



Investigation of a Graphical CONOPS Development Environment for Agile Systems Engineering

Final Technical Report SERC-2009-TR-003

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1 SUMMARY

As the bioterrorism program lead for a federal agency, you have been asked to draft a concept of operations (CONOPS) for an emergency response grid (ERG) that allows fast detection of and response to biological attacks on urban area. You log into the web-based agile CONOPS system (ACS). After logging in, you are prompted to (1) prepare an objective statement describing the purpose of the system, responsibilities of the team, and scope of the project and (2) identify potential team members and schedule the first meeting. The process has started...

Day 1-5: At their first session, the team, using ACS, identifies potential stakeholders within the DHS, the CDC, state emergency response agencies, city governments, individuals with expertise relevant to ERGs, and the system architect(s); and determines the relative participation levels appropriate for each. As the stakeholders are contacted the team uses ACS to define an initial concrete problem statement in a graphical representation.

Days 6-13: All stakeholders who have responded and have been approved to participate are given access to ACS. They find the problem statement and a link to a protected page where they map their desired conceptual characteristics for the ERG system graphically.

Days 14-20: The team consolidates all stakeholder input and calls a joint meeting with the stakeholders, through a combination of tele- and video-conferencing with shared access to the ACS graphical interface, to finalize a conceptual view of the desired ERG. Feedback is sought immediately from stakeholders unable to attend the meeting. All feedback is incorporated as comments on the graphical representation. While there are a few challenges (e.g., stakeholders' untimely responses and dynamics among some stakeholders) you realize this must be handled in an agile manner due to the evolving nature of the problem, and those challenges will be overcome using an agile approach. In the meantime, the team is gathering technical data necessary for the next step.

Days 21-27: Using ACS tools and the agreed upon conceptual view, the team produces an initial graphical representation so that the stakeholders can visualize the concept of operations. They then provide their inputs, and the CONOPS evolves according to the stakeholder needs and understanding. Through a series of joint sessions, the stakeholders negotiate various capabilities, evaluate tradeoffs, and assess risks using tools embedded in the ACS such as the multi-attribute trade-off analysis tool. Within a week, stakeholders converge on a set of prioritized capabilities for the ERG system including detecting small traces of the pathogens, measuring wind velocity, assessing chemical composition, providing video imagery, communicating incident information in a trustworthy and secure information network, GIS mapping and modeling of atmospheric conditions. Some stakeholders insist on including a training simulation

module, but given the additional cost this capability is deferred to later upgrades of the system.

Days 28-41: Based on the agreed upon capabilities, the team prepares a list of potential system components and a draft management plan. In three sessions of stakeholder negotiations, the system component list is refined and the system architecture is defined. The management plan is revised based on the availability of organizational resources involved in ERG deployment/management (as reported by stakeholders). The team finalizes all documentation.

Days 42-55: Stakeholders are provided with links to the system architecture, management plan and all artifacts of the CONOPS process within ACS and asked to solicit feedback within their respective organizations. In two joint sessions during this time period, stakeholders discuss their respective organizational inputs, resolve any conflicts among inputs, and agree on a final system architecture and management plan.

Day 56: The ACS has enabled you to automatically generate a standard CONOPS report (in either the IEEE or DoD format) and you can deliver it to your boss for final approval. Your boss is pleased to see that the final document is the result of input from over 20 stakeholders representing relevant constituents and commends you on completing the CONOPS in less than two months. The standard CONOPS document, models and scenario are then sent to the business units for final review prior to acquisition processes getting started.

This report describes the research behind the fictitious, but possible, ACS system discussed above. It is based on a survey of 23 openly available CONOPS across multiple industries and disciplines to understand what is important in a concept of operations, and what is not used. The report describes a process for arriving at a shared vision across multiple stakeholders. Currently there is no off-the-shelf tool to perform this task, but research is presented to assess the state of the technology for automating the process, and recommending a way ahead for further research, and prototyping of some aspects of an ACS like solution.

2 INTRODUCTION

This report is the result of a three month research task for the Systems Engineering Research Center¹ (SERC) to investigate what would be involved in producing a graphical CONOPS (Concept of Operations) development environment for agile systems engineering.

2.1 PROBLEM STATEMENT

CONOPS, if created on programs, are often generated in the form of lengthy documents supported by static images often developed in PowerPoint. This is a labor-intensive, time-consuming task involving multiple iterations of natural language descriptions, graphical flow descriptions and prototypical user interface representations. The resulting artifact is in an essentially static representation of the user's desires in an actionable form for developers. Reducing the time to create operational concepts, expanding the user-developer bandwidth and extending the static representation to a dynamic, environment-aware and malleable artifact should significantly reduce overall development time by shortening requirements elicitation and reducing rework due to misunderstanding. There is little ability to put the CONOPS in motion, visually observe behavior, interact with the analyst, communicate in real time, and develop a shared understanding of the problem or mission, and likely solution approaches. While there are complex modeling environments that allow dynamic modeling (simulations), they require extensive computer programming skill and significant time to build these simulations.

Using the extensive bodies of research in model based systems engineering, requirement elicitation, mental models and shared mental model articulation, negotiation and decision analysis tools, modeling tools, description languages, GUI generators and collaboration environments; our objective is to describe a graphical and interactive environment to model a concept of operations in support of agile development and lean systems engineering. To date, however, no comprehensive survey of existing capabilities and research has been undertaken with this specific objective in mind. It is anticipated there are a number of technologies and classes of tools that might be useful in this research.

