision making process. As available time is compressed, further limits are placed on the process to meet the time restrictions. These process limits could include considering less information or options (Adelman et al., 2003), changing decision making rules (Edland and Svenson, 1993), and/or acquiescing more easily in negotiation (Carnevale et al., 1993). These changes to the process to meet time requirements while attempting to maintain quality decisions are called adaptation strategies (Maule and Svenson, 1993).

The effects of adaptation strategies on the decision making process are modeled here by limiting the information considered in the decision making process. As the time for group decision making and consensus building is compressed, less of the potential information on the operational environment is accounted for in the domain's conceptualization. The information elements considered in the domain's conceptualization of the operational environment decreases proportionally with compression of time. Randomly eliminating nodes and/or links from the influence network could result in a model which is technically incomplete or nonsensical from a scenario stand point. Therefore elements were defined which could be eliminated from the influence network while maintaining consistency. Influence network elements (INEs) were defined as a set of one or more influence nodes and associated links. When one is removed from the influence network, the result is another complete influence net or an empty influence net. The INE includes all inbound links to any parent nodes included in the INE, all outbound links from any child nodes included in the INE, and all links between nodes in the INE.

Examples are shown in Fig. 34 and Fig. 35. The elements of the INEs are highlighted with orange boxes. In the first case, the INE contains only one node, "Port facilities becomes degraded." As describe above, all inbound arcs to parent nodes in the INE (in this case only "Port facilities becomes degraded") are included in the INE. All outbound arcs from child nodes in the INE, again the same "Port facilities becomes degraded" node, are also included. This INE contains one node, one inbound arc, and one outbound arc. Once this INE is eliminated, the model remains a complete influence net and reasonably accurate representation of the operational environment. The resulting conceptual model no longer accounts for the effects of cyber attacks on port facilities. The second example is similar but contains two nodes: "Cyber Attack Causes Country X to Switch Air Defense Assets to Backup Fiber Optic Network" and "Country X Switches to Secondary Air Defense System." In addition to the inbound and outbound arcs, this INE also contains all arcs between the contained nodes.

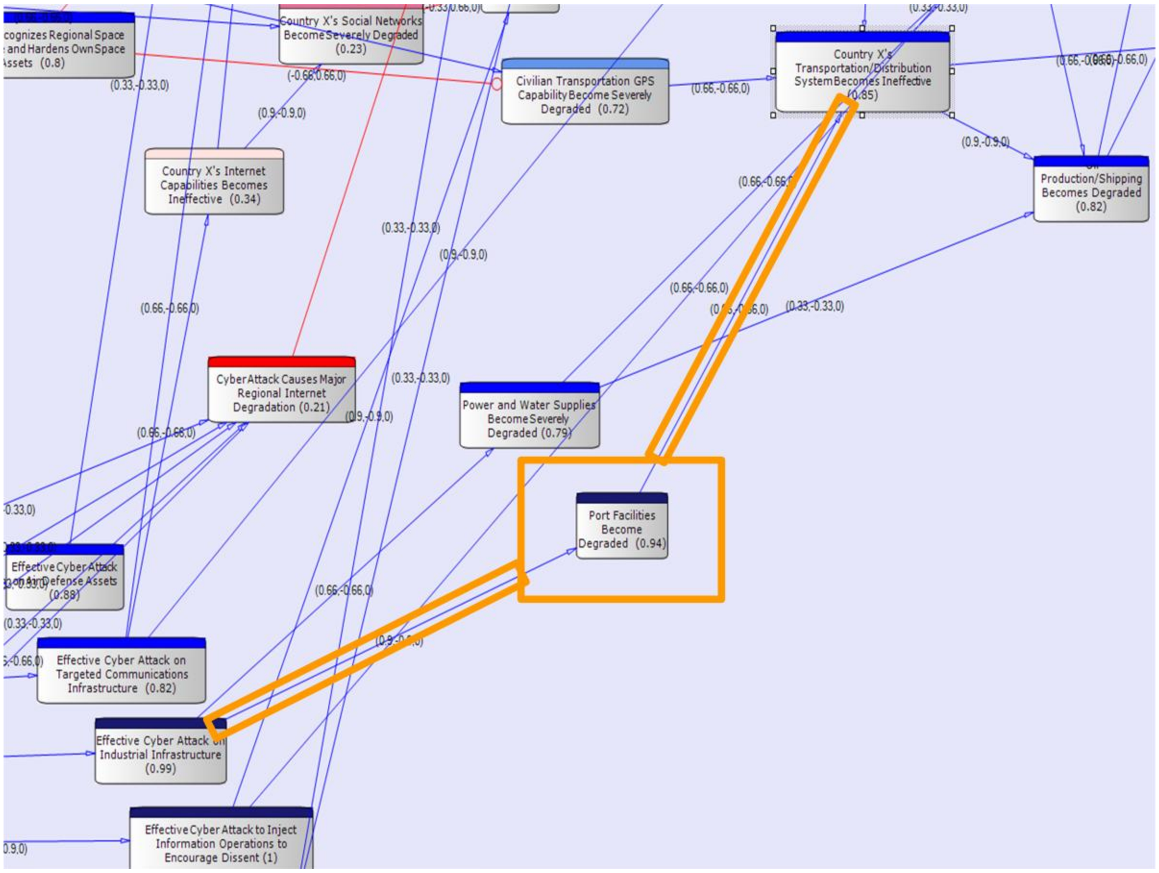


Figure 34 Example INE with One Node

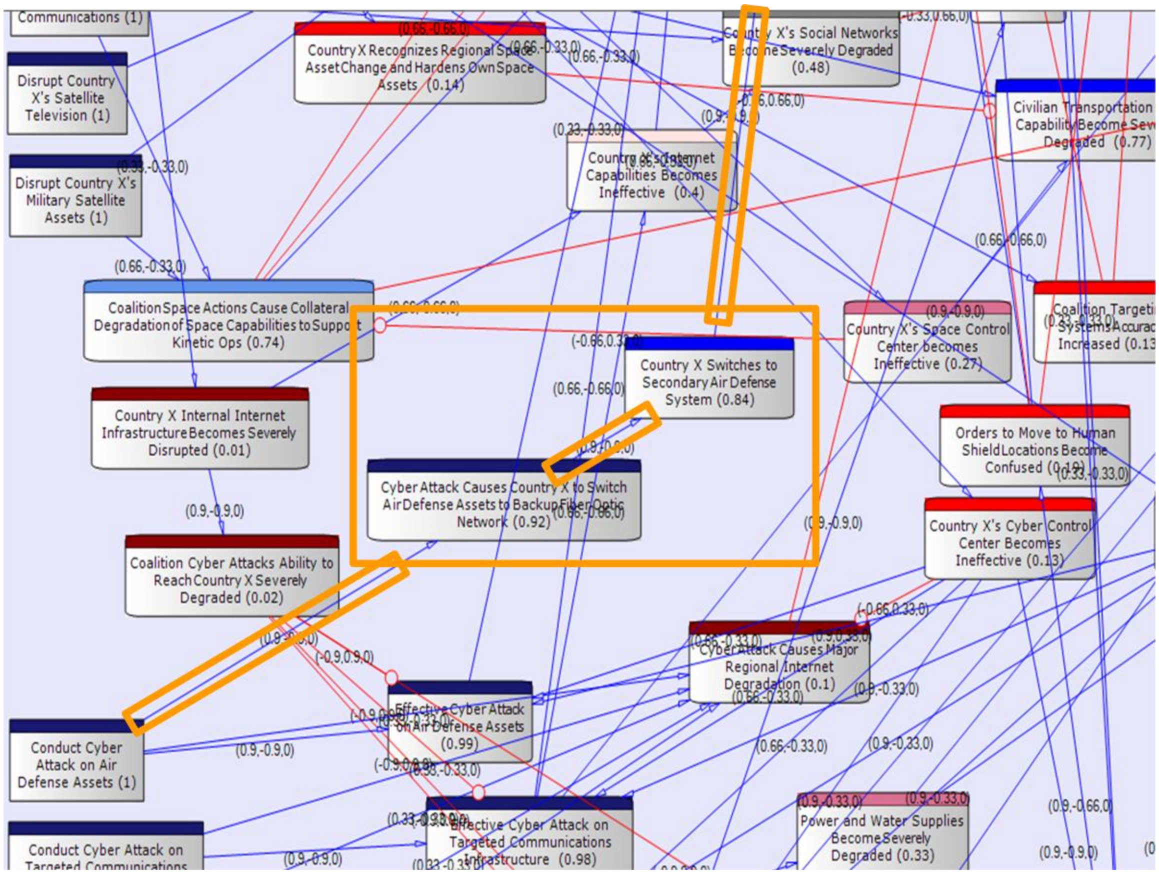


Figure 35 Example INE with Two Nodes

Using the INE definition, conceptual models can be reduced by discrete elements of causal relationships and the result will always be a smaller influence net (or an empty influence net). Initially INEs can be chosen so that each element is a specific causal relationship which has meaning in the scenario. This relationship can be eliminated from consideration and the resulting conceptual model is still a realistic representation of the operational environment (with simply one less relationship considered). At some point, elimination of further INE will result in a model which is still a complete influence net, but no longer realistically represents the operational environment. The point where this occurs is subjective and can best be determined by the subject manner experts that created the influence net. The assumption can be made that this point where the model begins to break down is theoretically related to the point in time compression effect research in which coping strategies can no longer maintain consistency of decision results (Adelman et al., 2003).

This approach to reducing the amount of information (INEs) considered as time is compressed was used to relate time compression to the effect on decision making. Consistent with the idea of coping strategies, the domain's conceptual models become less complex (considers less information) as time is compressed. The modeling of this is accomplished by eliminating a number of INEs from the influence model of the domain's conceptualization. If the resulting conceptual model has not crossed the subjective point described above, a COA will be chosen. The chosen COA will result in some level of performance. If the conceptual model has crossed the point where the decision making process begins to break down, then the decision making process fails.

The conceptual models from the case study for each level of integration were decomposed into INEs as described. Models of higher levels of integration contain all the INEs from lower integration level models. The integrated conceptual model contains 30 INEs, the level 2 de-conflicted model 24 INEs, and the level 1 de-conflicted model 21 INEs. Table 16 shows the breakdown of nodes contained in each INE for the integrated conceptual model (of which the other two levels are subsets). After the sixteenth INE is eliminated (in the integrated case), it was subjectively determined that the influence net no longer accurately represented the operational scenario. Once this occurs, performance estimates can no longer be obtained and the coordinated decision making processes may fail.

Table 16 INE Delineation for the Integrated Conceptual Model

INE	Node(s)
1	Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging
2	Orders to Move to Human Shield Locations Become Confused
3	Coalition Targeting Systems Accuracy Increased
4	Country X's Space Control Center becomes Ineffective
5	Additional Cyber Attack Approaches Enabled
6	Country X's Cyber Control Center Becomes Ineffective
7	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops
8	Country X Internal Internet Infrastructure Becomes Severely Disrupted, Coalition Cyber Attacks Ability to Reach Country X Severely Degraded
9	Cyber Attack Causes Country X to Switch Air Defense Assets to Backup Fiber Optic Network, Country X Switches to Secondary Air Defense System
10	International Opinion Turns Against Leader
11	General Strike Begins, Business Leaders No Longer Support Leader
12	Country X's Financial Reserves Become Depleted
13	Port Facilities Become Degraded
14	Country X's Social Networks Become Severely Degraded
15	Country X's Internet Capabilities Becomes Ineffective
16	Food and Supplies Become Extremely Limited
17	Secondary Air Defense Systems Effective
18	Luxury Goods No Longer Available, Most Regime Loyalist No Longer Support Leader
19	Coalition Airstrikes Cause Significant Civilian Casualties, Cyber Attack Causes Major Regional Internet Degradation, International Opinion Supports Coalition Actions , UN Sanctions Authorized
20	Significant Coalition Strike Asset Loss , Coalition Military Casualties and Equipment Loss Avoided
21	Military Units Begin Large Scale Defection, Military Leaders No Longer Support Leader
22	Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets, Civilian Transportation GPS Capability Become Severely Degraded, Country X's Transportation/Distribution System Becomes Ineffective

23	Military Becomes Ineffective, Brutal Suppression Begins, Brutal Suppression Continues, Kinetic Strikes Successful on Military, Kinetic Strike on Army Units, Mass Street Protests Begin, Effective Cyber Attack to Inject Information Operations to Encourage Dissent, Conduct Cyber Attack to Inject Information Operations to Encourage Dissent
24	Leader Loses Legitimacy in International Opinion
25	Conduct Cyber Attack on Military and Police C2, Effective CA on Military and Police
26	Kinetic Strike on Police Units, Kinetic Strikes Successful on Police, State Police Become Ineffective, Protest Organizers Rounded Up, Augment Regional Space Capacity with Non-military Assets, Primary Air Defense Systems Become Severely Degraded, Kinetic Strike on Air Defense Assets, Conduct Cyber Attack on Air Defense Assets, Effective Cyber Attack on Air Defense Assets
27	Conduct Cyber Attack on Industrial Infrastructure, Effective Cyber Attack on Industrial Infrastructure, Power and Water Supplies Become Severely Degraded, Oil Production/Shipping Becomes Degraded, China and Russian No Longer Support Leader
28	Country X's Telephone System Becomes Extremely Degraded
29	Conduct Cyber Attack on Targeted Communications Infrastructure, Effective Cyber Attack on Targeted Communications Infrastructure, Mass Protests Continue
30	Kinetic Strike on Electric Power Stations, Disrupt Country X's GPS Assets, Kinetic Strike on Country X Leader's Compound, Disrupt Country X's Satellite Communications, Country X's C2 Capability Becomes Severely Degraded, Disrupt Country X's Satellite Television, Disrupt Country X's Military Satellite Assets, Country X's Regime Propaganda Becomes Ineffective, Perception of Popular Support for the Leader, His Tribe/Ethnic Group No Longer Support Leader, Leader Agrees to Leave Power, Coalition Objectives Met

The method for determining performance of the resulting COAs is identical to that described in Section 4.3. Each domain will choose the best performing COA according to their current conceptualization (based on level of integration and time compression). The performance of the chosen COA will be determined according to the integrated model which represents the real operational environment. An example of the performance results as INEs are eliminated is shown in Table 17 for the integrated conceptual model.

Table 17 Performance of Results After Eliminating INEs

Number of INEs Eliminated	Coalition OBJs Met	Coalition Loss Avoidance	Leader Agrees to Leave Power
1	0.791	0.92	0.81
2	0.778	0.918	0.787
3	0.73	0.848	0.759
4	0.73	0.848	0.759
5	0.686	0.825	0.694
6	0.56	0.67	0.59
7	0.489	0.49	0.612
8	0.461	0.59	0.451
9	0.394	0.45	0.43
10	0.394	0.45	0.43
11	0.392	0.43	0.45
12	0.392	0.43	0.45
13	0.365	0.45	0.37
14	0.365	0.45	0.37
15	0.365	0.45	0.37
16	0.365	0.45	0.37

Using this approach, the performance can be estimated for the coordination process compression levels discussed previously. The level of performance by integration and coordination time compression levels is shown in Table 18. The less integrated conceptual models contain less information. As a result, they begin to break down more quickly as less information is used during time compressed decision making.

This can be seen after a 40% reduction in coordination time for de-confliction level 1 and a 60% reduction for de-confliction level 2. The only integration and compression level combination which has a 95% confidence of meeting the target planning time is 40% compression of the integrated approach. At this level of compression, the performance of the integrated COA is significantly reduced. However at the 20% coordination reduction time the integrated COA still offers significant potential performance benefits (over traditional approaches) with a 95% confidence that the total process time will be less than 48 hours and 30 minutes.

Table 18 Relating Time Compression to COA Performance

Integration and Compression Level	Process Time							COA Performance		
	Mean Total Process Time			Standard Deviation		High End of 95% Conf Inv		Coalition OBJs Met	Coalition Loss Avoidance	Leader Agrees to Leave Power
	Min	Hrs	% Reduction	Min	Hrs	Min	Hrs			
Fully Integrated COA	2989	49.8	NA	133	2.2	3015	50.3	0.802	0.903	0.85
4 Min Mean Phase Time(20% Process Time Reduction)	2887	48.1	3%	130	2.1	2912	48.5	0.686	0.825	0.694
3 Min Mean Phase Time(40% Process Time Reduction)	2827	47.1	5%	120	1.9	2850	47.5	0.392	0.43	0.45
Fully De-conflicted Level 2 COA	3160	52.7	NA	115	1.9	3182	53.0	0.56	0.67	0.59
4 Min Mean Phase Time(20% Process Time Reduction)	3075	51.2	3%	130	2.1	3100	51.7	0.394	0.45	0.43
3 Min Mean Phase Time(40% Process Time Reduction)	2995	49.9	5%	135	2.2	3021	50.4	0.365	0.45	0.37
2 Min Mean Phase Time (60% Process Time Reduction)	2928	48.8	7%	124	2.0	2952	49.2	NA	NA	NA
Fully De-conflicted Level 1 COA	3038	50.6	NA	113	1.8	3060	51.0	0.394	0.45	0.43
4 Min Mean Phase Time(20% Process Time Reduction)	2998	49.9	1%	125	2.0	3023	50.4	0.365	0.45	0.37
3 Min Mean Phase Time(40% Process Time Reduction)	2932	48.8	4%	133	2.2	2958	49.3	NA	NA	NA
2 Min Mean Phase Time (60% Process Time Reduction)	2867	47.8	6%	131	2.1	2893	48.2	NA	NA	NA

Based on the described modeling approach to estimating the effects of time compression, trade-offs may be necessary between performance and a high confidence of strict adherence to planning time restrictions. Significant performance improvements are possible but may require more flexibility in planning time. This approach should be viewed as an initial approximation of potential time compression effects. Research has shown that individuals and groups respond very differently to time compression of group decision making with greatly varying results (Maule and Hockey, 1993) (Edland and Svenson, 1993). Since coordination and consensus building times are small relative to the overall planning process time, it is expected that longer planning times will be less sensitive to compression based performance reduction. The assumption was made in this analysis that planning activity times could not be further compressed; however, it is possible that commanders may value the higher level of integration over some other aspects of planning. During planning, commanders could choose to reduce resources spent on other planning activities to ensure higher levels of integration and raise the probability of meeting a strict planning time requirement.

5.3.2 Sensitivity

Sensitivity analysis was conducted on both the conceptual model and process model.

5.3.2.1 Process Model Sensitivity

The difficulty in estimating process model parameters, particularly those involved with coordination, have been discussed. It was important to explore the sensitivity to these parameters. All the parameters were examined, but only key ones are discussed here: expected duration of coordination stages, expected number of iterations to achieve consensus, and the amount of iterative efficiency.

All the charts presented in this section are of the same format. The total planning process time is shown on the vertical axis in minutes with the 48 hour/2880 minute target time highlighted with a red line. The horizontal axis units are in the parameter for which the analysis is being conducted. The data points for "Current Approach Level 2" are aligned exactly on the parameter value, the other two approaches' data is offset slightly to the left and right for readability. They all represent the same parameter value. The gold box graphic shows the base parameter value results for each process. These base parameters are the same that were used in determining the results in the Table 13.

In general, the sensitivity analysis results show no unexpected jumps in process time with variations in parameter values. The model behaves as expected. Increases in required times and iterations cause increases in the total process time, and increases in iterative efficiency cause decreases in total time. Since the structure of the coordinations in each approach is slightly different, the effects of parameter variation are not uniform across all approaches.

The sensitivity of the process model to changes in expected coordination stage duration is shown in Fig. 34. The general trend was as expected; increasing the time for each stage leads to overall process time increases. The Co-design approach has seven separate coordinations with five iterations (base parameter value) each. De-confliction has one coordination with 25 iterations (base parameter value). Since de-confliction has many more repetitive iterations (iterations as part of the same coordination), it is affected more by iterative efficiency than the Co-design approach. As the expected time of each stage goes up, the iterative efficiency has more impact in the de-confliction approaches. This can be seen as the parameter is set to seven or ten minutes where de-confliction approaches begin to take relatively less expected time than the Co-design approach. The results of large increases in the expected number of iterations has a similar effect of decreasing the relative expected time of de-confliction approaches. This can be seen in Fig. 35. The increase and decrease in the expected iterations required is expressed as a percentage instead of a quantity because the base parameter values are different.

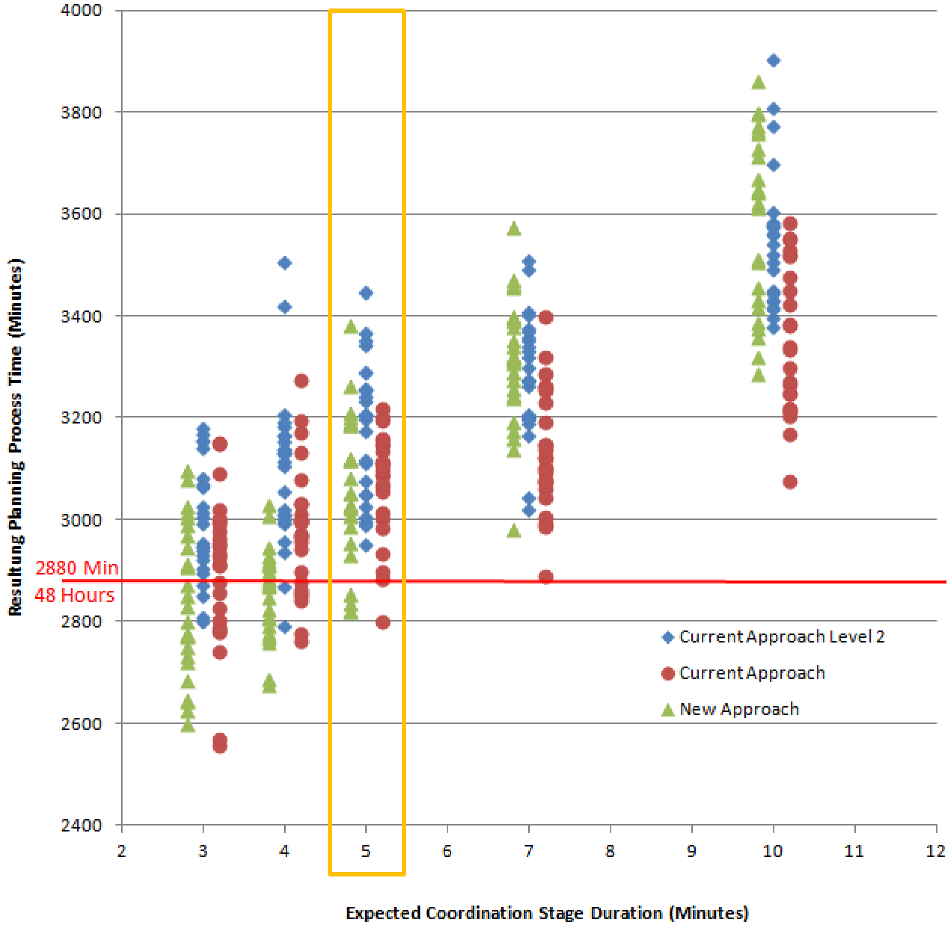


Figure 36 Expected Coordination Stage Duration Sensitivity

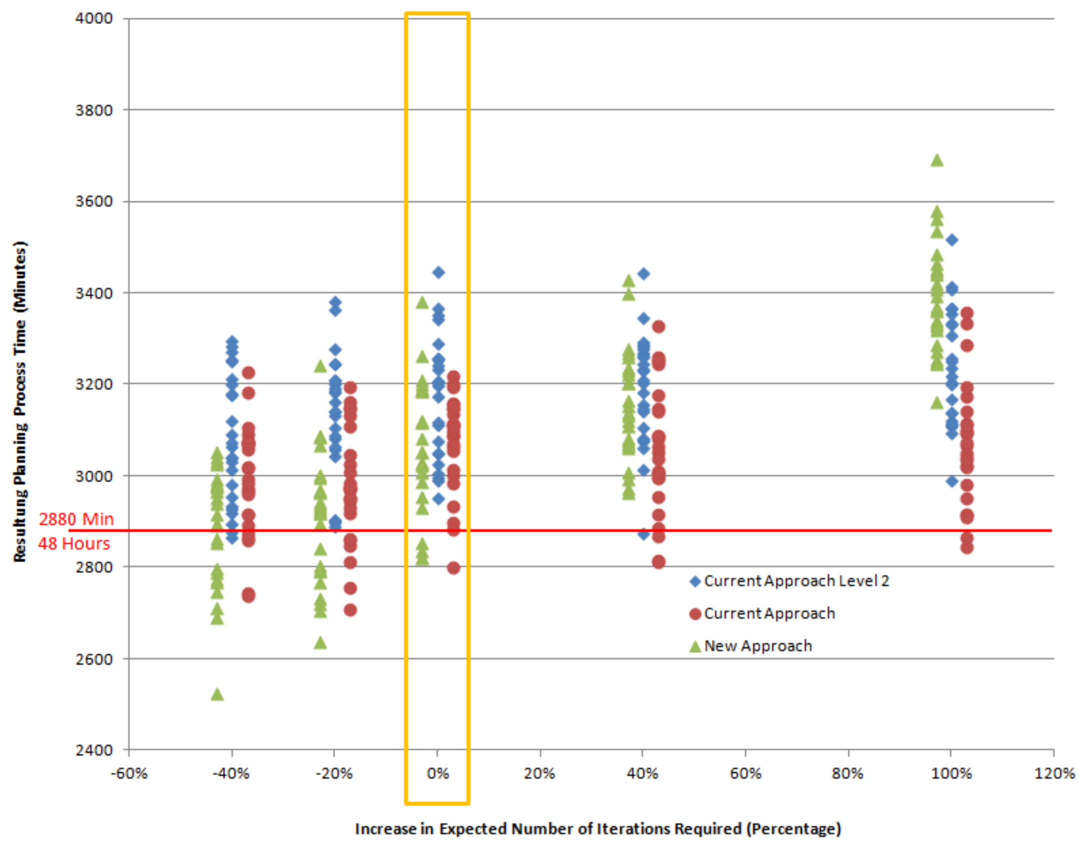


Figure 37 Expected Number of Iterations Sensitivity

Increasing iterative efficiency leads to overall process time decrease as shown in Fig. 36. In addition, the variability in total process time for the Co-design approach gets smaller as the efficiency increases. The effect of zero iterative efficiency was already shown in Table 12.

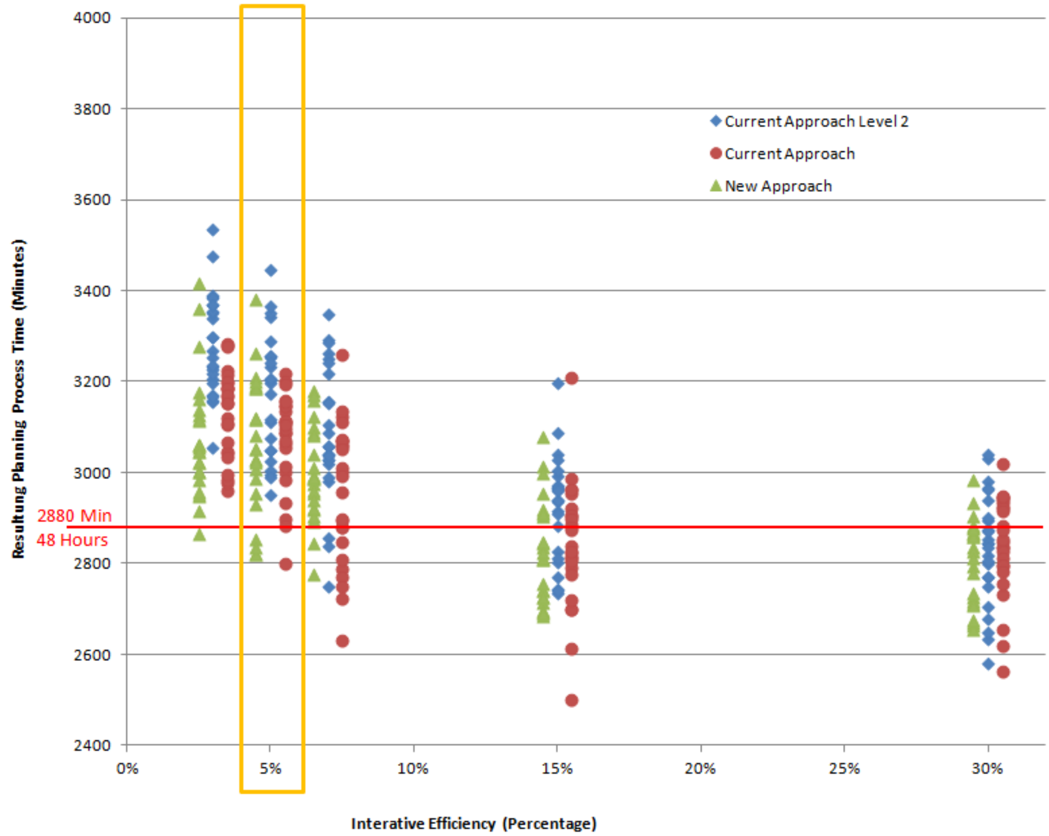


Figure 38 Iterative Efficiency Sensitivity

5.3.2.2 Conceptual Model Sensitivity

The sensitivity of the TIN model can be examined using software tools which are part of the Pythia software package. These tools explore the sensitivity of actionable events on any node. In addition, the sensitivity of influence links can be examined.

Table 19 Actionable Event Sensitivity

ActionsName	LowerProbability	UpperProbability	Difference
Kinetic Strike on Army Units	0.791	0.802	0.011
Kinetic Strike on Police Units	0.802	0.785	-0.017
Kinetic Strike on Air Defense Assets	0.785	0.802	0.017
Kinetic Strike on Electric Power Stations	0.802	0.725	-0.077
Disrupt Country X's GPS Assets	0.782	0.802	0.02
Disrupt Country X's Satellite Communications	0.802	0.788	-0.014
Disrupt Country X's Satellite Television	0.801	0.802	0.001
Disrupt Country X's Military Satellite Assets	0.802	0.769	-0.033
Conduct Cyber Attack on Air Defense Assets	0.802	0.771	-0.031
Conduct Cyber Attack on Targeted Communications Infrastructure	0.802	0.795	-0.007
Conduct Cyber Attack on Industrial Infrastructure	0.796	0.802	0.006
Conduct Cyber Attack to Inject Information Operations to Encourage Dissent	0.791	0.802	0.011
Conduct Cyber Attack on Military and Police C2	0.773	0.802	0.029
Kinetic Strike on Country X Leader's Compound	0.797	0.802	0.005
Augment Regional Space Capacity with Non-military Assets	0.755	0.802	0.047

Table 15 shows the sensitivity of each actionable event node in the TIN in relation to the goal node, "Coalition Objectives Met." The lower and upper probability show the effect on the goal node of that action. If the action is set to true, the goal node will reflect the upper probability value (with all other actions remaining unchanged). If the action is set to false, the goal node will reflect the lower probability value. If the difference is positive, the action will increase the probability of the goal node event. The magnitude of the difference represents the strength of the influence of that action. For the case study scenario, strong cross-domain effects favor certain actions and not others. "Kinetic Strike on Power Stations," for example, was designed in the scenario to be unfavorable in the integrated model. This is seen in the relatively large negative difference shown as the difference rating.

Table 15. In general the model sensitivity is designed to represent the desired effects. The sensitivity of influence links was also examined. As with the actions, several influences were designed to have significant effect in accordance with the modeled scenario. An example of the sensitivity analysis data for link influence is shown in Table 16. Link influences are separated into "h" values, the influence if the parent node is true, and "g" values, the influence if the parent node is false. The entire analysis in presented in Appendix A.

Table 20 influence Link Sensitivity Example

Parents	Children	MinhValue	MaxhValue	hDifference	MingValue	MaxgValue	gDifference
Leader Agrees to Leave Power	Coalition Objectives Met	0.677	0.905	0.228	0.747	0.857	0.11
Kinetic Strike on Army Units	Kinetic Strikes Successful on Military	0.796	0.805	0.01	0.802	0.802	0
Kinetic Strike on Army Units	Coalition Airstrikes Cause Significant Civilian Casualties	0.804	0.766	-0.038	0.802	0.802	0

Chapter Five has presented a case study representing a realistic operational level military planning scenario. The results of modeling this case study were then described in detail. These results demonstrate that Co-design has the potential to significantly increase performance through integration with only moderate increases in process time. The final chapter summarizes and describes contributions of this research effort. It also recommends potential avenues to extend this research.

CHAPTER SIX

CONCLUSIONS

6.1 Summary

This research has explored the challenges of integrated planning and, specifically, integrated COA development among cooperating domains. Chapter One discussed the background and importance of integration in military planning. Integration, and the related terms synchronization, synergy, coordination, and unity of effort, are some of the most emphasized concepts in current Western military strategy and doctrine. Increased integration allows military organizations to better address the emerging challenges of information age warfare. Improved integration also decreases operational risk while conserving capabilities and resources.

The research hypothesis was: It is possible to design integrated COAs within the timeframe currently used in mission planning by applying a method based on building a common conceptualization first. The resulting integrated COAs will be more effective. There are other options for improvement of military planning integration beyond increasing information sharing. The current approach of developing separate domain conceptualizations and related COAs first, then beginning a process of integration is inefficient.

Chapter Two explored research areas related to organizational communication and decision making and civilian and military planning and design. It explored the relationships of information and knowledge and how they are used to conceptualize situations or problems. Models of information and knowledge sharing were examined to determine key aspects that affect planning and decision making. The many challenges of group, collaborative, and inter-organizational decision making were also considered along with the characteristics of rational decision making and bounded rationality.

This chapter also surveyed the many types of military and civilian prescriptive and process oriented models of planning and design. The complementary nature of military planning and design was considered. Military operational design was also considered for its similarity to problem conceptualization in non-military fields. These non-military fields have presented research indicating common conceptual model building among parties in collaborative design, concurrent engineering, and cooperative work increase the integration level of the resulting product.

Finally this chapter examined analytical models which have been used in operational and strategic level military planning. A few models of the planning process were found, as well as numerous models supporting planning analysis. Two modeling approaches were particularly well suited for use in this research: Colored Petri Net modeling of the planning process and Timed Influence Net models of the operational environment.

Chapter Three examined further the definition of integration and methods to increase integration. Various United States Military and other definitions were examined to distill the key aspects of integration. The definition of integrated COA for this effort was established: an integrated COA is a COA in which all participating entities act as one organization in pursuit of a common goal; an integrated COA is one in which no higher estimation of performance can be obtained by changing the actions taken and action timing in each involved domain COA. Based on the definition of integrated COA and the examination of organization knowledge sharing and decision making, some basic requirements for integrated planning were then delineated. The chapter continued with an examination of the current approaches for planning integration and COA de-confliction.

Chapter Three ended with an explanation of a new approach, Co-design, and how it was developed. The new approach is a fundamentally different paradigm focusing on common conceptualization vs. knowledge sharing between separate conceptualizations. The new approach was related to similarities in existing operational design methods. In addition, the new approach was laid out in a series of manageable steps with necessary inputs identified. These inputs were then matched to outputs from current planning activities.

Chapter Four highlights a unique modeling approach. The modeling approach was conceived to examine the feasibility of the Co-design approach. It related the amount of coordination during planning to the integration level of the domain's conceptual models. In turn, the integration level of these conceptualizations drives the integration of the COAs chosen.

The process modeling approach was detailed starting with the structure and then proceeding to the execution. Key components of the process model structure were detailed with simple examples. The coordination modeling approach based on the 5-stage decision maker model was then presented. This approach was extended to include successive iterations as domain decision makers seek consensus during coordination.

Chapter Four continued with modeling approaches for conceptual modeling. TINs were used to represent the conceptualization of the operational environment. Methods were presented to model the changes in domain conceptual models that occur as appreciation for other domain actions and effects grows. These modeling paradigms were explained using a simplified example TIN of a military operation. The effects and relationships of various portions of the conceptual model were explained using this simple example. In addition, the method for evaluating the performance of COAs based on the integrated model was described. The chapter closed with a methodology which related the level of integration of planning to the performance of the resulting COAs.

Chapter Five presented a realistic operational level military scenario and examined the modeling results based on this case study. The scenario was based on concepts similar to the simpler example in Chapter Four, but added a third domain and more realistic complexity. The actions, effects, cross-domain effects, key influencers, and goal node were explained in detail. This gave an appreciation for how the more complex scenario components related to the same basic conceptual model relationships presented in Chapter Four.

This chapter went on to explain the process modeling parameters chosen to represent the case study scenario as accurately as possible. This included the methods for estimating activity and coordination times. The methodology for examining variability in both the coordination times and the number of iterations was also explored. The concept of iterative efficiency was also discussed in which later iterations of consensus building take less time as decision makers become more familiar with the problem and the process.

Chapter Five continued with the presentation of modeling results and analysis. It was demonstrated that, based on the modeling parameters, the Co-design approach supports significant COA performance improvement with marginal increases in the time required for planning. Results were examined with differing parameters including deterministic and stochastic activity time and iteration numbers and with and without iterative efficiency.

Chapter Five concluded with analysis of the results. This included analysis of potential impacts of model parameter estimation and application to realistic operational military planning situations. Most of the modeling planning approaches required more time than the scenario target of 48 hours. It was therefore important to consider the potential effects of process time compression if even small time extensions could not be afforded. This analysis was also presented. Finally, sensitivity analysis results for key model parameters were discussed.

6.2 Contributions

This research demonstrated a new approach to the C2 planning process which emphasizes integrated planning. This research has several important contributions:

1) A framework was articulated for the logical and efficient construction of a joint understanding of the operational environment between disparate domains (common conceptual model). Research in non-military fields suggests significant improvement is possible through common conceptualization. Time-sensitive operational and strategic military planning place important constraints on any potential collaboration. The Co-design approach was developed to maximize the use of existing planning and design activities while adding the minimum necessary coordination steps for common conceptualization.