¹ <http://www.sercuarc.org/>

2.2 RESEARCH APPROACH

This effort exercised several threads of research during the period of performance with the goals of:

- Examining core and customized CONOPS elements
- Mapping critical CONOPS Process Steps
- Developing an Agile CONOPS Process Framework
- Identifying current and emerging technologies that could serve as the toolbox for a graphical CONOPS system
- Recommending further research

We began with a survey of public, academic, and conference literature to understand the breadth and depth of research concerning the development of operational concepts. The results of that survey are contained in the annotated bibliography at the end of this report. Additionally, a review of 23 representative strategic, operational, and product-centric CONOPS was conducted. The results of this analysis can be found in Section 3.0.

Simultaneously, we interviewed key sources and subject matter experts in DoD and commercial enterprises who have experience developing operational concepts for their particular industry or domain. These results are documented in Section 3.5.

Based on the research and interview findings, we identified five key challenges to creating CONOPS efficiently and effectively: value proposition, translation of concept decisions into system attributes, shared mental model capability, human dimension, and process nonlinearity. These challenges are discussed in Section 3.6.

In Section 4.0, we address these challenges. We propose a three-stage agile CONOPS process that emphasizes stakeholder involvement and expedites shared mental model development (Section 4.1). Our notion of a graphical CONOPS system that incorporates current and emerging technologies is described in Section 4.2. Next, we highlight the salient features of our approach (Section 4.3).

Finally, based on the research conducted for this study, we make recommendations for future research that is necessary to bring our approach to fruition in Section 5.0.

3 CONOPS ANALYSIS

The Concept of Operations (CONOPS) as conceived today is a document that captures the user's needs and vision for anything being conceptualized for the purpose of transforming that concept into reality. The following sections further expand on that notion, and provide detailed analyses of representative bodies of knowledge on the subject.

3.1 DEFINITION

A Concept of Operations (CONOPS) is a document describing the characteristics of a proposed system from the viewpoint of its users. It is used to communicate the quantitative and qualitative system characteristics to all stakeholders and serve as a basis for stakeholder discussions on the issue. The CONOPS can help reach a "meeting of the minds" before the requirements process begins. It often conveys a clearer statement of intent than the requirements themselves.

The CONOPS approach provides an analysis activity and a document that bridges the gap between the user's needs and visions and the developer's technical specifications [IEEE1362]. In addition, the CONOPS document provides the following:

- A means of describing a user's operational needs without becoming bogged down in detailed technical issues that shall be addressed during the systems analysis activity.
- A mechanism for documenting a system's characteristics and the user's operational needs in a manner that can be verified by the user without requiring any technical knowledge beyond that required to perform normal job functions.
- A place for users to state their desires, visions, and expectations without requiring the provision of quantified, testable specifications. For example, the users could express their need for a "highly reliable" system, and their reasons for that need, without having to produce a testable reliability requirement. In this case, the user's need for "high reliability" might be stated in quantitative terms by the buyer prior to issuing a request for proposal (RFP), or it might be quantified by the developer during requirements analysis. In any case, it is the job of the buyer and/or the developer to quantify users' needs.

IEEE1362 further states that a CONOPS is a mechanism for users and buyer(s) to express thoughts and concerns on possible solution strategies. In some cases, design constraints dictate particular approaches. In other cases, there may be a variety of acceptable solution strategies. The CONOPS document allows users and buyer(s) to

record design constraints, provide the rationale for those constraints, and indicate the range of acceptable solution strategies.

3.2 CONOPS STANDARDS

The following standards are used by different industries to develop CONOPS documents:

- ANSI/AIAA G-043-1992 – guide from American National Standards Institute
- IEEE 1362-1998 – IEEE guide for CONOPS document
- DI-IPSC-81430 – DoD data item description for CONOPS document
- USDOT Federal Highway Administration CONOPS Template

Figure 1 is the ANSI Operations Concepts Document outline, Figure 2 is the IEEE CONOPS outline, and Figure 3 is the DoD CONOPS Elements. As can be seen, while each contains similar information, there are differences in sections, terms and completeness of content. For instance, while the ANSI standard calls for a system architecture to be part of the CONOPS, the two later standards – IEEE and DoD do not.