2) A modeling concept was developed and demonstrated which can potentially be extended to other research areas. It is difficult to model the effects of planning process changes on planning results. The approach used in this research related a model of the problem conceptualization to the performance of potential problem solutions based on that specific conceptualization. This concept could provide an approach for other research areas in which it is difficult to quantify the relationships between process integration and process results.

3) A new paradigm for C2 planning architectures is presented as an important design alternative for consideration. Since most western military planning processes are very similar, there is little differentiation in the functional, or operational, view of C2 planning architectures. Design alternatives are therefore currently focused on the systems

and services views. As a feasible functional view alternative the Co-design approach will allow architects to compare fundamentally different paradigms.

6.3 Future Work Recommendations

This research effort has identified many areas for further work and extension of examined concepts.

The feasibility of the Co-design approach has been demonstrated with process and conceptual modeling. Every effort was made to accurately estimate all modeling parameters. However, the further feasibility of the approach can only be shown with experiments that include the interaction of actual human decision makers. Formal experiments in operational level C2 are notoriously difficult to conduct. It is difficult to isolate the experiment effect when human factors such as experience, motivation, preferences, training, and others can have strong influences. However, feasibility studies can be conducted to determine whether the modeled consensus building can occur in realistic environments.

In the analysis presented in Chapter Five, the impact of strong cross-domain effects on COA performance was discussed. Although emphasis on integration indicates a general belief in these effects, an important research question is: what are the conditions for their existence and strength? Based on this research, existence conditions appear to be related to the operational environment and potential actions of the domains. Intuitively it would seem that as the amount of overlap of effects between domains increases so would the potential for strong cross-domain effects. Conversely, domains with little commonality between the effects of their actionable events may benefit little from increased planning integration. Additionally, it is unclear what potential characteristics of the environment influence the existence and strength of cross-domain effects. These concepts clearly require further study.

This research effort has focused on inter-domain integration. The domains considered were divided along functional lines. The domains were also at the same hierarchical level from a military command stand point, i.e., no domain was a superior headquarters to another domain. In relation to the delineation of domains this research can be expanded in several ways:

1) Vertical Integration. As described above, this research has focused on horizontal integration. The research can be expanded with the inclusion of superior and subordinate planning domains. This would illuminate the concept of conceptual model abstraction. Higher level domains coordinating with lower domains would be integrating equivalent models at different levels of abstraction.

2) Alternate Domain Division. The domains in this research were separated along functional lines. Other domain divisions may be quite interesting from a research stand point. One example which would have great interest for the United States Military would be delineation along the lines of information accessibility. Integrating across different security classification levels, which are ironically termed domains, would be a potentially very important extension of this work.

3) Lead Planning Domain. One integration approach used in military planning is that of supported and supporting organizations. The supported domain leads the planning and execution of the operation while supporting domains provide means for mission

accomplishment. This is similar to designating one domain as superior, as discussed in 1) above. However, an important research question is: if a domain is designated as lead, or supported, does that inhibit conceptualization of approaches which are not centered on that domain? For example, in the case study, if the strike domain was designated as the lead would strong cross-domain effect not centered on the strike domain be considered? This merits further research.

APPENDIX A

TERMS AND MODELS

7.1 Definition of Selected Terms

The terms specific to this research are defined by the author. The military term definitions are taken from the Department of Defense Dictionary of Military and Associated Terms, 2008.

Adaptation strategy - Strategies used in individual and group decision making in attempts to maintain decision quality as additional stress (such as time compression) is put on the process.

Command and control — The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.

Co-design - Co-design is a cooperative operational design process among domain participants. Five stages were developed to build incrementally the common conceptual model during mission analysis. This allows domains to agree on essential conceptual model elements one increment at a time to simplify consensus building. The five stages and the conceptual model component delineation were chosen to align with existing concepts in operational design. The five steps are termed design coordinations.

Combined domain COAs - An inter-domain COA which is not integrated. The actions selected by each domain are domain centric. The actions can be combined into one inter-domain COA which fails to account for any cross-domain effects.

CPN Tools - A software tool for modeling Colored Petri Nets. http://cpntools.org/

Crisis action planning (CAP) - One of the two types of joint operation planning. The Joint Operation Planning and Execution System process involving the time-sensitive development of joint operation plans and operation orders for the deployment, employment, and sustainment of assigned and allocated forces and resources in response to an imminent crisis. Crisis action planning is based on the actual circumstances that exist at the time planning occurs.

Current approach (or de-confliction) level 1 - In traditional military planning approaches, these domain COAs will be de-conflicted after they are developed and approved. During de-confliction, domains will share their planned actions and conceived effects. The goal of de-confliction is to eliminate or adjust actions and effects which have a significant negative impact on other domains. While de-confliction is focused on actions and effects and not explicitly on conceptual model integration, some conceptual model adjustment must occur. When domains share their intended actions at the beginning of the de-confliction process, other domains must conceptualize the effect those actions will have on the operational environment. The process of de-confliction raises the potential importance of actionable events and causal interactions which were previously unknown, not understood, or discounted. De-confliction is therefore modeled as slowly evolving domain conceptual models to incorporate knowledge of the actions and effects of other domains.

Current approach (or de-confliction) level 2 - Once level 1 de-confliction has been completed, a second level of de-confliction can be attempted. Level two de-confliction models the domains going beyond de-conflicting actions and events previously conceived by one or more domains. In level two, de-confliction domains consider potential negative cross-domain effects not previously comprehended which may be more evident now that domains can conceptualize each other's actions and effects.

Cyber domain - The cyber domain includes coalition offensive and defensive capabilities involving global networks of information systems. These capabilities can be used to degrade or protect other domain capabilities that rely on information systems. They can also be used to conduct information or psychological operations. As with kinetic attacks, there is also the possibility of collateral damage in cyber operations. Attacks may cause unintended degradation of enemy, friendly, or neutral party capabilities.

Design coordinations - The integrating processes or coordination steps in the Co-design approach. Step 1. Objective(s) and metric(s), Step 2. Key Influencers of objective(s), Step 3. Adversary and environment potential actions, Step 4. Organizations'

(Domains') potential actions, and Step 5. System structure (interactions, constraints, synergies). These five steps are envisioned as enabling joint conceptual model creation.

Domain - The term domain is used throughout this research to indicate separate functional components that must cooperate for mission accomplishment (e.g. Kinetic, Space, Cyber, etc.)

Integrated COA - A COA in which all participating entities act as one organization in pursuit of common goal(s); a COA in which no higher estimation of performance can be obtained by changing the actions taken and action timing in each involved domain

Integrating processes - Term for any process that involves coordination between domains during planning.

Iterative coordination process efficiency - The concept of later iterations of consensus building taking less time as the leaders involved become increasingly familiar with the joint decision for which consensus is sought, each other's positions, and the process itself.

Joint Operation Planning and Execution System - A system of joint policies, procedures, and reporting structures, supported by communications and computer systems, that is used by the joint planning and execution community to monitor, plan, and execute mobilization, deployment, employment, sustainment, redeployment, and demobilization activities associated with joint operations.

Joint option awareness - The understanding of how well a COA meets the commander's criteria and the underlying aspects which effect how well a COA meets the criteria.

Key influencers (KI) - The events that directly affect the objective are the key influencers. They represent a key decision in that domain's operational design process: "Which events most influence the objective?"

Kinetic domain - The kinetic strike domain represents military capabilities such as aerial bombardment, missile and rocket strikes, and naval gunfire. This domain can have devastating physical effects on adversary military and non-military capabilities. These physical effects are not always delivered with the intended precision and control, which creates the potential for civilian casualties and collateral infrastructure damage. Kinetic strikes also have the significant psychological effects which may be intended or unintended as well as being obvious or non-obvious in advance of the strike.

Military planning (standard phases):

1. Mission analysis - Mission analysis is a process of assessing the situation. Commanders (supported by their staffs and informed by subordinate and adjacent commanders and by other partners) gather, analyze, and synthesize information to orient themselves on the current conditions of the operational environment. The commander and staff conduct mission analysis to better understand the situation and problem, and identify what the command must accomplish, when and where it must be done, and most importantly why—the purpose of the operation.

2. COA development - A COA is a broad potential solution to an identified problem. The COA development step generates options for follow-on analysis and comparison that satisfy the commander's intent and planning guidance. During COA development, planners use the problem statement, mission statement, commander's intent, planning guidance, and the various knowledge products developed during mission analysis to develop COAs.

3. COA analysis - COA analysis enables commanders and staffs to identify difficulties or coordination problems as well as probable consequences of planned actions for each COA being considered. It helps them think through the tentative plan. COA analysis may require commanders and staffs to revisit parts of the COA as discrepancies arise. COA analysis not only appraises the quality of each COA but also uncovers potential execution problems, decisions, and contingencies. In addition, COA analysis influences how commanders and staffs understand the problem and may require the planning process to restart.

4. COA comparison - COA comparison is an objective process to evaluate COAs independently of each other and against set evaluation criteria approved by the commander and staff. The goal to identify the strengths and weaknesses of COAs enable selecting a COA with the highest probability of success and further developing it in an operation plan or order.

5. COA approval - After the decision briefing, the commander selects the COA to best accomplish the mission. If the commander rejects all COAs, the staff starts COA development again. If the commander modifies a proposed COA or gives the staff an

entirely different one, the staff war-games the new COA and presents the results to the commander with a recommendation.

6. Detailed planning/Order production -The staff prepares the order or plan by turning the selected COA into a clear, concise concept of operations and required supporting information. The COA statement becomes the concept of operations for the plan. The COA sketch becomes the basis for the operation overlay. Orders and plans provide all the information subordinates need for execution. Mission orders avoid unnecessary constraints that inhibit subordinate initiative. The staff assists subordinate staffs with their planning and coordination.

Operational design - The conception and construction of the framework that underpins a campaign or major operation plan and its subsequent execution.

Operational environment - A composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander

Pythia - A software tool for modeling timed influence networks. Developed by GMU Systems Architecture Lab.

Space domain - The space domain includes all coalition capabilities involving military and civilian satellites and ground stations, and kinetic and non-kinetic methods to degrade or protect those capabilities. Space capabilities include global positioning, intelligence gathering, communication, command and control, and others. The space domain can use coalition assets in attempts to bolster friendly capability as well as degrade adversary capabilities.

Stove-pipe approach to planning - A domain centric planning approach in which information from other domains is only considered when available.

Strong cross-domain effects - Strong cross-domain effects are intended to model the benefits of higher levels of integration. These effects may also not be obvious to planners using a domain centric approach. Only with the understanding of how multiple domains can approach the problem can these effects be conceptualized. They are divided into those which have negative effects on other domains and those which have positive ones.

Supported command or domain - A command or domain which is designated to lead an operation. The commander having primary responsibility for all aspects of a task assigned by the Joint Strategic Capabilities Plan or other joint operation planning authority. In the context of joint operation planning, this term refers to the commander who prepares operation plans or operation orders in response to requirements of the Chairman of the Joint Chiefs of Staff. In the context of a support command relationship, the commander who receives assistance from another commander's force or capabilities, and who is responsible for ensuring that the supporting commander understands the assistance required.

7.2 Models

7.2.1 Pythia Model

7.2.1.1 Model Nodes

Node Types: Actionable Event (AE), Key Influencer (KI), Goal Node (GN), Enemy/Environment Effect (EE)

Table 21 Conceptual Model Nodes

Type	Node ID	Node Name
AE	1	Kinetic Strike on Army Units
AE	2	Kinetic Strike on Police Units
AE	4	Kinetic Strike on Air Defense Assets
AE	5	Kinetic Strike on Electric Power Stations
AE	6	Disrupt Country X's GPS Assets
AE	7	Disrupt Country X's Satellite Communications
AE	8	Disrupt Country X's Satellite Television
AE	9	Disrupt Country X's Military Satellite Assets
AE	10	Conduct Cyber Attack on Air Defense Assets
AE	11	Conduct Cyber Attack on Targeted Communications Infrastructure
AE	13	Conduct Cyber Attack on Industrial Infrastructure
AE	14	Conduct Cyber Attack to Inject Information Operations to Encourage Dissent
AE	48	Conduct Cyber Attack on Military and Police C2
AE	65	Kinetic Strike on Country X Leader's Compound
AE	66	Augment Regional Space Capacity with Non-military Asset
KI	0	Leader Agrees to Leave Power
EE	3	Coalition Airstrikes Cause Significant Civilian Casualties
EE	12	Cyber Attack Causes Major Regional Internet Degradation (0
EE	15	Mass Street Protests Begin
EE	16	General Strike Begins
EE	17	Military Units Begin Large Scale Defection
EE	18	Port Facilities Become Degraded

EE	19	Luxury Goods No Longer Available
EE	20	Power and Water Supplies Become Severely Degraded
EE	21	Country X's Regime Propaganda Becomes Ineffective
EE	22	Food and Supplies Become Extremely Limited
EE	23	Country X's Telephone System Becomes Extremely Degraded
EE	24	Country X's Internet Capabilities Becomes Ineffective
EE	25	State Police Become Ineffective
EE	26	Military Becomes Ineffective
EE	27	Primary Air Defense Systems Become Severely Degraded
EE	28	Brutal Suppression Continues
EE	29	Protest Organizers Rounded Up
KI	30	Leader Loses Legitimacy in International Opinion
KI	31	China and Russian No Longer Support Leader
KI	32	Military Leaders No Longer Support Leader
KI	33	Business Leaders No Longer Support Leader
KI	34	His Tribe/Ethnic Group No Longer Support Leader
KI	35	Most Regime Loyalist No Longer Support Leader
EE	36	Civilian Transportation GPS Capability Become Severely Degraded
EE	37	Country X's Financial Reserves Become Depleted
EE	38	Oil Production/Shipping Becomes Degraded
EE	39	UN Sanctions Authorized
EE	40	International Opinion Turns Against Leader
EE	41	Country X's Transportation/Distribution System Becomes Ineffective
EE	42	Perception of Popular Support for the Leader

EE	43	Country X's C2 Capability Becomes Severely Degraded
EE	44	Country X's Social Networks Become Severely Degraded
EE	45	Kinetic Strikes Successful on Police
EE	46	Kinetic Strikes Successful on Military
EE	47	International Opinion Supports Coalition Actions
EE	49	Mass Protests Continue
GN	50	Coalition Objectives Met
KI	51	Coalition Military Casualties and Equipment Loss Avoided
EE	52	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops
EE	53	Significant Coalition Strike Asset Loss
EE	54	Cyber Attack Causes Country X to Switch Air Defense Assets to Backup Fiber Optic Network
EE	55	Country X Internal Internet Infrastructure Becomes Severely Disrupted
EE	56	Coalition Cyber Attacks Ability to Reach Country X Severely Degraded
EE	57	Effective CA on Military and Police
EE	58	Effective Cyber Attack on Air Defense Assets
EE	59	Effective Cyber Attack on Targeted Communications Infrastructure
EE	60	Effective Cyber Attack on Industrial Infrastructure
EE	61	Effective Cyber Attack to Inject Information Operations to Encourage Dissent
EE	62	Country X Switches to Secondary Air Defense System
EE	63	Secondary Air Defense Systems Effective
EE	64	Brutal Suppression Begin
EE	67	Country X's Space Control Center becomes Ineffective

EE	68	Country X's Cyber Control Center Becomes Ineffective
EE	69	Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets
EE	70	Orders to Move to Human Shield Locations Become Confused
EE	71	Coalition Targeting Systems Accuracy Increased
EE	72	Additional Cyber Attack Approaches Enabled
EE	73	Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging

7.2.1.2 Model Links

Table 22 Conceptual Model Links

Link ID	Origin Node ID	Destination Node ID	Influence Direction and Strength
154	0	50	(0.66,-0.66,0)
81	1	46	(0.66,-0.66,0)
92	1	3	(0.33,-0.33,0)
180	1	53	(0.33,-0.33,0)
189	1	15	(0.33,-0.33,0)
80	2	45	(0.9,-0.9,0)
93	2	3	(0.33,-0.33,0)
181	2	53	(0.33,-0.33,0)
190	2	15	(0.33,-0.33,0)
147	3	47	(-0.66,0.66,0)
76	4	27	(0.66,-0.66,0)
94	4	3	(0.33,-0.33,0)

182	4	53	(0.33,-0.33,0)
179	5	63	(-0.33,0.33,0)
191	5	15	(-0.33,0.33,0)
87	5	43	(0.66,-0.66,0)
95	5	3	(0.33,-0.33,0)
146	5	23	(0.66,-0.66,0)
158	5	55	(0.9,-0.9,0)
183	5	53	(0.33,-0.33,0)
84	6	36	(0.66,-0.66,0)
85	6	43	(0.33,-0.33,0)
86	7	43	(0.66,-0.66,0)
153	7	44	(0.66,-0.66,0)
157	7	52	(0.33,-0.33,0)
79	8	21	(0.66,-0.66,0)
156	9	52	(0.66,-0.33,0)
188	9	43	(0.66,-0.66,0)
167	10	58	(0.9,-0.9,0)
195	10	12	(0.33,-0.33,0)
226	10	54	(0.9,-0.9,0)
143	11	12	(0.33,-0.33,0)
168	11	59	(0.9,-0.9,0)
196	12	47	(-0.33,0.33,0)
144	13	12	(0.33,-0.33,0)
169	13	60	(0.9,-0.9,0)
145	14	12	(0.33,-0.33,0)
170	14	61	(0.9,-0.9,0)
152	15	49	(0.9,-0.9,0)
184	15	47	(0.66,-0.66,0)
185	15	64	(0.9,-0.9,0)
118	16	33	(0.66,-0.66,0)
124	16	41	(0.66,-0.33,0)
113	17	32	(0.66,-0.66,0)
100	18	41	(0.66,-0.66,0)
114	19	35	(0.9,-0.9,0)
134	20	22	(0.66,-0.66,0)
137	20	38	(0.33,-0.33,0)
131	21	42	(-0.66,0.66,0)
193	22	42	(-0.66,0.66,0)
97	23	44	(0.66,-0.66,0)