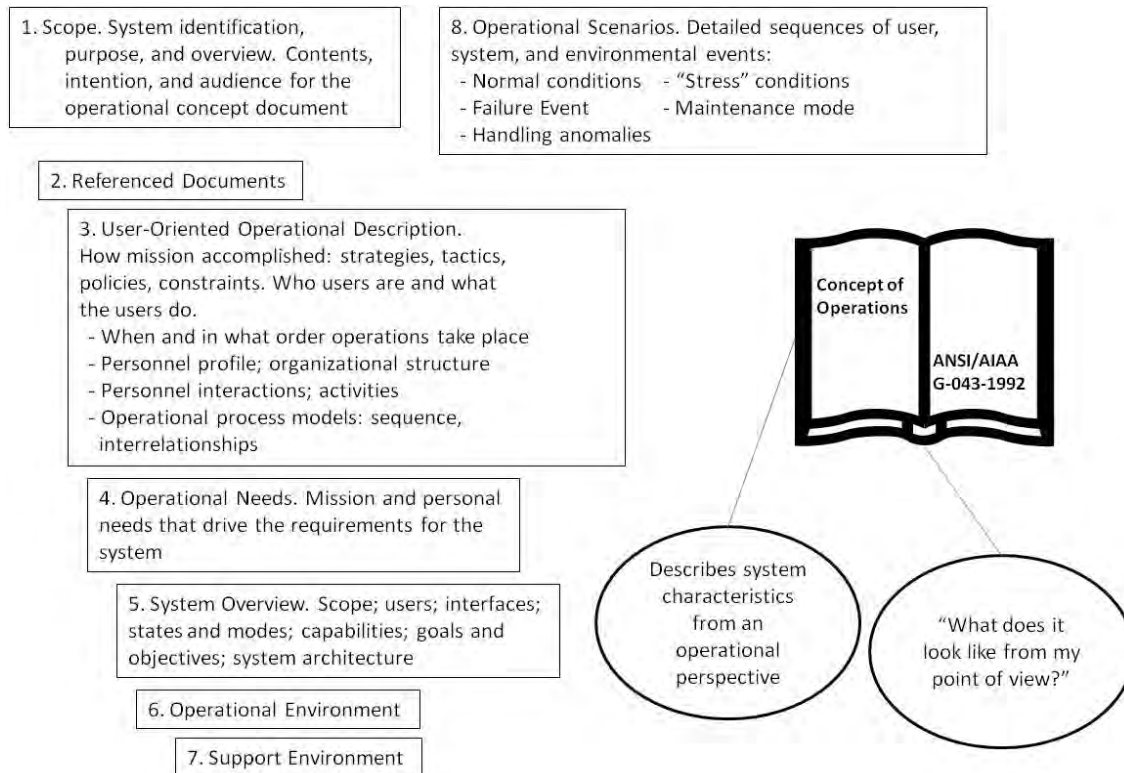


Figure 1: ANSI/AIAA Outline for Operations Concept Document

Title page
Revision chart
Preface
Table of contents
List of figures
List of tables
1. Scope
1.1 Identification
1.2 Document overview
1.3 System overview
2. Referenced documents
3. Current system or situation
3.1 Background, objectives, and scope
3.2 Operational policies and constraints
3.3 Description of the current system or situation
3.4 Modes of operation for the current system or situation
3.5 User classes and other involved personnel
3.6 Support environment
4. Justification for and nature of changes
4.1 Justication of changes
4.2 Description of desired changes
4.3 Priorities among changes
4.4 Changes considered but not included
5. Concepts for the proposed system
5.1 Background, objectives, and scope
5.2 Operational policies and constraints
5.3 Description of the proposed system
5.4 Modes of operation
5.5 User classes and other involved personnel
5.6 Support environment
6. Operational scenarios
7. Summary of impacts
7.1 Operational impacts
7.2 Organizational impacts
7.3 Impacts during development
8. Analysis of the proposed system
8.1 Summary of improvements
8.2 Disadvantages and limitations
8.3 Alternatives and trade-offs considered
9. Notes
Appendices
Glossary

Figure 2: IEEE 1362-1998 CONOPS Document Outline

Scope	• Identification. • System overview. • Document overview.
References	• Title, revision, and date of all documents referenced in this document.
Current system or situation	• Background, objectives, and scope • Operational policies and constraints • Description of current system or situation • Users or Involved Personnel • Support Concept
Justification for Change	• Justification for change • Description of Needed Changes • Priorities for change • Changes considered but not included • Assumptions and constraints
Concepts for New/Modified System	• Background, Objectives and Scope • Operational Policies and Constraints • Description of the new or modified system • Users or Involved Personnel • Support Concept
Operational Scenarios	• One or more operational scenarios that illustrate the role of the new or modified system, its interaction with users, its interface to other systems, and all states or modes identified
Summary of Impacts	• Operational • Organizational • Impacts during development
Analysis of Proposed System	• Advantages • Disadvantages • Alternatives and Tradeoffs

Figure 3: DI-IPSC-81430 CONOPS Elements (DoD)

3.3 TYPES OF CONOPS

Normally, a CONOPS falls into one of three categories, as listed below:

- Development of a New System
- Modification/ Upgrade/ Change to Existing System/Product
- Operational Strategy (which may also include end of life activities)

3.4 CONOPS CONTENTS

To better understand the detailed contents of CONOPS, we looked at 23 different CONOPS documents for real world systems developed by a variety of government and private sector institutions for new systems, modifications to existing systems and for mapping out operational strategies. These documents represented strategic, operational, and product-centric perspectives. The goal was to see to what extent each of the CONOPS documents had incorporated the entirety of the CONOPS elements and to what extent different elements had been omitted. We examined 12 CONOPS documents at a strategic element level (as identified in Appendix E) and another 13 CONOPS documents at detailed step levels. We also looked at the process, where documented, through which the CONOPS was created. Table 1 represents the industries and sectors of the studied CONOPS.

Table 1: Representative Industries for Mined CONOPS

Software Engineering	IT Systems
Aerospace	Weather Systems
Defense	General/Cross-Industry
Transportation	Communications
Education	Pharmaceutical

The names of the individual documents are shown in boxes 1, 2-8 in Figure 1. By mapping the sections in each actual CONOPS document to those in the standards, the most common sections for describing a concept of operations were identified.

3.4.1 CONOPS COMPARISON

Table 2: CONOPS Comparison Matrix

[illegible]

3.4.2 CONTENTS ANALYSIS

Analysis of the CONOPS comparison matrix in Table 2 was conducted in four stages. First, the matrix allowed for determination of which CONOPS elements were most and least commonly used among the collected examples. Next, a comparison was done to identify the common traits of CONOPS with the industry as a variable. This identification led to an investigation into the adherence of the examples to existing standards, analyzed both independently and by industry. Finally, the last useful analysis made possible by this matrix involved evaluating the format of the CONOPS examples.