135	23	43	(0,0,0)
98	24	44	(0.9,-0.9,0)
136	24	43	(0,0,0)
107	25	29	(-0.66,0.66,0)
108	26	28	(-0.9,0.9,0)
120	26	17	(0.66,-0.66,0)
142	27	3	(-0.9,0.9,0)
174	27	53	(-0.66,0.66,0)
138	27	45	(0.66,-0.66,0)
139	27	46	(0.66,-0.66,0)
149	27	26	(0.33,-0.33,0)
109	28	49	(-0.9,0.9,0)
110	29	49	(-0.66,0.66,0)
125	30	0	(0.33,-0.33,0)
126	31	0	(0.66,-0.66,0)
127	32	0	(0.9,-0.9,0)
128	33	0	(0.33,-0.33,0)
129	34	0	(0.66,-0.66,0)
130	35	0	(0.9,-0.9,0)
99	36	41	(0.66,-0.66,0)
112	37	32	(0.33,-0.33,0)
115	37	35	(0.66,-0.66,0)
122	37	34	(0.66,-0.66,0)
104	38	37	(0.66,-0.66,0)
111	38	31	(0.66,-0.66,0)
132	39	38	(0.66,-0.66,0)
133	39	19	(0.9,-0.9,0)
105	40	39	(0.66,-0.66,0)
106	40	30	(0.9,-0.9,0)
101	41	22	(0.33,-0.33,0)
102	41	19	(0.66,-0.66,0)
103	41	38	(0.9,-0.9,0)
119	42	30	(-0.66,0.66,0)
123	42	34	(-0.33,0.33,0)
88	43	27	(0.66,-0.66,0)
89	43	25	(0.33,0,0)
90	43	26	(0.33,-0.33,0)
91	43	21	(0.33,-0.33,0)
121	43	17	(0.33,-0.33,0)

197	43	15	(0.33,-0.33,0)
96	44	15	(-0.33,0.66,0)
141	45	25	(0.66,-0.99,0)
140	46	26	(0.66,-0.66,0)
231	46	73	(0.9,-0.9,0)
148	47	39	(0.9,-0.9,0)
166	48	57	(0.9,-0.9,0)
203	48	12	(0.66,-0.66,0)
116	49	42	(-0.9,0.9,0)
117	49	16	(0.66,-0.66,0)
155	51	50	(0.66,-0.66,0)
177	52	51	(-0.66,0.66,0)
227	52	45	(-0.66,0.66,0)
228	52	46	(-0.66,0.66,0)
178	52	53	(0.66,-0.33,0)
176	53	51	(-0.66,0.66,0)
172	54	62	(0.9,-0.9,0)
159	55	24	(0.66,-0.66,0)
160	55	56	(0.9,-0.9,0)
161	56	57	(-0.9,0.9,0)
162	56	58	(-0.9,0.9,0)
163	56	59	(-0.9,0.9,0)
164	56	60	(-0.9,0.9,0)
165	56	61	(-0.9,0.9,0)
150	57	26	(0.33,-0.33,0)
151	57	25	(0.33,-0.33,0)
204	57	70	(0.9,-0.66,0)
232	57	73	(0.66,-0.66,0)
75	58	27	(0.33,-0.33,0)
82	59	23	(0.66,-0.66,0)
83	59	24	(0.66,-0.66,0)
192	59	49	(0.9,-0.9,0)
74	60	20	(0.66,-0.66,0)
77	60	18	(0.9,-0.9,0)
78	61	15	(0.9,-0.9,0)
194	61	17	(0.66,-0.66,0)
171	62	63	(0.9,-0.33,0)
173	63	3	(0.9,-0.33,0)
175	63	53	(0.9,-0.33,0)

186	64	28	(0.66,-0.66,0)
187	64	40	(0.66,-0.66,0)
198	65	43	(0.33,-0.33,0)
199	65	67	(0.66,-0.33,0)
200	65	68	(0.66,-0.33,0)
201	65	3	(0.9,-0.9,0)
234	65	53	(0.33,-0.33,0)
235	66	53	(-0.33,0.33,0)
202	66	69	(0.66,-0.66,0)
218	66	71	(0.66,-0.33,0)
219	66	72	(0.66,-0.33,0)
224	66	45	(0.33,-0.33,0)
225	66	46	(0.33,-0.33,0)
208	67	52	(-0.66,0.33,0)
209	67	36	(0.66,-0.66,0)
215	68	12	(-0.66,0.33,0)
210	68	58	(0.66,-0.33,0)
211	68	59	(0.66,-0.33,0)
212	68	60	(0.66,-0.33,0)
213	68	61	(0.9,-0.33,0)
214	68	57	(0.9,-0.9,0)
216	69	36	(-0.66,0.66,0)
217	69	43	(-0.66,0.66,0)
207	70	53	(-0.9,0.33,0)
237	70	3	(-0.9,0.33,0)
205	70	46	(0.9,-0.33,0)
206	70	45	(0.9,-0.33,0)
229	71	3	(-0.9,0.33,0)
230	71	53	(-0.66,0.33,0)
220	72	59	(0.9,-0.33,0)
221	72	60	(0.9,-0.33,0)
222	72	61	(0.9,-0.33,0)
223	72	57	(0.9,-0.33,0)
236	72	58	(0.9,0.33,0)
233	73	32	(0.9,-0.9,0)

7.2.1.3 Model Link Sensitivity

Table 23 Model Link Sensitivity

Parents	Children	MinhValue	MaxhValue	hDifference	MingValue	MaxgValue	gDifference
Leader Agrees to Leave Power	Coalition Objectives Met	0.677	0.905	0.228	0.747	0.857	0.11
Kinetic Strike on Army Units	Kinetic Strikes Successful on Military	0.796	0.805	0.01	0.802	0.802	0
Kinetic Strike on Army Units	Coalition Airstrikes Cause Significant Civilian Casualties	0.804	0.766	-0.038	0.802	0.802	0
Kinetic Strike on Army Units	Significant Coalition Strike Asset Loss	0.806	0.642	-0.164	0.802	0.802	0
Kinetic Strike on Army Units	Mass Street Protests Begin	0.8	0.807	0.007	0.802	0.802	0
Kinetic Strike on Police Units	Kinetic Strikes Successful on Police	0.802	0.802	0	0.801	0.802	0.001
Kinetic Strike on Police Units	Coalition Airstrikes Cause Significant Civilian Casualties	0.802	0.802	0	0.82	0.8	-0.02
Kinetic Strike on Police Units	Significant Coalition Strike Asset Loss	0.802	0.802	0	0.823	0.796	-0.026
Kinetic Strike on Police Units	Mass Street Protests Begin	0.802	0.802	0	0.694	0.803	0.11
Coalition Airstrikes Cause Significant Civilian Casualties	International Opinion Supports Coalition Actions	0.779	0.815	0.036	0.791	0.809	0.017
Kinetic Strike on Air Defense Assets	Primary Air Defense Systems Become Severely Degraded	0.776	0.832	0.056	0.802	0.802	0
Kinetic Strike on Air Defense Assets	Coalition Airstrikes Cause Significant Civilian Casualties	0.804	0.766	-0.038	0.802	0.802	0
Kinetic Strike on Air Defense Assets	Significant Coalition Strike Asset Loss	0.806	0.642	-0.164	0.802	0.802	0
Kinetic Strike on Electric Power Stations	Country X's C2 Capability Becomes Severely Degraded	0.802	0.802	0	0.801	0.804	0.003
Kinetic Strike on Electric Power Stations	Coalition Airstrikes Cause Significant Civilian Casualties	0.802	0.802	0	0.82	0.8	-0.02
Kinetic Strike on Electric Power Stations	Country X's Telephone System Becomes Extremely Degraded	0.802	0.802	0	0.803	0.801	-0.001
Kinetic Strike on Electric Power Stations	Country X Internal Internet Infrastructure Becomes Severely Disrupted	0.802	0.802	0	0.803	0.795	-0.007
Kinetic Strike on Electric Power Stations	Secondary Air Defense Systems Effective	0.802	0.802	0	0.809	0.77	-0.039
Kinetic Strike on Electric Power Stations	Significant Coalition Strike Asset Loss	0.802	0.802	0	0.823	0.796	-0.026
Kinetic Strike on Electric Power Stations	Mass Street Protests Begin	0.802	0.802	0	0.8	0.807	0.007
Disrupt Country X's GPS Assets	Civilian Transportation GPS Capability Become Severely Degraded	0.791	0.812	0.021	0.802	0.802	0
Disrupt Country X's GPS Assets	Country X's C2 Capability Becomes Severely Degraded	0.802	0.836	0.034	0.802	0.802	0
Disrupt Country X's Satellite Communications	Country X's C2 Capability Becomes Severely Degraded	0.802	0.802	0	0.801	0.804	0.003
Disrupt Country X's Satellite Communications	Country X's Social Networks Become Severely Degraded	0.802	0.802	0	0.804	0.801	-0.003
Disrupt Country X's Satellite Communications	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops	0.802	0.802	0	0.808	0.799	-0.009
Disrupt Country X's Satellite Television	Country X's Regime Propaganda Becomes Ineffective	0.801	0.803	0.002	0.802	0.802	0
Disrupt Country X's Military Satellite Assets	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops	0.802	0.802	0	0.808	0.799	-0.009
Disrupt Country X's Military Satellite Assets	Country X's C2 Capability Becomes Severely Degraded	0.802	0.802	0	0.801	0.804	0.003
Conduct Cyber Attack on Air Defense Assets	Effective Cyber Attack on Air Defense Assets	0.802	0.802	0	0.782	0.804	0.023
Conduct Cyber Attack on Air Defense Assets	Cyber Attack Causes Major Regional Internet Degradation	0.802	0.802	0	0.806	0.797	-0.009
Conduct Cyber Attack on Air Defense Assets	Cyber Attack Causes Country X to Switch Air Defense Assets to Backup Fiber Optic Network	0.802	0.802	0	0.803	0.797	-0.005
Conduct Cyber Attack on Targeted Communications Infrastructure	Cyber Attack Causes Major Regional Internet Degradation	0.802	0.802	0	0.806	0.797	-0.009
Conduct Cyber Attack on Targeted Communications Infrastructure	Effective Cyber Attack on Targeted Communications Infrastructure	0.802	0.802	0	0.793	0.803	0.01
Cyber Attack Causes Major Regional Internet Degradation	International Opinion Supports Coalition Actions	0.784	0.804	0.02	0.793	0.821	0.028
Conduct Cyber Attack on Industrial Infrastructure	Cyber Attack Causes Major Regional Internet Degradation	0.803	0.786	-0.017	0.802	0.802	0
Conduct Cyber Attack on Industrial Infrastructure	Effective Cyber Attack on Industrial Infrastructure	0.801	0.802	0.001	0.802	0.802	0
Conduct Cyber Attack to Inject Information Operations to Encourage Dissent	Cyber Attack Causes Major Regional Internet Degradation	0.803	0.786	-0.017	0.802	0.802	0
Conduct Cyber Attack to Inject Information Operations to Encourage Dissent	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.8	0.802	0.002	0.802	0.802	0
Mass Street Protests Begin	Mass Protests Continue	0.796	0.805	0.009	0.801	0.802	0.002
Mass Street Protests Begin	International Opinion Supports Coalition Actions	0.778	0.826	0.048	0.8	0.804	0.004
Mass Street Protests Begin	Brutal Suppression Begins	0.774	0.805	0.031	0.802	0.802	0
General Strike Begins	Business Leaders No Longer Support Leader	0.793	0.806	0.013	0.801	0.804	0.003
General Strike Begins	Country X's Transportation/Distribution System Becomes Ineffective	0.788	0.81	0.022	0.779	0.804	0.024
Military Units Begin Large Scale Defection	Military Leaders No Longer Support Leader	0.795	0.812	0.017	0.76	0.808	0.048
Port Facilities Become Degraded	Country X's Transportation/Distribution System Becomes Ineffective	0.784	0.816	0.031	0.798	0.804	0.005
Luxury Goods No Longer Available	Most Regime Loyalist No Longer Support Leader	0.753	0.812	0.059	0.798	0.827	0.029
Power and Water Supplies Become Severely Degraded	Food and Supplies Become Extremely Limited	0.801	0.802	0.001	0.802	0.802	0
Power and Water Supplies Become Severely Degraded	Oil Production/Shipping Becomes Degraded	0.8	0.816	0.016	0.783	0.803	0.019
Country X's Regime Propaganda Becomes Ineffective	Perception of Popular Support for the Leader	0.803	0.801	-0.001	0.802	0.798	-0.004
Food and Supplies Become Extremely Limited	Perception of Popular Support for the Leader	0.803	0.801	-0.001	0.802	0.798	-0.004
Country X's Telephone System Becomes Extremely Degraded	Country X's Social Networks Become Severely Degraded	0.802	0.8	-0.002	0.803	0.801	-0.002
Country X's Telephone System Becomes Extremely Degraded	Country X's C2 Capability Becomes Severely Degraded	0.802	0.814	0.012	0.802	0.825	0.023

Parents	Children	MinhValue	MaxhValue	hDifference	MingValue	MaxgValue	gDifference
Power and Water Supplies Become Severely Degraded	Oil Production/Shipping Becomes Degraded	0.8	0.816	0.016	0.783	0.803	0.019
Country X's Regime Propaganda Becomes Ineffective	Perception of Popular Support for the Leader	0.803	0.801	-0.001	0.802	0.798	-0.004
Food and Supplies Become Extremely Limited	Perception of Popular Support for the Leader	0.803	0.801	-0.001	0.802	0.798	-0.004
Country X's Telephone System Becomes Extremely Degraded	Country X's Social Networks Become Severely Degraded	0.802	0.8	-0.002	0.803	0.801	-0.002
Country X's Telephone System Becomes Extremely Degraded	Country X's C2 Capability Becomes Severely Degraded	0.802	0.814	0.012	0.802	0.825	0.023
Country X's Internet Capabilities Becomes Ineffective	Country X's Social Networks Become Severely Degraded	0.803	0.801	-0.003	0.802	0.801	-0.001
Country X's Internet Capabilities Becomes Ineffective	Country X's C2 Capability Becomes Severely Degraded	0.802	0.814	0.012	0.802	0.825	0.023
State Police Become Ineffective	Protest Organizers Rounded Up	0.802	0.802	-0.001	0.802	0.802	-0.001
Military Becomes Ineffective	Brutal Suppression Continues	0.803	0.797	-0.005	0.803	0.802	-0.001
Military Becomes Ineffective	Military Units Begin Large Scale Defection	0.797	0.805	0.007	0.8	0.805	0.005
Primary Air Defense Systems Become Severely Degraded	Kinetic Strikes Successful on Police	0.802	0.802	0	0.802	0.802	0.001
Primary Air Defense Systems Become Severely Degraded	Kinetic Strikes Successful on Military	0.801	0.802	0.001	0.723	0.804	0.081
Primary Air Defense Systems Become Severely Degraded	Coalition Airstrikes Cause Significant Civilian Casualties	0.805	0.796	-0.009	0.81	0.794	-0.016
Primary Air Defense Systems Become Severely Degraded	Military Becomes Ineffective	0.801	0.804	0.003	0.794	0.803	0.01
Primary Air Defense Systems Become Severely Degraded	Significant Coalition Strike Asset Loss	0.806	0.796	-0.01	0.811	0.74	-0.071
Brutal Suppression Continues	Mass Protests Continue	0.793	0.804	0.011	0.799	0.803	0.003
Protest Organizers Rounded Up	Mass Protests Continue	0.788	0.803	0.014	0.801	0.804	0.002
Leader Loses Legitimacy in International Opinion	Leader Agrees to Leave Power	0.792	0.85	0.058	0.679	0.807	0.127
China and Russian No Longer Support Leader	Leader Agrees to Leave Power	0.778	0.837	0.059	0.679	0.816	0.137
Military Leaders No Longer Support Leader	Leader Agrees to Leave Power	0.723	0.853	0.129	0.779	0.815	0.036
Business Leaders No Longer Support Leader	Leader Agrees to Leave Power	0.794	0.843	0.049	0.643	0.808	0.165
His Tribe/Ethnic Group No Longer Support Leader	Leader Agrees to Leave Power	0.781	0.833	0.052	0.661	0.819	0.158
Most Regime Loyalist No Longer Support Leader	Leader Agrees to Leave Power	0.765	0.817	0.052	0.714	0.842	0.129
Civilian Transportation GPS Capability Become Severely Degraded	Country X's Transportation/Distribution System Becomes Ineffective	0.793	0.807	0.014	0.781	0.809	0.028
Country X's Financial Reserves Become Depleted	Military Leaders No Longer Support Leader	0.799	0.814	0.015	0.741	0.804	0.063
Country X's Financial Reserves Become Depleted	Most Regime Loyalist No Longer Support Leader	0.796	0.834	0.038	0.764	0.808	0.043
Country X's Financial Reserves Become Depleted	His Tribe/Ethnic Group No Longer Support Leader	0.787	0.81	0.024	0.797	0.811	0.014
Oil Production/Shipping Becomes Degraded	Country X's Financial Reserves Become Depleted	0.771	0.816	0.046	0.8	0.806	0.006
Oil Production/Shipping Becomes Degraded	China and Russian No Longer Support Leader	0.776	0.815	0.039	0.8	0.806	0.006
UN Sanctions Authorized	Oil Production/Shipping Becomes Degraded	0.798	0.814	0.015	0.78	0.804	0.024
UN Sanctions Authorized	Luxury Goods No Longer Available	0.771	0.807	0.037	0.798	0.826	0.029
International Opinion Turns Against Leader	UN Sanctions Authorized	0.797	0.824	0.027	0.772	0.806	0.035
International Opinion Turns Against Leader	Leader Loses Legitimacy in International Opinion	0.797	0.803	0.006	0.801	0.807	0.006
Country X's Transportation/Distribution System Becomes Ineffective	Food and Supplies Become Extremely Limited	0.802	0.802	0.001	0.802	0.802	0
Country X's Transportation/Distribution System Becomes Ineffective	Luxury Goods No Longer Available	0.795	0.835	0.04	0.787	0.804	0.018
Country X's Transportation/Distribution System Becomes Ineffective	Oil Production/Shipping Becomes Degraded	0.773	0.807	0.033	0.8	0.811	0.011
Perception of Popular Support for the Leader	Leader Loses Legitimacy in International Opinion	0.8	0.802	0.002	0.801	0.809	0.009
Perception of Popular Support for the Leader	His Tribe/Ethnic Group No Longer Support Leader	0.797	0.803	0.005	0.797	0.826	0.029
Country X's C2 Capability Becomes Severely Degraded	Primary Air Defense Systems Become Severely Degraded	0.802	0.802	0	0.763	0.822	0.059
Country X's C2 Capability Becomes Severely Degraded	State Police Become Ineffective	0.802	0.802	0	0.802	0.803	0.001
Country X's C2 Capability Becomes Severely Degraded	Military Becomes Ineffective	0.802	0.802	0	0.78	0.804	0.024
Country X's C2 Capability Becomes Severely Degraded	Country X's Regime Propaganda Becomes Ineffective	0.802	0.802	0	0.8	0.802	0.002
Country X's C2 Capability Becomes Severely Degraded	Military Units Begin Large Scale Defection	0.802	0.802	0	0.779	0.804	0.025
Country X's C2 Capability Becomes Severely Degraded	Mass Street Protests Begin	0.802	0.802	0	0.696	0.803	0.107
Country X's Social Networks Become Severely Degraded	Mass Street Protests Begin	0.782	0.803	0.021	0.798	0.804	0.006
Kinetic Strikes Successful on Police	State Police Become Ineffective	0.802	0.802	0.001	0.802	0.802	0
Kinetic Strikes Successful on Military	Military Becomes Ineffective	0.793	0.808	0.015	0.802	0.802	0
Kinetic Strikes Successful on Military	Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging	0.751	0.808	0.057	0.802	0.804	0.002
International Opinion Supports Coalition Actions	UN Sanctions Authorized	0.761	0.81	0.049	0.799	0.819	0.02
Conduct Cyber Attack on Military and Police C2	Effective CA on Military and Police	0.791	0.804	0.013	0.802	0.802	0
Conduct Cyber Attack on Military and Police C2	Cyber Attack Causes Major Regional Internet Degradation	0.804	0.786	-0.018	0.802	0.802	0
Mass Protests Continue	Perception of Popular Support for the Leader	0.803	0.799	-0.004	0.803	0.802	-0.001