The sample size of this evaluation was somewhat small, and any conclusions should be validated with a larger number of CONOPS examples from each industry and CONOPS type. At first glance, it appeared as if there were few patterns to be extracted from the data. It seemed as if the contents of each CONOPS example were largely based on the choices of the author or the organization for which they were prepared. However, placing the matrix results into a graphical form provided a visual and side-by-side comparison, which enabled some conclusions to be reached.

3.4.2.1 CONOPS ELEMENT STRUCTURE

One goal was to determine which elements or sections were the most commonly used across the surveyed CONOPS documents. Table 3 shows which 15 sections appeared in at least half of the documents.

Table 3: Most Commonly Used CONOPS Elements

	Element	Occurrences	% of Total
Proposed System	Description (Concept)	23	100.00
Proposed System	System Capabilities	20	86.96
Proposed System	Objectives	18	78.26
Proposed System	Operational Environment	16	69.57
Proposed System	System Interfaces	16	69.57
Proposed System	Personnel Activities	14	60.87
Current System	Background	13	56.52
Proposed System	Personnel Profile	13	56.52
Proposed System	Personnel Type	13	56.52
Changes	Mission Needs	12	52.17
Proposed System	Scope	12	52.17
Proposed System	Operational Policies	12	52.17
Proposed System	High level Requirements	12	52.17
Analysis	Summary of Improvements	12	52.17
Miscellaneous	Operational Scenarios	12	52.17
23 Total CONOPS Examples studied			

Since the CONOPS documents represent how a new (or upgrade of an existing) system will be used in an operational context, it seems obvious that the proposed system description would be found in all twenty-three of the CONOPS examined, as was found to be true. Also appearing in the vast majority of the surveyed CONOPS were the proposed system objectives and scope, important for assisting in managing scope creep. The majority of CONOPS went into some level of detail when examining the problem space. It would also be natural to believe that the criticality of early definition of a proposed system's capabilities, interface and operational environment would also be part of every CONOPS, but the analysis shows that these items only appeared in 75% of the CONOPS examples.

More troublesome, almost 70% of the CONOPS (69.57%) researched did not actually list or identify specific mission needs. This becomes a challenge to the systems developers who have the responsibility to build a system that satisfies those specific needs. Also noted was that of the twenty-three CONOPS evaluated, nearly a third had no description of the background or context of the current system or situation. Each of the CONOPS standards used as guidance in this study calls for the system background to be laid out prior to describing the proposed system. The standards also recommend that a full description of the current system/situation be made available in the CONOPS document, yet almost half of the examined examples neglected to include such a description. Generally speaking, there was a shortage of information relating to the current system/situation. In over 50% of the CONOPS examined, the provided current system background was a list of current system components in use. Table 4 shows the least often used elements, found in less than 25% of the CONOPS examples.

Table 4: Least Commonly Used CONOPS Elements

	Element	Occurrences	% of Total
Current System	Non-functional Attributes	1	4.35
Miscellaneous	Stakeholder Assessment	1	4.35
Current System	Performance Characteristics	2	8.70
Changes	Considered but not included	2	8.70
Current System	Organizational Structure	3	13.04
Current System	System Interfaces	3	13.04
Miscellaneous	Associated Risks	3	13.04
Current System	Modes of Operation	4	17.39
Current System	Personnel Interfaces	4	17.39
Changes	Personnel Needs	4	17.39
23 Total CONOPS Examples studied			

Of the ten elements listed in Table 4, six of them are related to the current system/situation. Some of these, including personnel and system interfaces and modes of operation are significant to the operation of a system. Another particularly weak area not addressed in most of the CONOPS was stakeholder assessment. While system

stakeholders include those who will operate and support the system (in Table 2, they are grouped together as personnel and support), little attention was paid to other stakeholders who do not directly interact with the system, including acquisitions staff, and government and regulatory agencies. Stakeholder assessment was not included in any of the standards and is typically addressed throughout the early stages of development, which perhaps explains the reason why it was found in only one of the examples.

Yet another weak area was the changes/alternatives that were considered but not included in the proposed system. The neglect of these elements may highlight the common systems engineering error of not keeping the problem and solution spaces separate. Finally, less than 20% of the CONOPS examples identified the associated risks of the system and its development. This was unexpected given the fact that many of the examples were written by/for government agencies, which are typically highly concerned with thorough risk analysis.

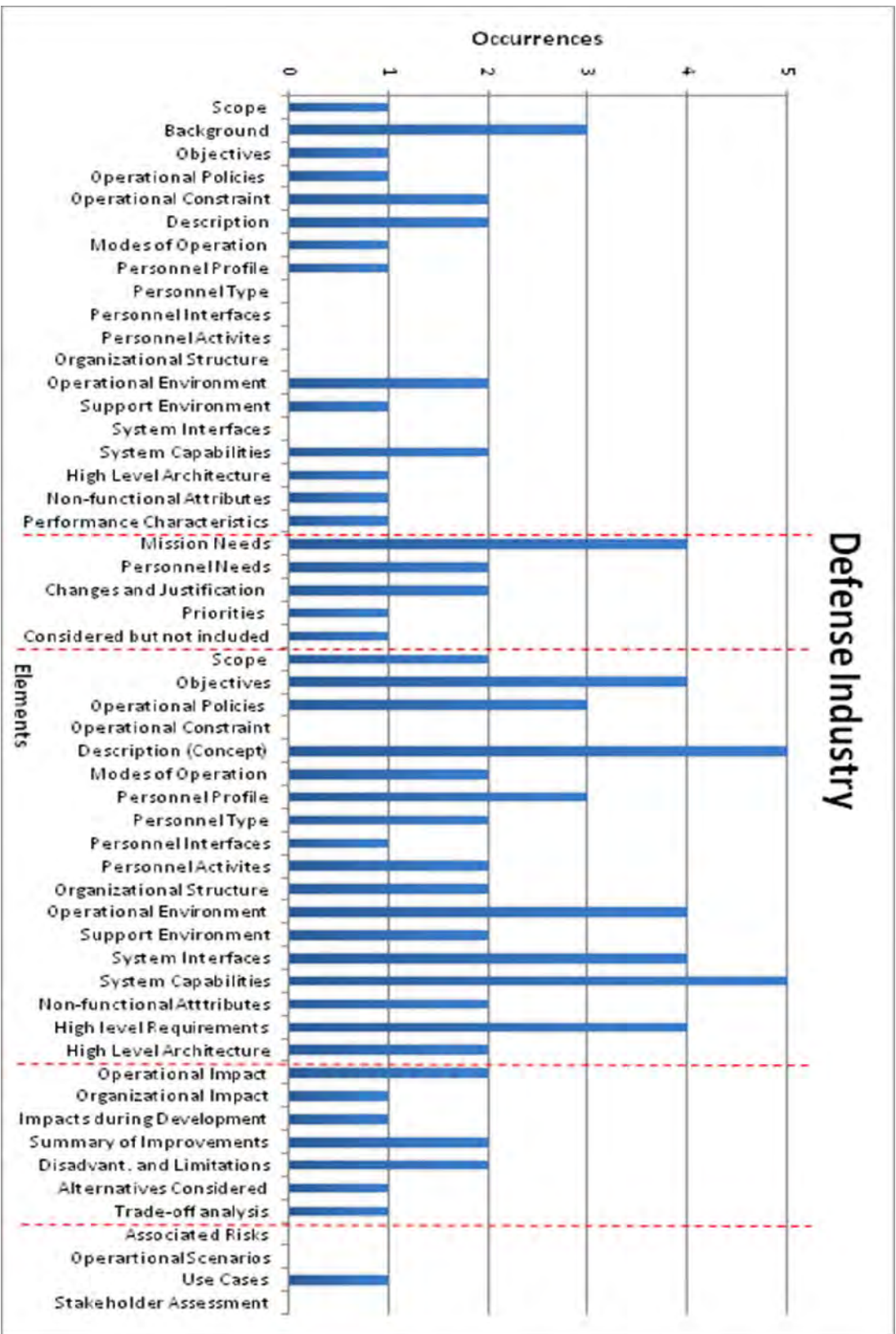
3.4.2.2 CONOPS ELEMENTS BY INDUSTRY

The next layer of analysis made of this data was examination of common CONOPS traits by industry. To facilitate this analysis, three general industries were identified, (defense, software and aerospace) with each containing five of the CONOPS examples (Figures 4, 5, and 6). This division ended up excluding eight examples that did not fit into these categories, but made for easier evaluation of the data. Since exactly five examples from each industry were used, the scales are the same in each chart, and the height of the bars in the following graphs represents the number of specific CONOPS examples which contained the elements listed in the x-axis. The dotted red lines correspond to the topic boundaries found on Table 2.

Certain observations can be made regarding the industry specific CONOPS examples. In the software industry, most of the CONOPS examples did a thorough evaluation of the proposed system, yet there was little effort expended in describing the current system. Contrast this to the aerospace industry, where the CONOPS contained more information related to the current system.

Typically, the CONOPS examined were for new systems that did not exist or systems that were meant to completely replace existing systems. In the aerospace industry, there is much more dependence on legacy systems and component reuse, which would require a deeper understanding of the current system. The defense industry is similar to aerospace in that legacy systems are dominant platforms from which to develop new systems. But strangely, similar to software systems, defense system CONOPS provided less analysis of current systems/situations. This is an area that would benefit greatly from evaluation of additional examples, as well as access to classified CONOPS.

Defense industry CONOPS examples also appear to have scored poorly in evaluating risks associated with system development, as well as other general impacts of system development and implementation. As mentioned previously, this result is interesting in respect to government entities in general and the defense industry specifically, as both are particularly concerned with risk analysis and mitigation. Another observation regarding industry specific CONOPS was in the level of detail used to examine use cases, operational scenarios and modes of operation. In the software industry, these three elements ranked relatively high, with aerospace CONOPS giving less detail and the defense CONOPS giving almost no detail for these aspects. The reason for this disparity is unknown, and perhaps investigation of more CONOPS in these industries will provide some further insights.