Parents	Children	MinhValue	MaxhValue	hDifference	MingValue	MaxgValue	gDifference
Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops	Kinetic Strikes Successful on Military	0.798	0.802	0.005	0.796	0.805	0.009
Significant Coalition Strike Asset Loss	Coalition Military Casualties and Equipment Loss Avoided	0.768	0.817	0.049	0.758	0.827	0.068
Cyber Attack Causes Country Xto Switch Air Defense Assets to Backup Fiber Optic Network	Country X Switches to Secondary Air Defense System	0.802	0.802	-0.001	0.802	0.799	-0.003
Country X Internal Internet Infrastructure Becomes Severely Disrupted	Country X's Internet Capabilities Becomes Ineffective	0.802	0.802	0	0.804	0.8	-0.004
Country X Internal Internet Infrastructure Becomes Severely Disrupted	Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	0.803	0.802	-0.001	0.803	0.795	-0.008
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective CA on Military and Police	0.8	0.802	0.002	0.792	0.803	0.011
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective Cyber Attack on Air Defense Assets	0.802	0.802	0	0.793	0.804	0.011
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective Cyber Attack on Targeted Communications Infrastructure	0.802	0.802	0	0.798	0.804	0.005
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective Cyber Attack on Industrial Infrastructure	0.801	0.802	0.001	0.801	0.802	0.001
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.8	0.802	0.002	0.801	0.802	0.002
Effective CA on Military and Police	Military Becomes Ineffective	0.799	0.808	0.009	0.802	0.802	0
Effective CA on Military and Police	State Police Become Ineffective	0.802	0.803	0.001	0.802	0.802	0
Effective CA on Military and Police	Orders to Move to Human Shield Locations Become Confused	0.735	0.809	0.075	0.802	0.802	0
Effective CA on Military and Police	Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging	0.791	0.81	0.019	0.8	0.802	0.003
Effective Cyber Attack on Air Defense Assets	Primary Air Defense Systems Become Severely Degraded	0.79	0.826	0.036	0.799	0.803	0.004
Effective Cyber Attack on Targeted Communications Infrastructure	Country X's Telephone System Becomes Extremely Degraded	0.802	0.801	-0.001	0.802	0.802	0
Effective Cyber Attack on Targeted Communications Infrastructure	Country X's Internet Capabilities Becomes Ineffective	0.803	0.799	-0.004	0.802	0.802	0
Effective Cyber Attack on Targeted Communications Infrastructure	Mass Protests Continue	0.798	0.803	0.005	0.797	0.803	0.006
Effective Cyber Attack on Industrial Infrastructure	Power and Water Supplies Become Severely Degraded	0.799	0.803	0.004	0.802	0.802	0
Effective Cyber Attack on Industrial Infrastructure	Port Facilities Become Degraded	0.777	0.805	0.027	0.802	0.802	0
Effective Cyber Attack to Inject Information Operations to Encourage Dissent	Mass Street Protests Begin	0.765	0.807	0.042	0.802	0.802	0
Effective Cyber Attack to Inject Information Operations to Encourage Dissent	Military Units Begin Large Scale Defection	0.796	0.81	0.014	0.802	0.802	0
Country X Switches to Secondary Air Defense System	Secondary Air Defense Systems Effective	0.803	0.802	-0.001	0.823	0.791	-0.032
Secondary Air Defense Systems Effective	Coalition Airstrikes Cause Significant Civilian Casualties	0.808	0.791	-0.017	0.809	0.801	-0.008
Secondary Air Defense Systems Effective	Significant Coalition Strike Asset Loss	0.817	0.745	-0.072	0.805	0.801	-0.004
Brutal Suppression Begins	Brutal Suppression Continues	0.803	0.796	-0.006	0.802	0.802	0
Brutal Suppression Begins	International Opinion Turns Against Leader	0.785	0.81	0.025	0.801	0.804	0.003
Kinetic Strike on Country X Leader's Compound	Country X's C2 Capability Becomes Severely Degraded	0.802	0.836	0.034	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Country X's Space Control Center becomes Ineffective	0.789	0.809	0.02	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Country X's Cyber Control Center Becomes Ineffective	0.785	0.81	0.025	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Coalition Airstrikes Cause Significant Civilian Casualties	0.813	0.766	-0.047	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Significant Coalition Strike Asset Loss	0.806	0.642	-0.164	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	0.807	0.799	-0.008	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Coalition Targeting Systems Accuracy Increased	0.779	0.814	0.035	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Additional Cyber Attack Approaches Enabled	0.793	0.806	0.014	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Kinetic Strikes Successful on Police	0.802	0.802	0.001	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Kinetic Strikes Successful on Military	0.8	0.805	0.005	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Significant Coalition Strike Asset Loss	0.823	0.796	-0.026	0.802	0.802	0
Country X's Space Control Center becomes Ineffective	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops	0.805	0.796	-0.008	0.803	0.757	-0.046
Country X's Space Control Center becomes Ineffective	Civilian Transportation GPS Capability Become Severely Degraded	0.792	0.807	0.015	0.8	0.804	0.004
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Air Defense Assets	0.8	0.803	0.003	0.797	0.802	0.005
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Targeted Communications Infrastructure	0.801	0.803	0.002	0.8	0.802	0.002
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Industrial Infrastructure	0.802	0.802	0	0.79	0.802	0.012
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.801	0.802	0.001	0.772	0.802	0.03
Country X's Cyber Control Center Becomes Ineffective	Effective CA on Military and Police	0.801	0.802	0.001	0.769	0.804	0.035
Country X's Cyber Control Center Becomes Ineffective	Cyber Attack Causes Major Regional Internet Degradation	0.802	0.792	-0.01	0.803	0.801	-0.002
Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	Civilian Transportation GPS Capability Become Severely Degraded	0.782	0.807	0.025	0.801	0.802	0.001
Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	Country X's C2 Capability Becomes Severely Degraded	0.802	0.802	0.001	0.802	0.809	0.007
Orders to Move to Human Shield Locations Become Confused	Kinetic Strikes Successful on Military	0.79	0.803	0.013	0.786	0.803	0.016
Orders to Move to Human Shield Locations Become Confused	Kinetic Strikes Successful on Police	0.801	0.802	0.001	0.802	0.802	0
Orders to Move to Human Shield Locations Become Confused	Significant Coalition Strike Asset Loss	0.816	0.76	-0.056	0.803	0.792	-0.011
Orders to Move to Human Shield Locations Become Confused	Coalition Airstrikes Cause Significant Civilian Casualties	0.817	0.79	-0.027	0.802	0.8	-0.002

Parents	Children	MinhValue	MaxhValue	hDifference	MingValue	MaxgValue	gDifference
Coalition Cyber Attacks Ability to Reach Country X Severely Degraded	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.8	0.802	0.002	0.801	0.802	0.002
Effective CA on Military and Police	Military Becomes Ineffective	0.799	0.808	0.009	0.802	0.802	0
Effective CA on Military and Police	State Police Become Ineffective	0.802	0.803	0.001	0.802	0.802	0
Effective CA on Military and Police	Orders to Move to Human Shield Locations Become Confused	0.735	0.809	0.075	0.802	0.802	0
Effective CA on Military and Police	Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging	0.791	0.81	0.019	0.8	0.802	0.003
Effective Cyber Attack on Air Defense Assets	Primary Air Defense Systems Become Severely Degraded	0.79	0.826	0.036	0.799	0.803	0.004
Effective Cyber Attack on Targeted Communications Infrastructure	Country X's Telephone System Becomes Extremely Degraded	0.802	0.801	-0.001	0.802	0.802	0
Effective Cyber Attack on Targeted Communications Infrastructure	Country X's Internet Capabilities Becomes Ineffective	0.803	0.799	-0.004	0.802	0.802	0
Effective Cyber Attack on Targeted Communications Infrastructure	Mass Protests Continue	0.798	0.803	0.005	0.797	0.803	0.006
Effective Cyber Attack on Industrial Infrastructure	Power and Water Supplies Become Severely Degraded	0.799	0.803	0.004	0.802	0.802	0
Effective Cyber Attack on Industrial Infrastructure	Port Facilities Become Degraded	0.777	0.805	0.027	0.802	0.802	0
Effective Cyber Attack to Inject Information Operations to Encourage Dissent	Mass Street Protests Begin	0.765	0.807	0.042	0.802	0.802	0
Effective Cyber Attack to Inject Information Operations to Encourage Dissent	Military Units Begin Large Scale Defection	0.796	0.81	0.014	0.802	0.802	0
Country X Switches to Secondary Air Defense System	Secondary Air Defense Systems Effective	0.803	0.802	-0.001	0.823	0.791	-0.032
Secondary Air Defense Systems Effective	Coalition Airstrikes Cause Significant Civilian Casualties	0.808	0.791	-0.017	0.809	0.801	-0.008
Secondary Air Defense Systems Effective	Significant Coalition Strike Asset Loss	0.817	0.745	-0.072	0.805	0.801	-0.004
Brutal Suppression Begins	Brutal Suppression Continues	0.803	0.796	-0.006	0.802	0.802	0
Brutal Suppression Begins	International Opinion Turns Against Leader	0.785	0.81	0.025	0.801	0.804	0.003
Kinetic Strike on Country X Leader's Compound	Country X's C2 Capability Becomes Severely Degraded	0.802	0.836	0.034	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Country X's Space Control Center becomes Ineffective	0.789	0.809	0.02	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Country X's Cyber Control Center Becomes Ineffective	0.785	0.81	0.025	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Coalition Airstrikes Cause Significant Civilian Casualties	0.813	0.766	-0.047	0.802	0.802	0
Kinetic Strike on Country X Leader's Compound	Significant Coalition Strike Asset Loss	0.806	0.642	-0.164	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	0.807	0.799	-0.008	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Coalition Targeting Systems Accuracy Increased	0.779	0.814	0.035	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Additional Cyber Attack Approaches Enabled	0.793	0.806	0.014	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Kinetic Strikes Successful on Police	0.802	0.802	0.001	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Kinetic Strikes Successful on Military	0.8	0.805	0.005	0.802	0.802	0
Augment Regional Space Capacity with Non-military Assets	Significant Coalition Strike Asset Loss	0.823	0.796	-0.026	0.802	0.802	0
Country X's Space Control Center becomes Ineffective	Coalition Space Actions Cause Collateral Degradation of Space Capabilities to Support Kinetic Ops	0.805	0.796	-0.008	0.803	0.757	-0.046
Country X's Space Control Center becomes Ineffective	Civilian Transportation GPS Capability Become Severely Degraded	0.792	0.807	0.015	0.8	0.804	0.004
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Air Defense Assets	0.8	0.803	0.003	0.797	0.802	0.005
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Targeted Communications Infrastructure	0.801	0.803	0.002	0.8	0.802	0.002
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack on Industrial Infrastructure	0.802	0.802	0	0.79	0.802	0.012
Country X's Cyber Control Center Becomes Ineffective	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.801	0.802	0.001	0.772	0.802	0.03
Country X's Cyber Control Center Becomes Ineffective	Effective CA on Military and Police	0.801	0.802	0.001	0.769	0.804	0.035
Country X's Cyber Control Center Becomes Ineffective	Cyber Attack Causes Major Regional Internet Degradation	0.802	0.792	-0.01	0.803	0.801	-0.002
Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	Civilian Transportation GPS Capability Become Severely Degraded	0.782	0.807	0.025	0.801	0.802	0.001
Country X Recognizes Regional Space Asset Change and Hardens Own Space Assets	Country X's C2 Capability Becomes Severely Degraded	0.802	0.802	0.001	0.802	0.809	0.007
Orders to Move to Human Shield Locations Become Confused	Kinetic Strikes Successful on Military	0.79	0.803	0.013	0.786	0.803	0.016
Orders to Move to Human Shield Locations Become Confused	Kinetic Strikes Successful on Police	0.801	0.802	0.001	0.802	0.802	0
Orders to Move to Human Shield Locations Become Confused	Significant Coalition Strike Asset Loss	0.816	0.76	-0.056	0.803	0.792	-0.011
Orders to Move to Human Shield Locations Become Confused	Coalition Airstrikes Cause Significant Civilian Casualties	0.817	0.79	-0.027	0.802	0.8	-0.002
Coalition Targeting Systems Accuracy Increased	Coalition Airstrikes Cause Significant Civilian Casualties	0.812	0.792	-0.02	0.803	0.796	-0.007
Coalition Targeting Systems Accuracy Increased	Significant Coalition Strike Asset Loss	0.812	0.787	-0.024	0.804	0.764	-0.04
Additional Cyber Attack Approaches Enabled	Effective Cyber Attack on Targeted Communications Infrastructure	0.8	0.802	0.003	0.8	0.802	0.002
Additional Cyber Attack Approaches Enabled	Effective Cyber Attack on Industrial Infrastructure	0.802	0.802	0	0.788	0.802	0.014
Additional Cyber Attack Approaches Enabled	Effective Cyber Attack to Inject Information Operations to Encourage Dissent	0.801	0.802	0.001	0.768	0.802	0.034
Additional Cyber Attack Approaches Enabled	Effective CA on Military and Police	0.8	0.803	0.003	0.764	0.802	0.038
Additional Cyber Attack Approaches Enabled	Effective Cyber Attack on Air Defense Assets	0.797	0.803	0.006	0.801	0.804	0.003
Kinetic Strike Effect on Military Leader Loyalty Greatly Increased by Targeted Cyber Messaging	Military Leaders No Longer Support Leader	0.741	0.813	0.072	0.801	0.808	0.007

7.2.2 CPN Model

7.2.2.1 Model Declarations

Table 24 CPN Model Declarations

Color Sets
colset UNIT = unit;
colset STRING = string timed;
colset NSTRING = product INT * STRING timed;
colset NCLSTRING = product INT * INT * STRING timed;
colset Results= product Number *Choice *Choice * Choice * NewCoordLevel timed;
colset Information = STRING;

colset Method = STRING;
colset Sequential = BOOL timed;
colset Choice = STRING;
colset Number = INT;
colset Sequential2 = product Number * BOOL timed;
colset Fusion = BOOL;
colset Fusion2 = product Number * BOOL;
colset Guidance = product Number * BOOL;
colset WantToIterate = BOOL;
colset Guidance2 = BOOL;
colset ConsensusIterations = INT;
colset IterChoice = BOOL;
colset LeadIterChoice = product Number * IterChoice;
colset IterDecline = INT;
colset OutInfo = STRING;
colset IterationNum = INT;
colset OutAllottedTime = INT;
colset OutStartCoordLevel = INT;
colset OutTargetCoordLevel = INT;
colset OutAllottedIterations = INT;
colset NewCoordLevel = INT;
colset OutMethod = product Fusion * Guidance2 * Method;
colset CoordConstraints = product OutAllottedTime * OutAllottedIterations * OutTargetCoordLevel;
colset ProcessInput = product Number * OutInfo * CoordConstraints * OutStartCoordLevel * OutMethod timed;
colset Input = product Number * Guidance2 * Method * Information * Fusion * OutStartCoordLevel *CoordConstraints timed;
colset Assessment = product Number *Method * Information * Fusion * OutStartCoordLevel *CoordConstraints timed;
colset Situation = product Number * Method * Information * Fusion * OutStartCoordLevel *CoordConstraints timed;
colset ProcessedAssessment = product Number * Method * Information * Fusion * OutStartCoordLevel *CoordConstraints timed;
colset AssessWGuidance = product Number *Guidance2 * Method * Information * Fusion * Sequential * OutStartCoordLevel *CoordConstraints timed;

colset Info = product Number *Method * Information *OutStartCoordLevel *CoordConstraints timed;
colset Response = product Number *Choice * Guidance2 * Fusion * Sequential * Method *CoordConstraints * WantToIterate * NewCoordLevel * IterationNum timed;
colset Output = product Number *Choice *Choice * Choice * Guidance2 * Fusion * Sequential * ConsensusIterations * NewCoordLevel timed;
colset Info2 = product Number *Choice * Guidance2 * Fusion * Sequential *Method *NewCoordLevel * CoordConstraints * WantToIterate * IterationNum timed;
colset Assessment2 = product Number *Choice * Choice * Choice * Guidance2 * Fusion * Sequential *Method *NewCoordLevel * CoordConstraints * WantToIterate * IterationNum timed;
colset ProcessedAssessment2 = product Number *Choice * Choice * Choice * Guidance2 * Fusion * Sequential *Method *NewCoordLevel * CoordConstraints * WantToIterate * IterationNum timed;
colset SCL_NLIST = list INT;
colset TYPE_NLIST = list INT;
colset CC_NLIST = list INT;
colset Star = product Number * CC_NLIST * SCL_NLIST * TYPE_NLIST;
colset AIR_DESIGN = INT;
colset AIR_COA = INT;
colset AIR_COORD_APPR = INT;
colset AIR_TASKS_OPSCONCEPT = INT;
colset AIR_OPS_TIMING = INT;
colset CYBER_DESIGN = INT;
colset CYBER_COA = INT;
colset CYBER_COORD_APPR = INT;
colset CYBER_TASKS_OPSCONCEPT = INT;
colset CYBER_OPS_TIMING = INT;
colset SPACE_DESIGN = INT;
colset SPACE_COA = INT;
colset SPACE_COORD_APPR = INT;
colset SPACE_TASKS_OPSCONCEPT = INT;
colset SPACE_OPS_TIMING = INT;

colset OBJ_METRICS = INT;
colset KEY_INF = INT;
colset AD_ENV = INT;
colset AE = INT;
colset STRUCTURE = INT;
Variables
var g: Guidance2;
var m: Method;
var id1: IterDecline;
var f:Fusion;
var id2: IterDecline;
var ncl: NewCoordLevel;
var ncl3: NewCoordLevel;
var itn: IterationNum;
var itn1: IterationNum;
var itn2: IterationNum;
var itn3: IterationNum;
var id3: IterDecline;
var cc1: OutAllottedTime;
var scl: OutStartCoordLevel;
var cc2: OutAllottedIterations;
var cc3: OutTargetCoordLevel;
var n: Number;
var cc: CoordConstraints;
var dmc1: Choice;
var dmc3: Choice;
var dmc2: Choice;
var i: Information;
var n2: Number;
var n1: Number;
var n3: Number;
var n4: Number;
var n5: Number;
var n6: Number;
var n7: Number;
var n8: Number;
var n9: Number;
var n10: Number;