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Figure 4: CONOPS Elements in the Defense Industry

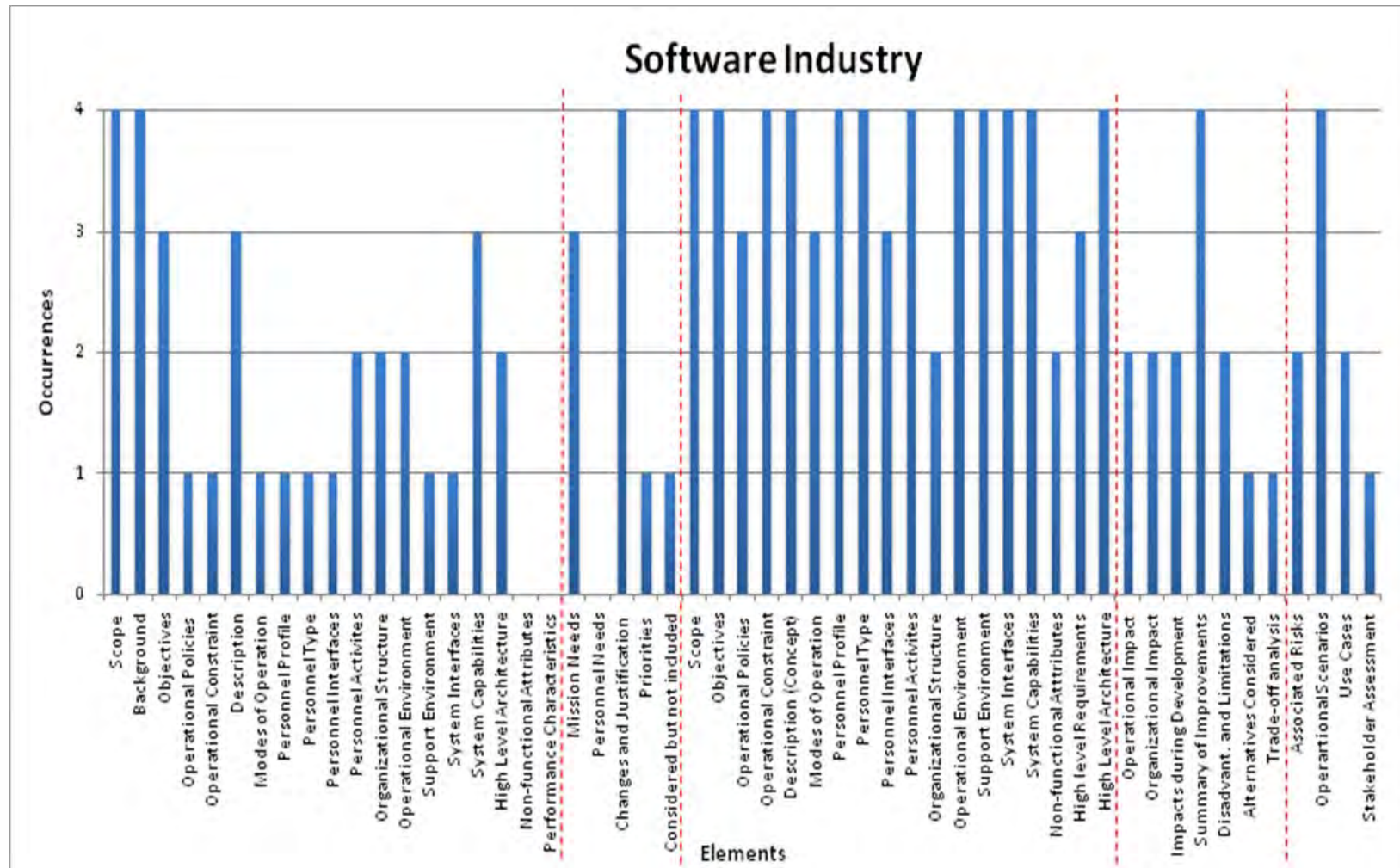


Figure 5: CONOPS Elements in the Software Industry

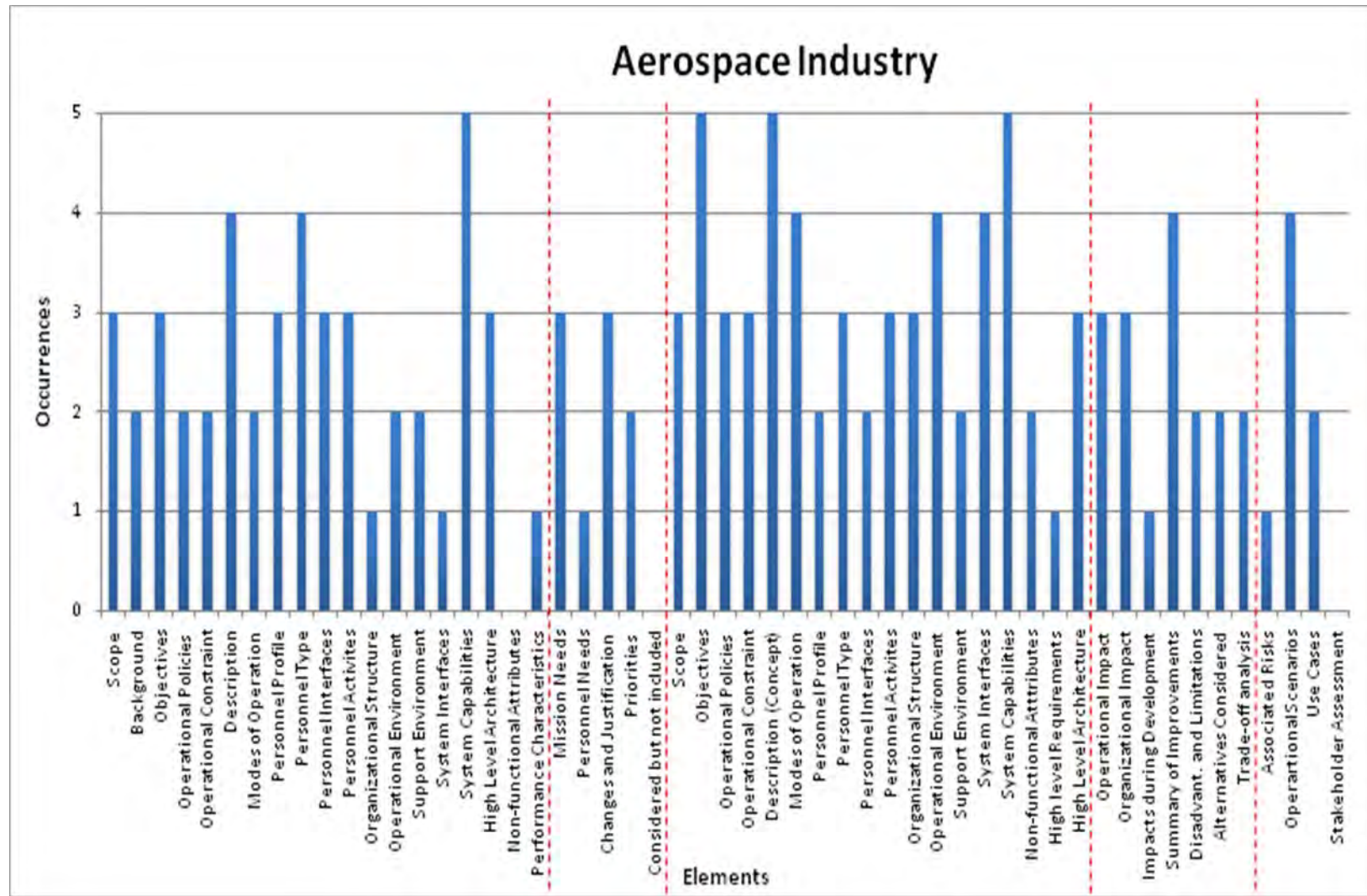


Figure 6: CONOPS Elements in the Aerospace Industry

It appears that the aerospace and software industry CONOPS have the most in common while the defense industry differs from both of them by many factors. Another observation is that the aerospace industry utilizes many of the categories at a higher rate than the other two industries. There has been nothing in our research that would explain this and nothing in the standards that would cause this to happen.

Quantitatively, since there were equal numbers of examples and elements for each industry, the total “scores” were added up to give an impression of which industries have the most inclusive CONOPS (in relation to the specific element evaluated). While this is not a measure of the quality of the CONOPS examples, since it took no account of what was written, it is a measure of the inclusivity of information. The score was calculated by adding up the number of CONOPS examples that include each element. Using this approach, the maximum score for each industry would be 265 (53 elements [excluding those involving format] * maximum score of 5 out of 5 = 265). The software and aerospace industries both scored 136 (average score of 2.6 per element [out of 5 maximum]) and the defense industry scored 90 (average of 1.7 per element). Again, although these scores are not an effective measure of the quality of CONOPS, they may be useful in understanding how the CONOPS match up against the standards. This is summarized in Table 5.

Table 5: CONOPS Completeness

	Software CONOPS	Aerospace CONOPS	DoD CONOPS
Number of CONOPS Elements	53	53	53
Average use per element	2.6	2.6	1.7
Maximum Score Possible	265	265	265
Completeness Score	136	136	90

3.4.2.3 CONOPS ELEMENTS: STANDARDS VERSUS EXAMPLES

When looking at the 18 categories that can be found in all four CONOPS standards only nine (50% of the 18 categories) were documented at a rate of 50% or more in the reviewed CONOPS (Table 6). Using the logic that those 18 categories must be the most critical since they are referenced in all four standards one might expect to find all 18 categories utilized in the majority of CONOPS reviewed. However, the four least utilized categories out of the 18 are all related to personnel (Personnel Needs, Personnel Activities, Personnel Types, and Personnel Profiles). These are used at a rate of only 22% or less in the CONOPS reviewed. It is also interesting to note that 5 out of the 9 least utilized categories are related to personnel attributes of the proposed system.

Since the elements for the matrix in Table 2 were chosen using the four leading CONOPS standards, it was expected that each example and each industry as a group would contain elements that conform to their relevant standard. Contrary to expectation, most of the examples in this study followed the format of one of the IEEE

and AIAA standards. The AIAA standard is fairly antiquated, and the Federal Highway Administration standard tends to be highway transportation specific, therefore this leads authors of non-defense CONOPS documents to use the more inclusive and adaptable IEEE standard as a guide to CONOPS development. The CONOPS examples used for this study varied in their degree of conformance to the IEEE standard, but no industry group of CONOPS conformed complete to any single standard.

Table 6: Comparative Analysis with CONOP Standards

Element	% of Total	AIAA	DoT	DoD	IEEE
Description (Concept)	100.00	1	1	1	1
System Capabilities	86.96	1	1	1	1
Objectives	78.26	1	1	1	1
Operational Environment	69.57	1	1	1	1
System Interfaces	69.57	1	1	1	1
Personnel Activities	60.87	1	1	1	1
Background	56.52	1	1	1	1
Mission Needs	52.17	1	1	1	1
Scope	52.17	1	1	1	1
Support Environment	47.83	1	1	1	1
Modes of Operation	47.83	1	1	1	1
High Level Architecture	43.48	1	1	1	1
Personnel Interfaces	39.13	1	1	1	1
Organizational Structure	34.78	1	1	1	1
Personnel Profile	21.74	1	1	1	1
Personnel Activities	21.74	1	1	1	1
Personnel Type	21.74	1	1	1	1
Personnel Needs	17.39	1	1	1	1
23 Total CONOPS Examples studied					

3.4.2.4 CONOPS GRAPHICAL ELEMENTS

A final analysis of the surveyed CONOPS was in relation to the format of CONOPS documents. This was of specific interest to this research task, which is aimed at creating a visual representation of CONOPS documentation. Table 7 shows that of the twenty-three CONOPS examined, close to 75% were made up of a mixture of text and graphics, just over 25% had text only, and none of them were presented with only graphics.