var n11: Number;
var s: Sequential;
var c1: Choice;
var c2: Choice;
var s1: Sequential;
var c3: Choice;
var s2: Sequential;
var ic: IterChoice;
var ic1: IterChoice;
var ic2: IterChoice;
var ic3: IterChoice;
var num:INT;
var OM_ncl: INT;
var KI_ncl: INT;
var AdE_ncl: INT;
var AE_ncl: INT;
var SC_ncl: INT;
var CMOE_ncl: INT;
var JTCONOPS_ncl: INT;
var CIT_ncl: INT;
var tnl: TYPE_NLIST;
Values
val Token_Type = "Current Approach";
val Number_Tokens = 25;
val ccp =[1,1,1,1,1,1,1,0,0];
val ccc1 =[0,0,0,0,0,0,0,2,0];
val ccc2 =[0,0,0,0,0,0,0,2,3];
val ccn =[0,0,0,0,0,0,0,0,0];
val sc =[2,2,2,2,2,2,2,2,2];
val tp = [1,1,1,1,1,1,1,0,0];
val tc1 = [0,0,0,0,0,0,0,1,0];
val tc2 =[0,0,0,0,0,0,0,1,1];
val tn = [0,0,0,0,0,0,0,0,0];
val ccl_val_list = [[1,1,1,1,1,1,1,0,0],[0,0,0,0,0,0,0,2,0], [0,0,0,0,0,0,0,2,3],[0,0,0,0,0,0,0,0,0]];
val scl_val_list = [[2,2,2,2,2,2,2,2,2],[2,2,2,2,2,2,2,2,2], [2,2,2,2,2,2,2,2,2],[2,2,2,2,2,2,2,2,2]];

val tnl_val_list = [[1,1,1,1,1,1,1,0,0],[0,0,0,0,0,0,0,1,0], [0,0,0,0,0,0,0,1,1],[0,0,0,0,0,0,0,0,0]];
val TestCases = 1`(1,"New Approach")++ 1`(2,"Current Approach")++ 1`(3,"Current Approach Level2")++ 1`(4,"No Coord")
val process_time_list = [60,10,60,60,90,60,60, 90,90,60,90,90,60,90,60,60,60,10,90,60,60,60, 60,60,60,60,30,60,30,60,30,400,400,60];
val cc_list = [(0,0,0),(10,8,100),(1,25,2000),(1,5,2000)];
val scl_list = [10,20,30,40,50,60];
val coi = 4;

val TI_coord_time_list = [coi,coi,coi,coi,coi];
val TII_coord_time_list = [coi,coi,coi,coi,coi];
val TIII_coord_time_list = [coi,coi,coi,coi,coi];

val TI_mu_to_sigma = 0.2;
val TI_dec = 0.05;
val TI_min = 2;
val TII_mu_to_sigma = 0.2;
val TII_dec = 0.05;
val TII_min = 2;
val TIII_mu_to_sigma = 0.2;
val TIII_dec = 0.05;
val TIII_min = 2;

val TI_Iter_Num =5.0;
val TII_Iter_Num =25.0;
val TIII_Iter_Num =5.0;
val TI_Iter_Var = 4.0;
val TII_Iter_Var = 25.0;
val TIII_Iter_Var = 4.0;
val process_mu_to_sigma = 0.2;
val type_list = [(false,false,"D"), (false,false,"C")];

Functions
fun ttcc(str)= if str = "New Approach" then ccp else if str ="Current Approach" then ccc1 else if str ="Current Approach Level2" then ccc2 else ccn;
fun ttt(str)= if str = "New Approach" then tp else if str ="Current Approach" then tc1 else if str ="Current Approach Level2" then tc2 else tn;
fun TI_CoordLevelCalc2 (ncl,itn) = if itn = 1 then ncl+20 else ncl +20;
fun TII_CoordLevelCalc2 (ncl,itn) = round (real(ncl)+(37.6/25.0));
fun TIII_CoordLevelCalc2 (ncl,itn) = if itn = 1 then ncl+20 else ncl +20;

fun CoordLevelCalc1 (scl,f,m) =
if f then
  if m = "S" then scl +15
  else scl +5
else
  if m = "S" then scl +10
  else scl;

fun proc_time(n) = round(normal(real(List.nth(process_time_list,n)), (real(List.nth(process_time_list,n))* process_mu_to_sigma)* (real(List.nth(process_time_list,n))* process_mu_to_sigma)));
fun bell_m1(n,itn) = round(normal(real(List.nth(TI_coord_time_list,n)), real(List.nth(TI_coord_time_list,n)) * TI_mu_to_sigma * real(List.nth(TI_coord_time_list,n)) * TI_mu_to_sigma)- real(List.nth(TI_coord_time_list,n))*TI_dec*real(itn));

fun bell_m2(n,itn) = round(normal(real(List.nth(TII_coord_time_list,n)), real(List.nth(TII_coord_time_list,n)) * TII_mu_to_sigma * real(List.nth(TII_coord_time_list,n)) * TII_mu_to_sigma)- real(List.nth(TII_coord_time_list,n))*TII_dec*real(itn));
fun bell_m3(n,itn) = round(normal(real(List.nth(TIII_coord_time_list,n)), real(List.nth(TIII_coord_time_list,n)) * TIII_mu_to_sigma * real(List.nth(TIII_coord_time_list,n)) * TIII_mu_to_sigma)- real(List.nth(TIII_coord_time_list,n))*TIII_dec*real(itn));
fun TI_SA_time (f,t) = if f then t+ 2 else t;

fun TI_IF_time (f,itn,t) =
 if itn = 0 then
   if f then t
   else 0
else t;

fun TI_TP_time (t) = t;

fun TI_CI_time(g,itn,t) =
 if itn = 0 then
   if g then t
   else 0
else t;

fun TI_RS_time (t)= t;
fun check5(n,n1,n2,n3,n4)= if (n=n1) andalso (n1=n2) andalso (n2=n3) andalso (n3=n4) then true else false;
fun check6(n,n1,n2,n3,n4,n5)= if (n=n1) andalso (n1=n2) andalso (n2=n3) andalso (n3=n4) andalso (n4=n5) then true else false;
fun Lead (m) = if m ="C" then true else false;

fun TI_IterDecision (cc1,cc2,cc3,itn,ncl) = if (itn <cc2-1) andalso (TI_CoordLevelCalc2(ncl,itn) < cc3) then true else false;
fun TII_IterDecision (cc1,cc2,cc3,itn,ncl) = if (itn <cc2) andalso (TII_CoordLevelCalc2(ncl,itn) < cc3) then true else false;
fun TIII_IterDecision (cc1,cc2,cc3,itn,ncl) = if (itn <cc2-1) andalso (TIII_CoordLevelCalc2(ncl,itn) < cc3) then true else false;
fun CC_DET (ccnl,num) = List.nth(cc_list,List.nth(ccnl,num));
fun SCL_DET(sclnl,num) = List.nth(scl_list,List.nth(sclnl,num));
fun TYPE_DET(tnl,num) = List.nth(type_list,List.nth(tnl,num));
fun CMOE_INT_DET (OM_ncl,KI_ncl,AdE_ncl,AE_ncl,SC_ncl)= SC_ncl;
fun ICOA_INT_DET (JTCONOPS_ncl,CIT_ncl)= CIT_ncl;

7.2.2.2 Model Structure

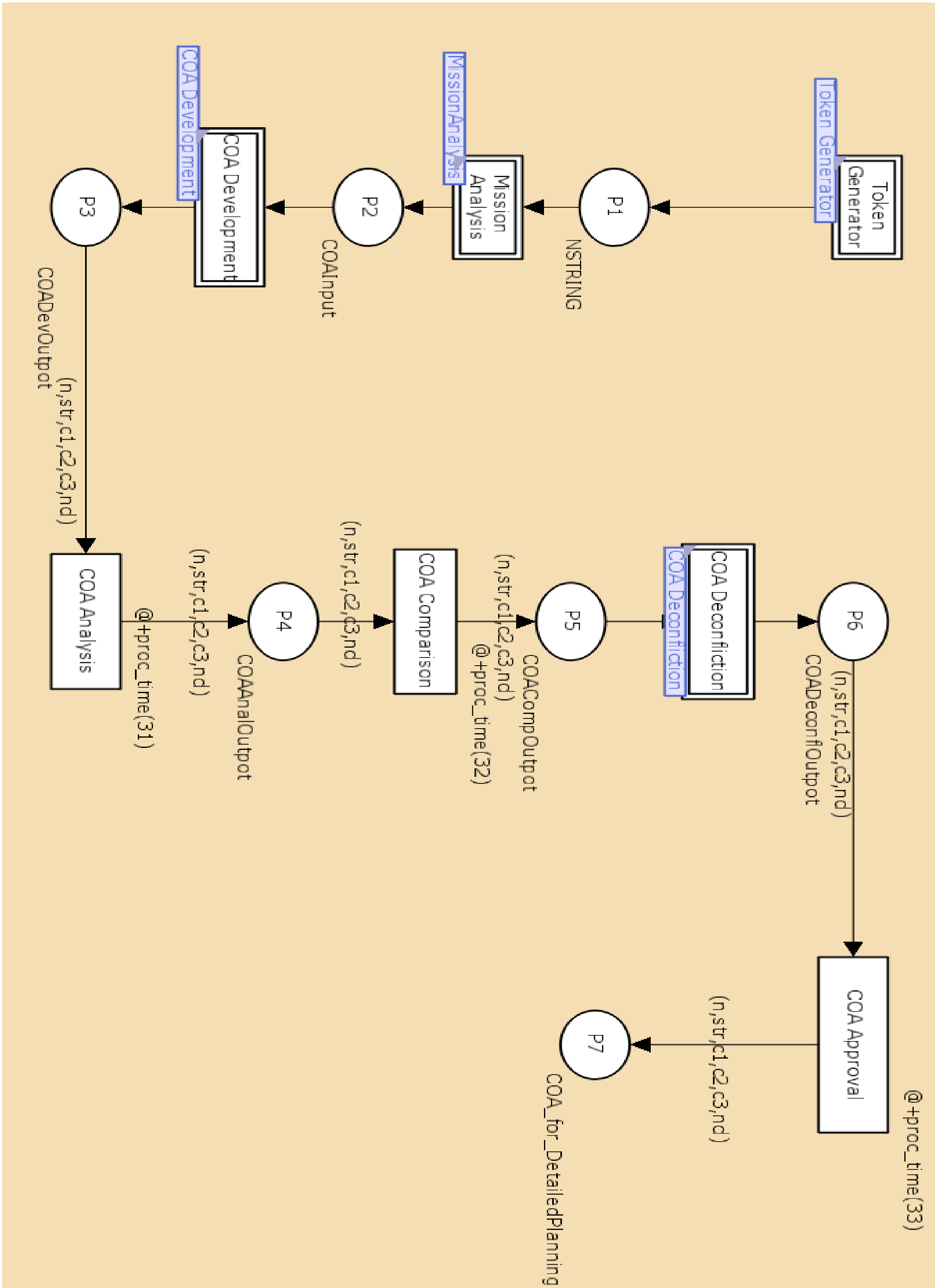


Figure 39 Planning Main

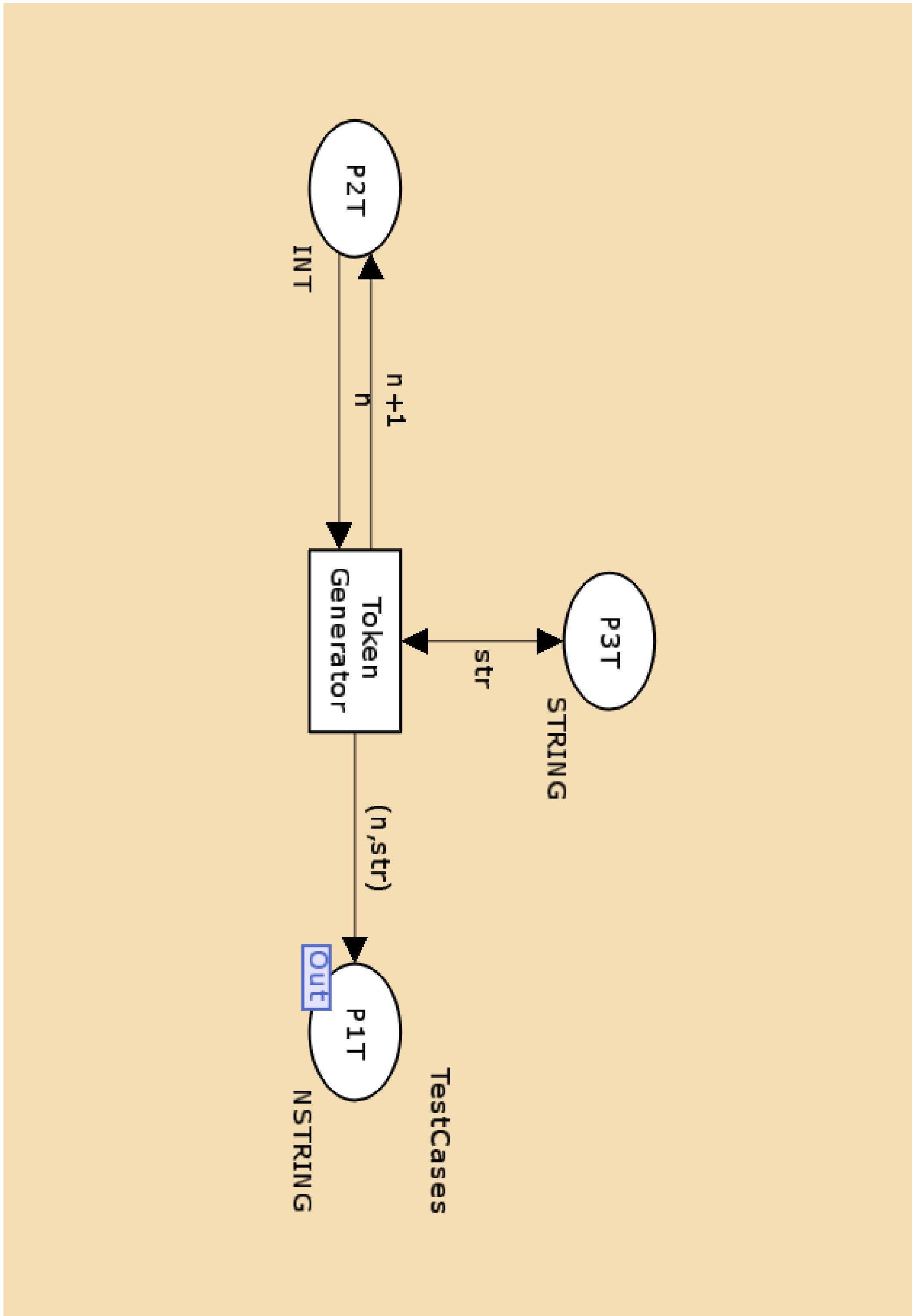


Figure 40 Token Generator

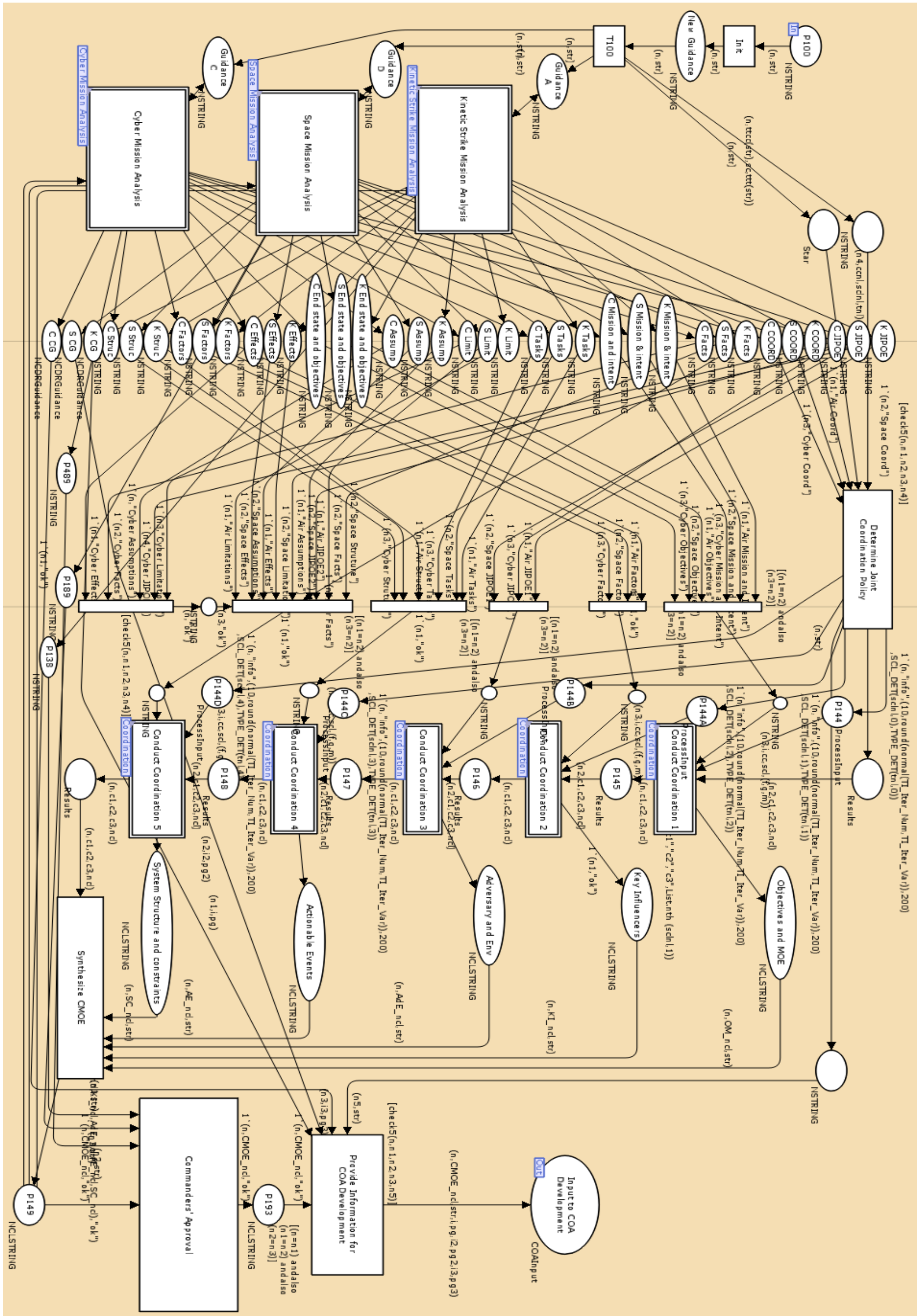


Figure 41 Mission Analysis

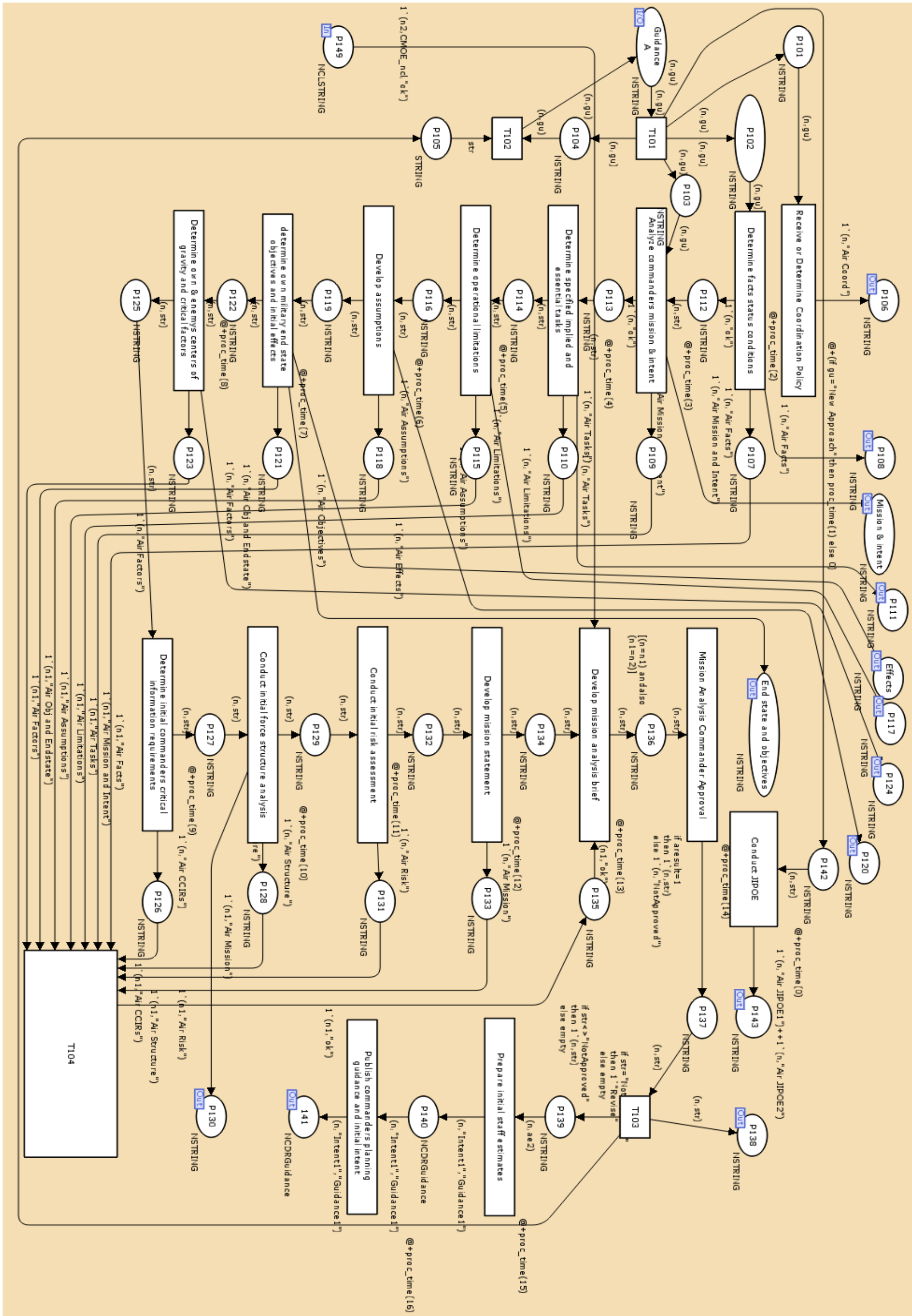


Figure 42 Kinetic Strike Mission Analysis

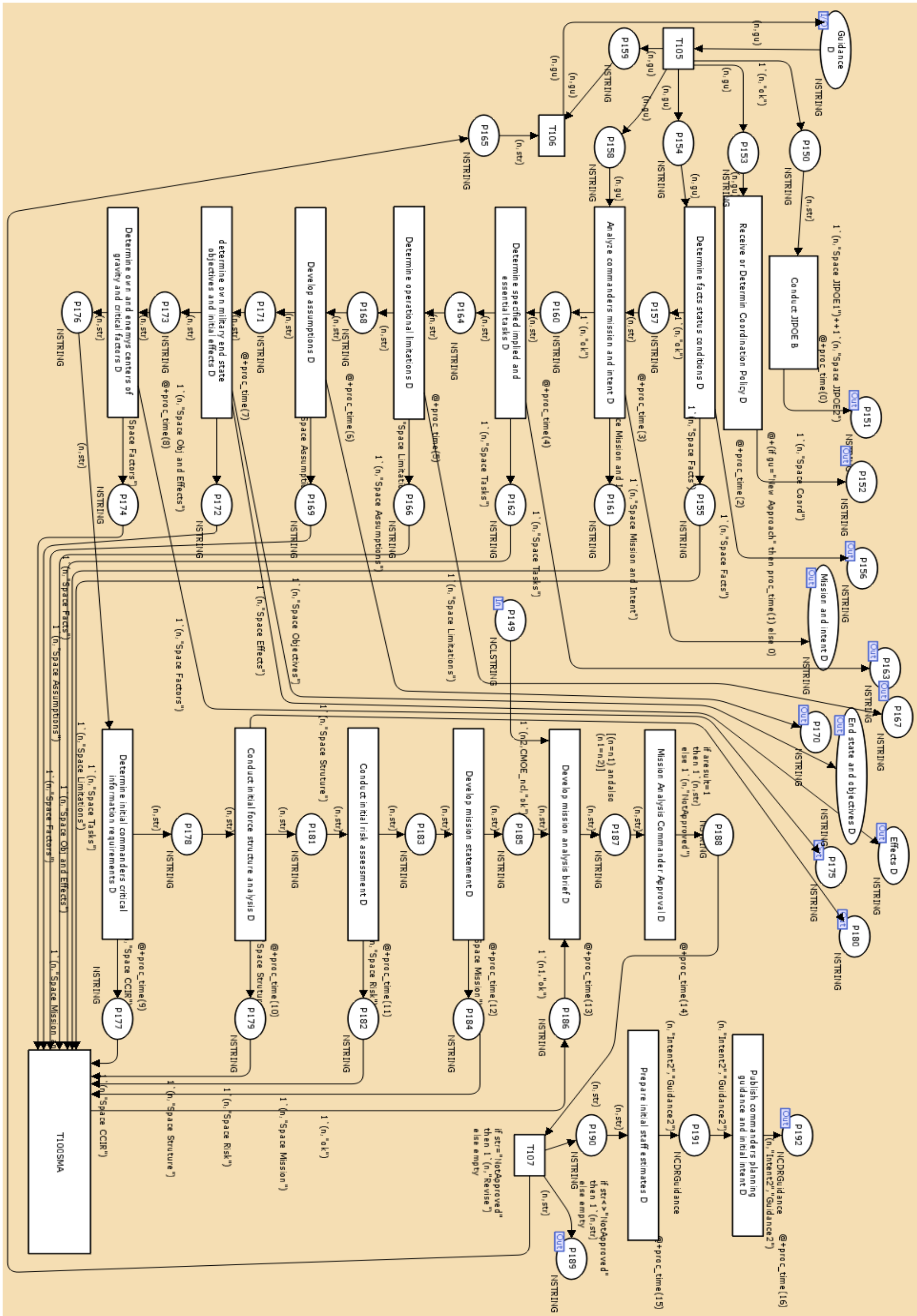


Figure 43 Space Mission Analysis

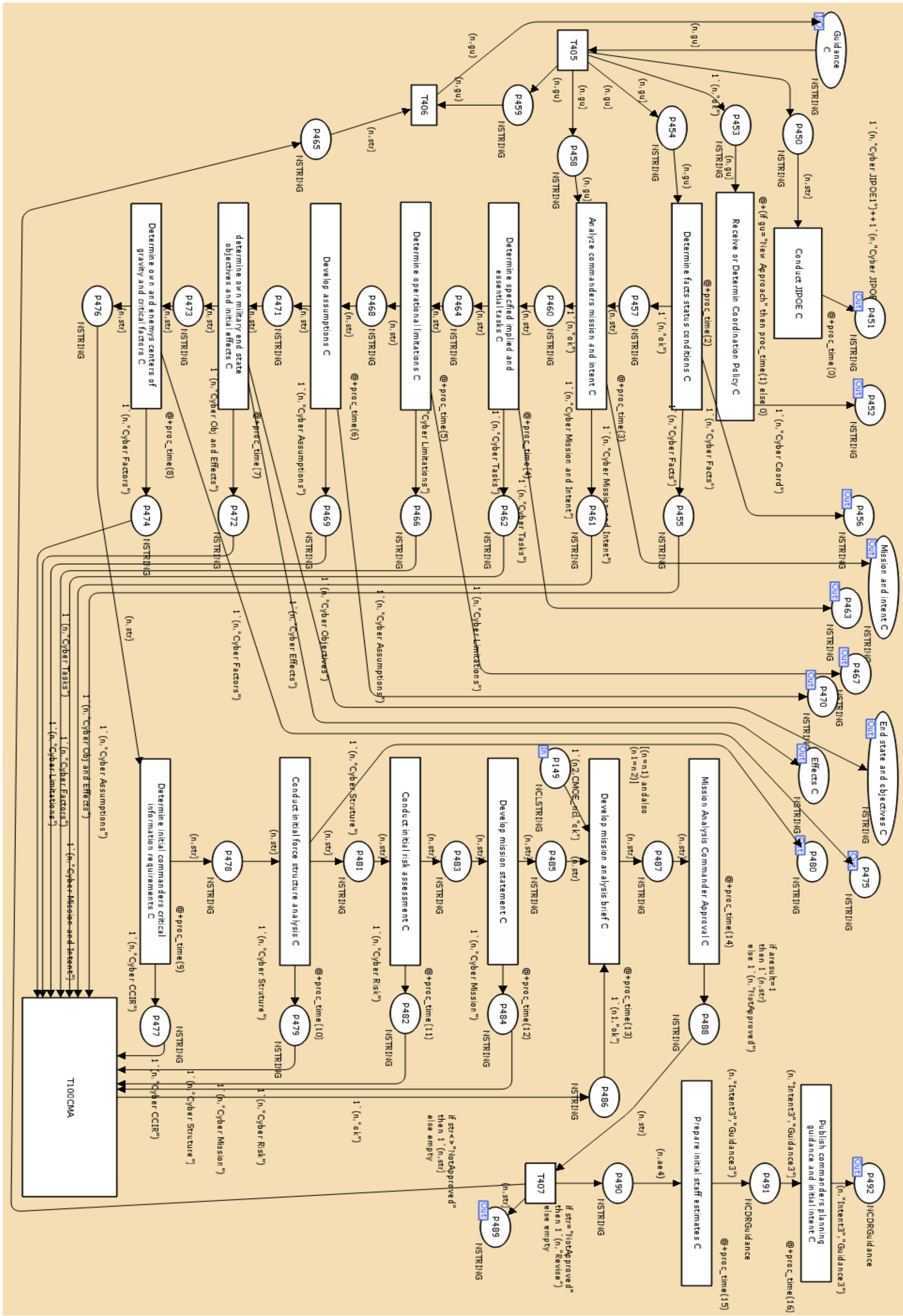


Figure 44 Cyber Mission Analysis

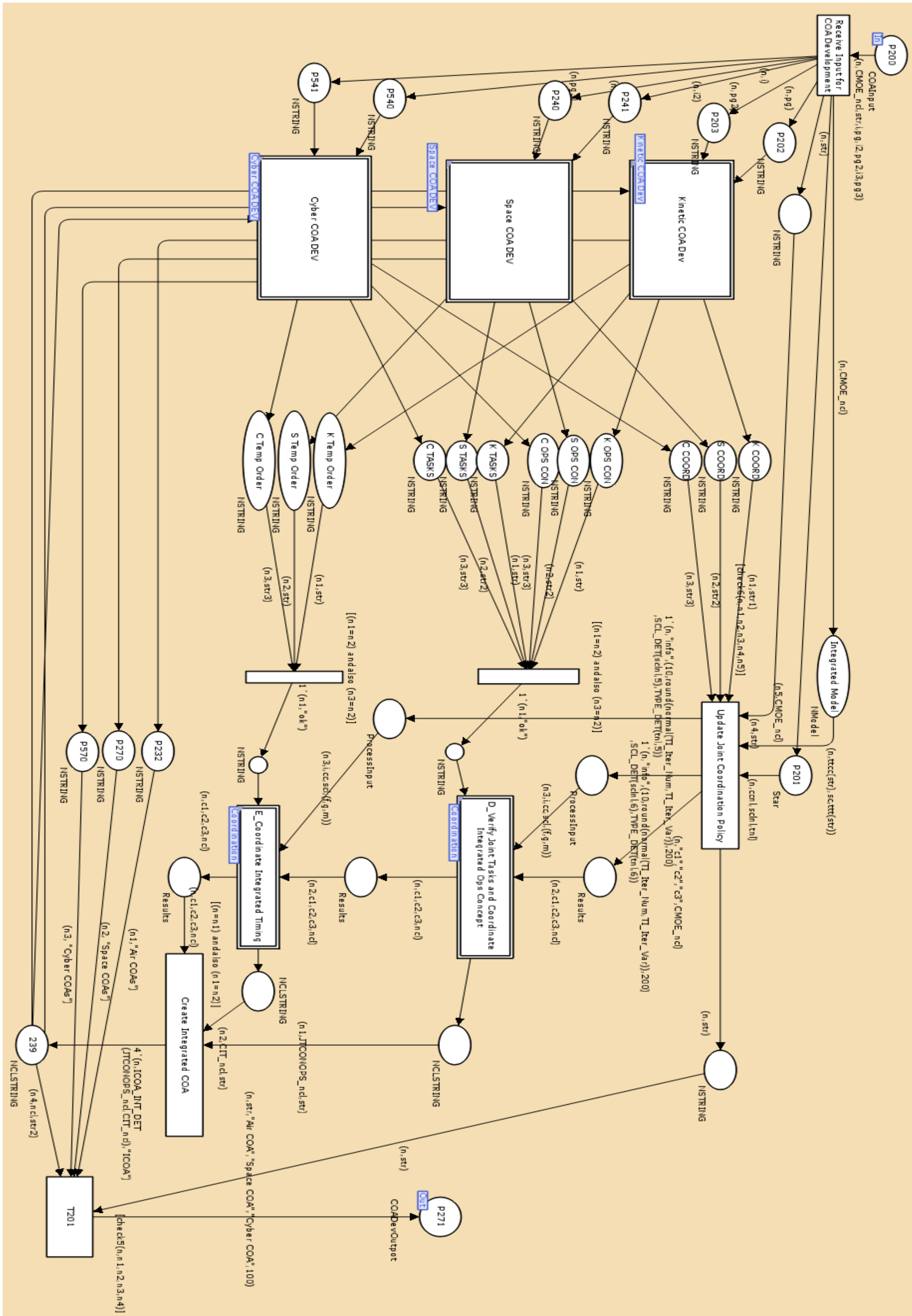


Figure 45 COA Development

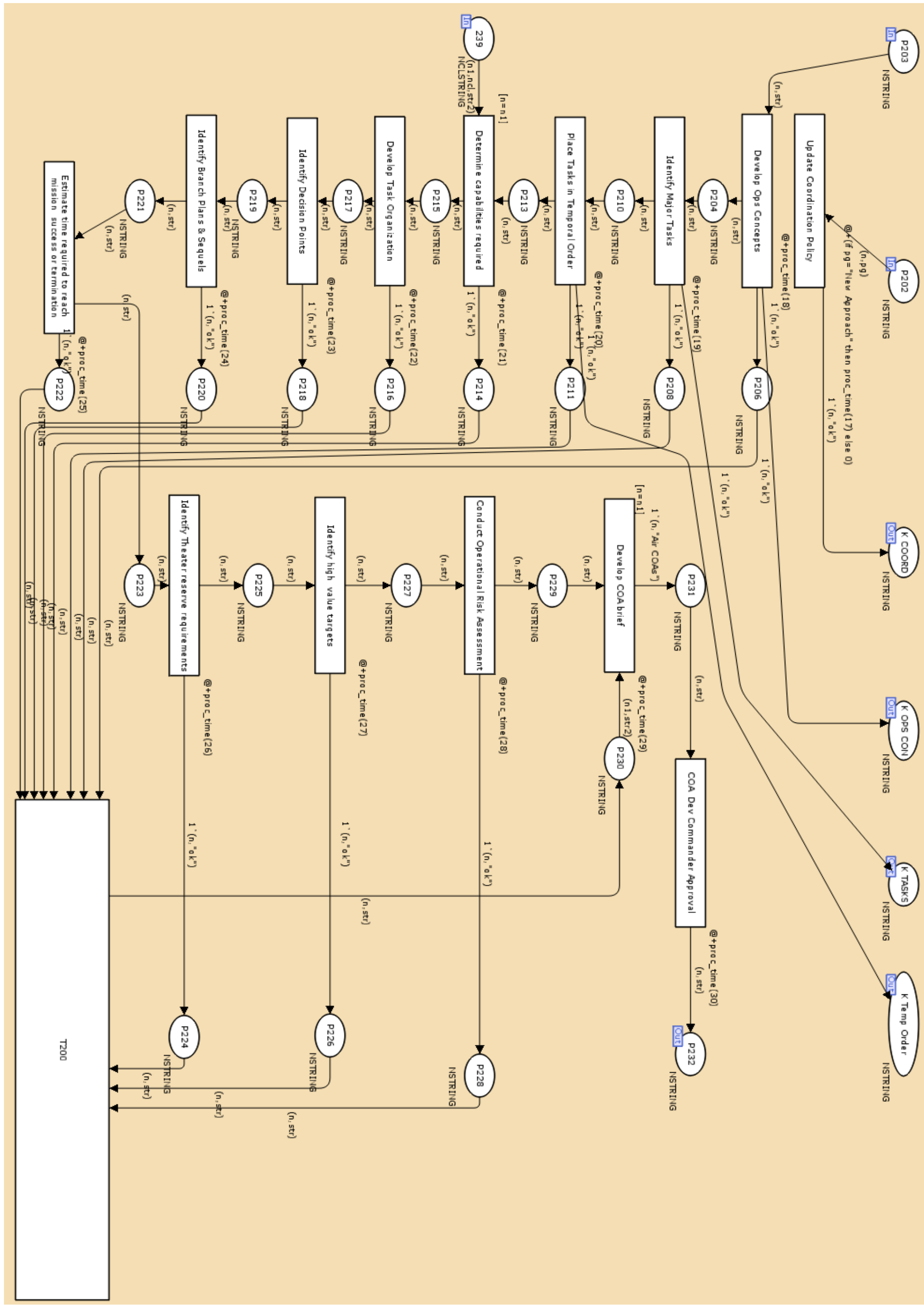


Figure 46 Kinetic Strike COA Development

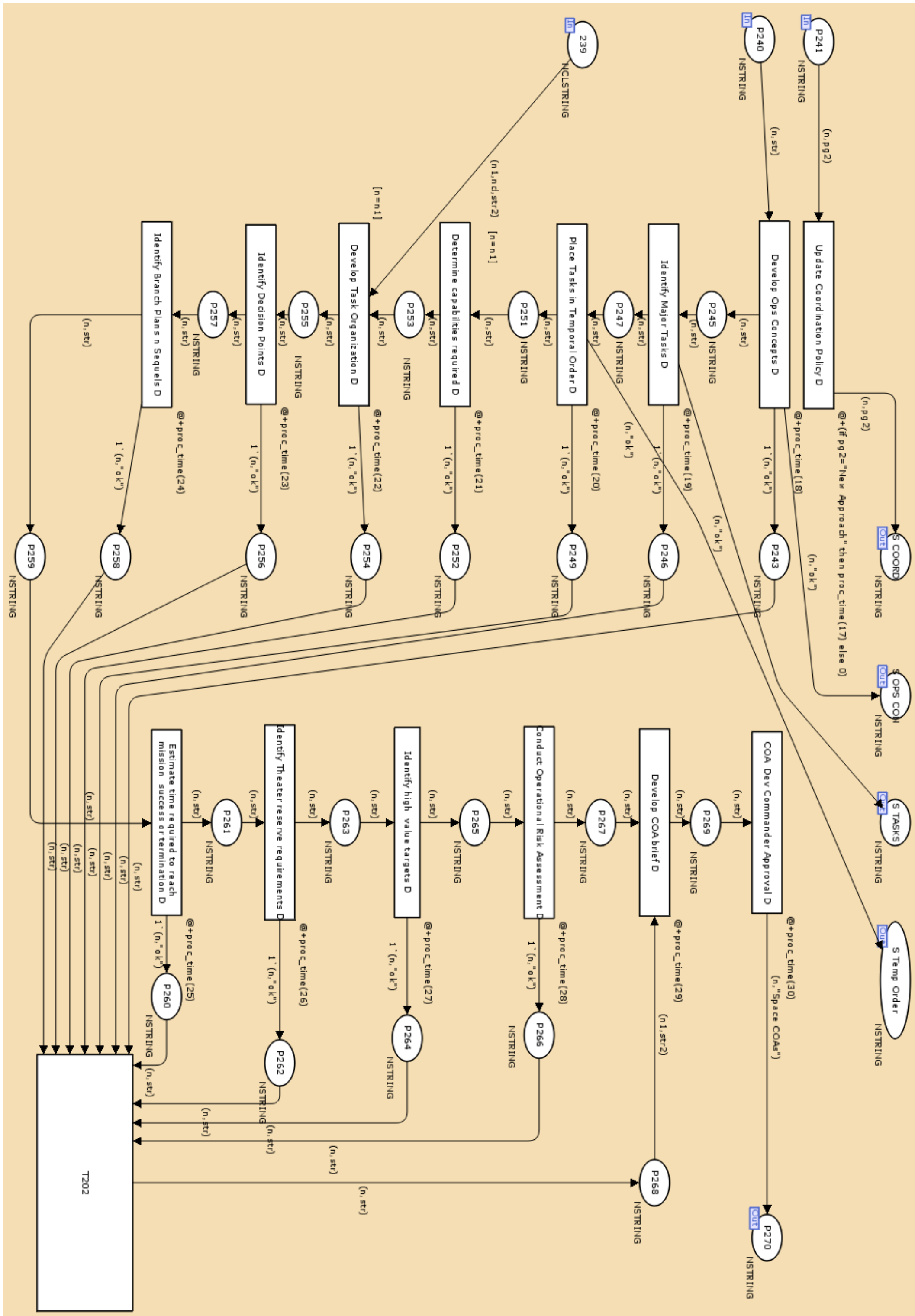


Figure 47 Space COA Development

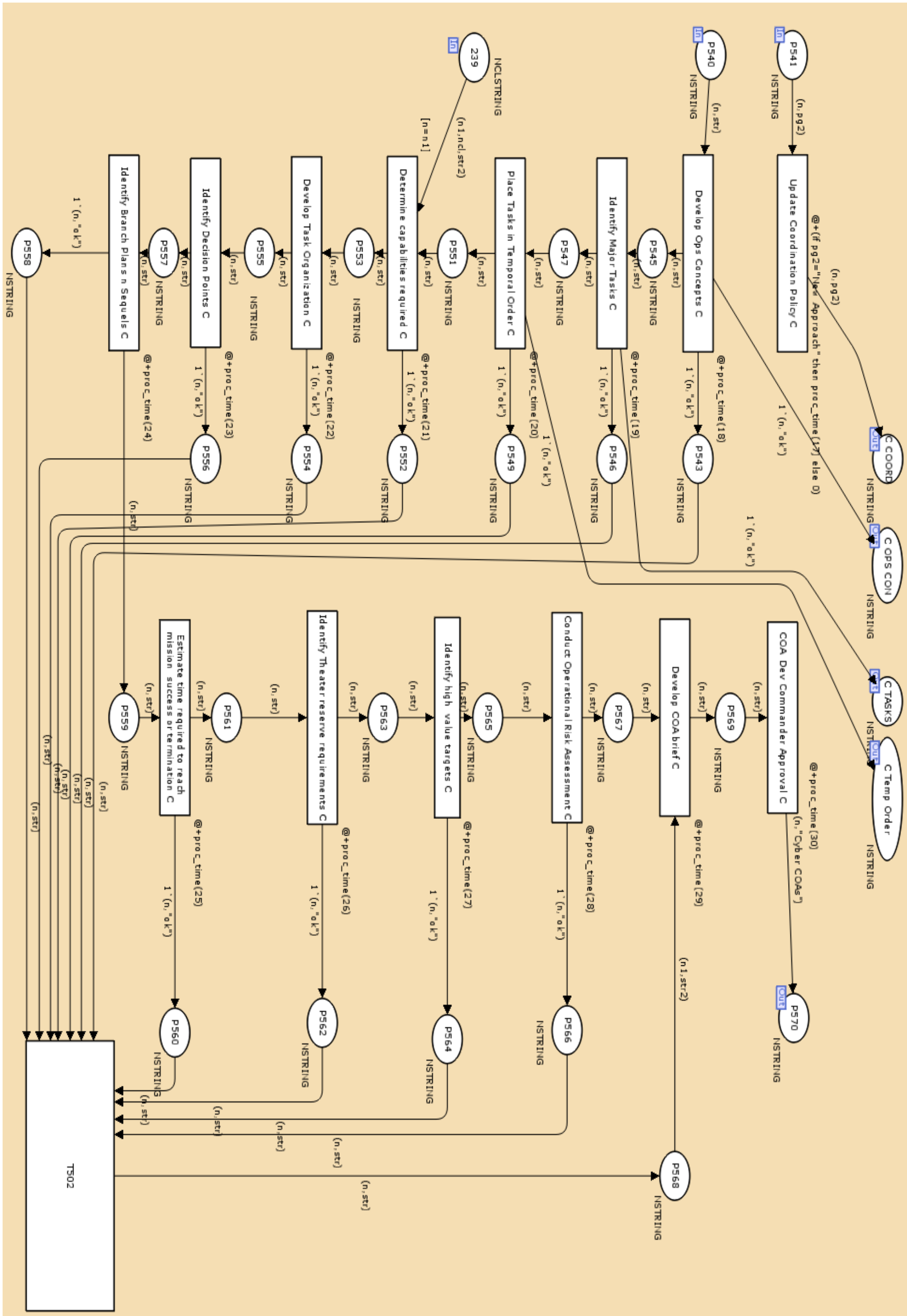


Figure 48 Cyber COA Development

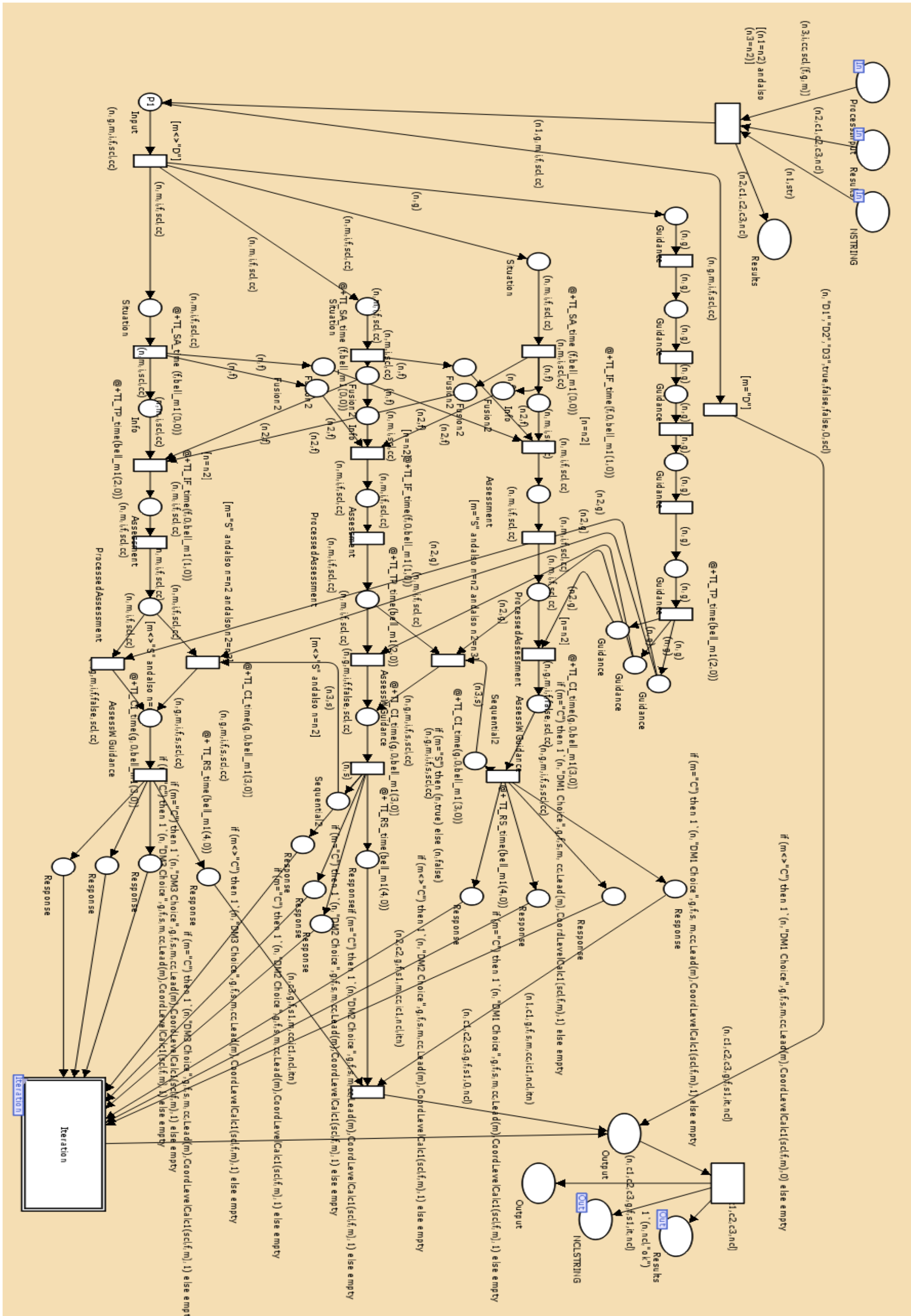


Figure 49 Coordination

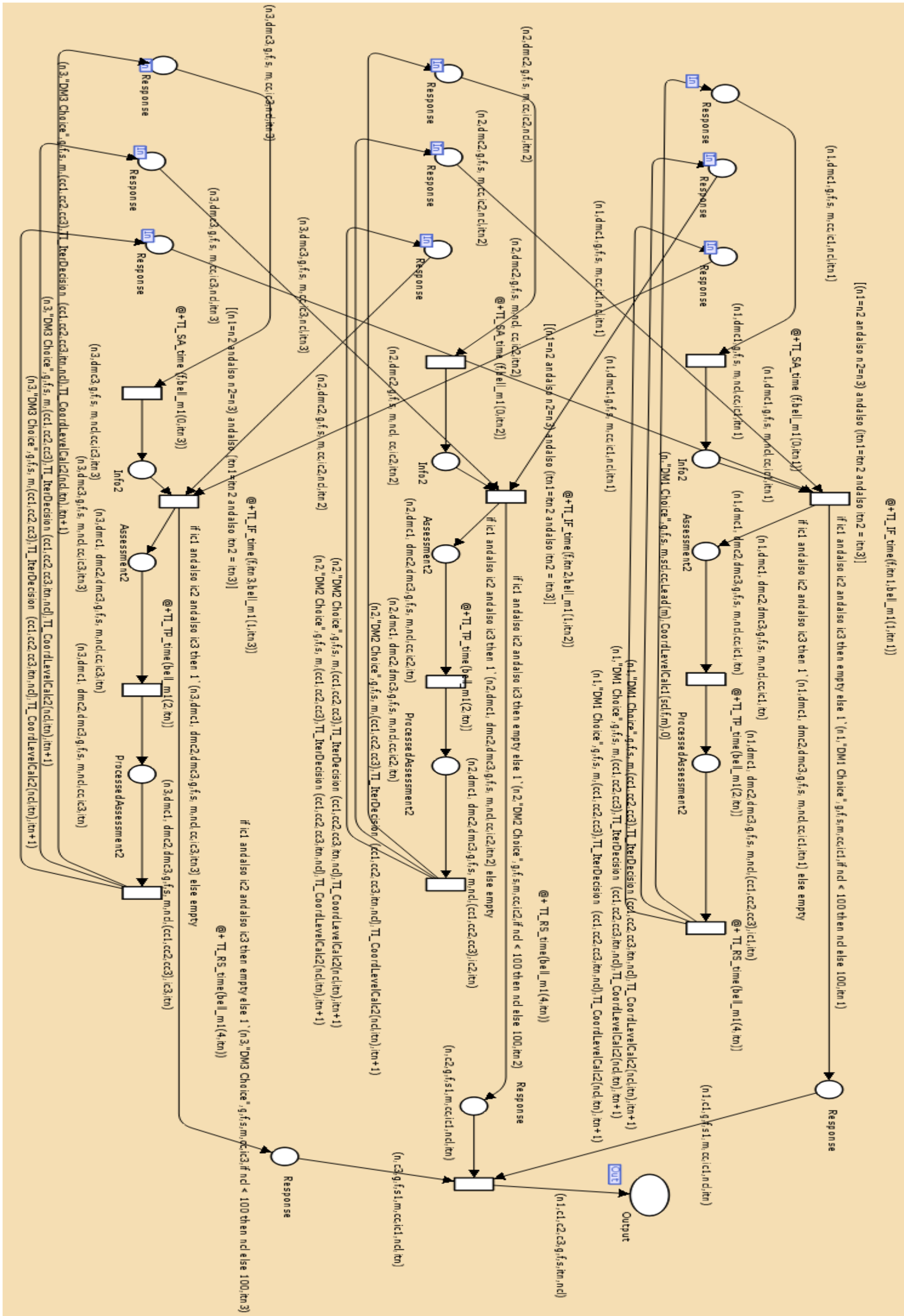


Figure 50 Coordination Iteration

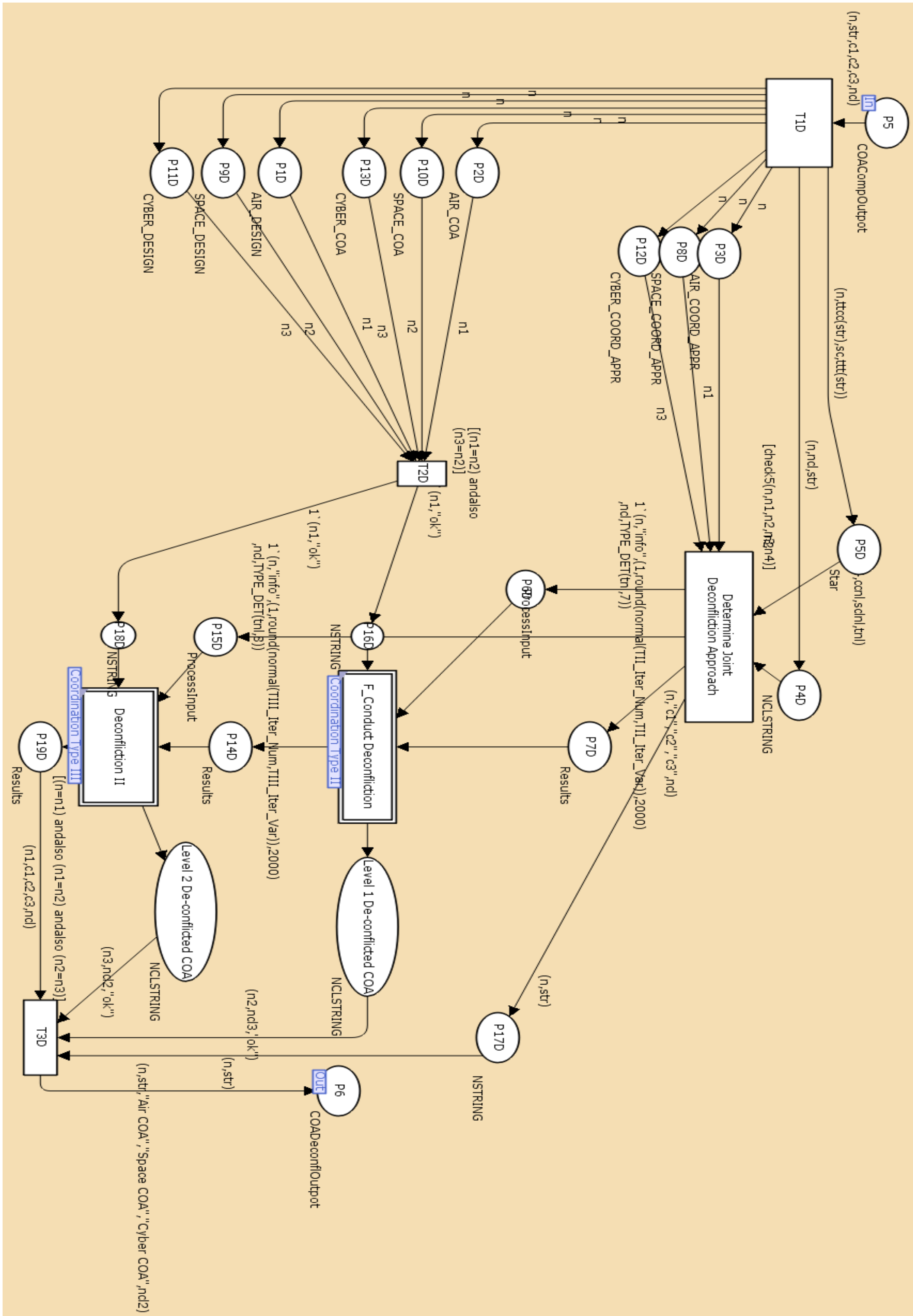


Figure 51 De-Confliction

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REFERENCES

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