Table 7: CONOPS Graphical Elements

Format/Graphics	Occurrences	% of Total
Text Only	6	26.09
Text and Graphics	17	73.91
Graphics Only	0	0.00
Flowcharts	10	43.48
Organizational Charts	5	21.74
Context Diagram	5	21.74
Formal SE Diagrams	2	8.70
Survey/Data Graphics	3	13.04
High Level Architecture	11	47.83
23 Total CONOPS Examples studied		

Of the seventeen examples that had utilized graphics, ten included some form of data or process flowchart or high-level architecture graphic. However, only two of them incorporated a formal systems engineering graphic. These results highlight that while there may be a desire to incorporate graphics to improve clarity, there is a lack of structure when choosing what types of graphics to include.

3.4.2.5 POTENTIAL SOURCES OF SOURCE DATA BIAS

This analysis was performed based on a collection of CONOPS which were free and accessible via the Internet. This may bias the analysis in following three directions, as a result of the data:

1. Private companies are typically interested in protecting any edge they have over their competition, therefore they are frequently unwilling to release information related to proprietary products and processes.
2. Government entities restrict the release of sensitive information for reasons of national security, therefore reducing in number what should have been the largest pool from which to select examples.
3. As can be seen by examining the last column of the matrix in Table 2, many of the CONOPS examples are rather short in length. Due to the two points listed above, companies and government entities often allow the release of certain information from CONOPS documents to be used in shorter, less detailed conference and white papers. These CONOPS may not only exclude sensitive information, but may also exclude some of the elements that this matrix has been examining, leading to misrepresentation in the analysis.

3.4.3 CONOPS ANALYSIS CONCLUSIONS

Summarizing the CONOPS analysis, of the issues identified, the following key issues may be significant in developing an agile approach for graphical CONOPS:

- Less than 75% of the CONOPS researched actually list or identify specific mission needs.
- Nearly a third had no description of the background or context of the current system or situation.
- There was a shortage of information relating to the current system/situation.
- Little attention was paid to other stakeholders who do not directly interact with the system, including acquisitions staff, and government and regulatory agencies.
- Stakeholder assessment was not included in any of the standards and is typically addressed later throughout the early stages of development.
- Less than 20% of the CONOPS examples identified associated risks of the system and its development.
- The four least utilized categories out of the 18 are all related to personnel (Personnel Needs, Personnel Activities, Personnel Types, and Personnel Profiles).

3.5 CURRENT CONOPS CREATION PROCESS

Another task performed was to research published process documents and conduct interviews across domains to understand how the CONOPS process plays out in the field. While many organizations do not call the resulting product a “concept of operations”, the spirit of activities is the same. The following sections detail one DoD process, and recounts the results of several industry interviews.

We found that CONOPS documents that adhered to all the different steps took as long as 30 months to produce. In other cases, when the bare minimum elements were selected, CONOPS documents were finished within 3 months. In most cases the CONOPS development process was performed by a core CONOPS team and the draft was sent out for review to the relevant stakeholders. It was found that the required time to gain consensus through back and forth discussions among the various stakeholders in the organization consumed the bulk of the CONOPS development effort. Also the text-based nature of the CONOPS makes editing of CONOPS documents a time-consuming and challenging process. In most cases the CONOPS seems to have been produced only due to documentation requirements rather than as a strategic/tactical system planning tool. This defies the original purpose of the CONOPS which is to mediate between user and developer communities and other stakeholders in a way that a system can be designed holistically and in an integrated fashion. We present the Air Force Space Command CONOPS process as the representative/traditional approach used by most organizations today.

3.5.1 AIR FORCE SPACE COMMAND PROCESS

The Air Force space command (AFSPC) CONOPS creation process is shown in Figure 7. This is a very traditional view and seems representative of government agencies as well as large DoD contractors. The flow says nothing about the content creation of the CONOPS, just the CONOPS artifact creation process.

The AFSPC states that some CONOPS are created to support administrative processes, and other are created for programs. They use the CONOPS to provide vision for the directorate office, and it is intended to describe how the system or capabilities will be operated and utilized by the directorate.

The CONOPS is used for many purposes by the AFSPC. Some of those uses include:

- Headquarters extracts operational requirements from the CONOPS and uses it as a framework for developing their Operational Requirements Document (ORD).
- Other directorates may use the CONOPS for developing their internal documents.
- The air wings use the CONOPS when developing their concept of employment (COE) and may use the CONOPS for Operation Plan (OPLAN) development.
- Agencies outside the command also have a vested interest in the CONOPS.
- The system program offices (SPO) use the CONOPS as guidance to direct the contractors in system architecture development as part of the acquisition process.
- Contractors use the CONOPS as guidance for developing internal architectural documents to meet requirements.
- The Air Force Operational Test and Evaluation Center (AFOTEC) uses the CONOPS when conducting their operational assessment (OA) and as part of the operational test and evaluation (OT&E) concept development.

In general, the CONOPS provides guidance to those users requiring direction and/or information on developing their own documents [AFSPCI 10-606].

Figure 8 shows how the AFSPC takes the flow from Figure 7, and translates it into a notional schedule. The process is extremely linear, and the example translates into a 6-month event.

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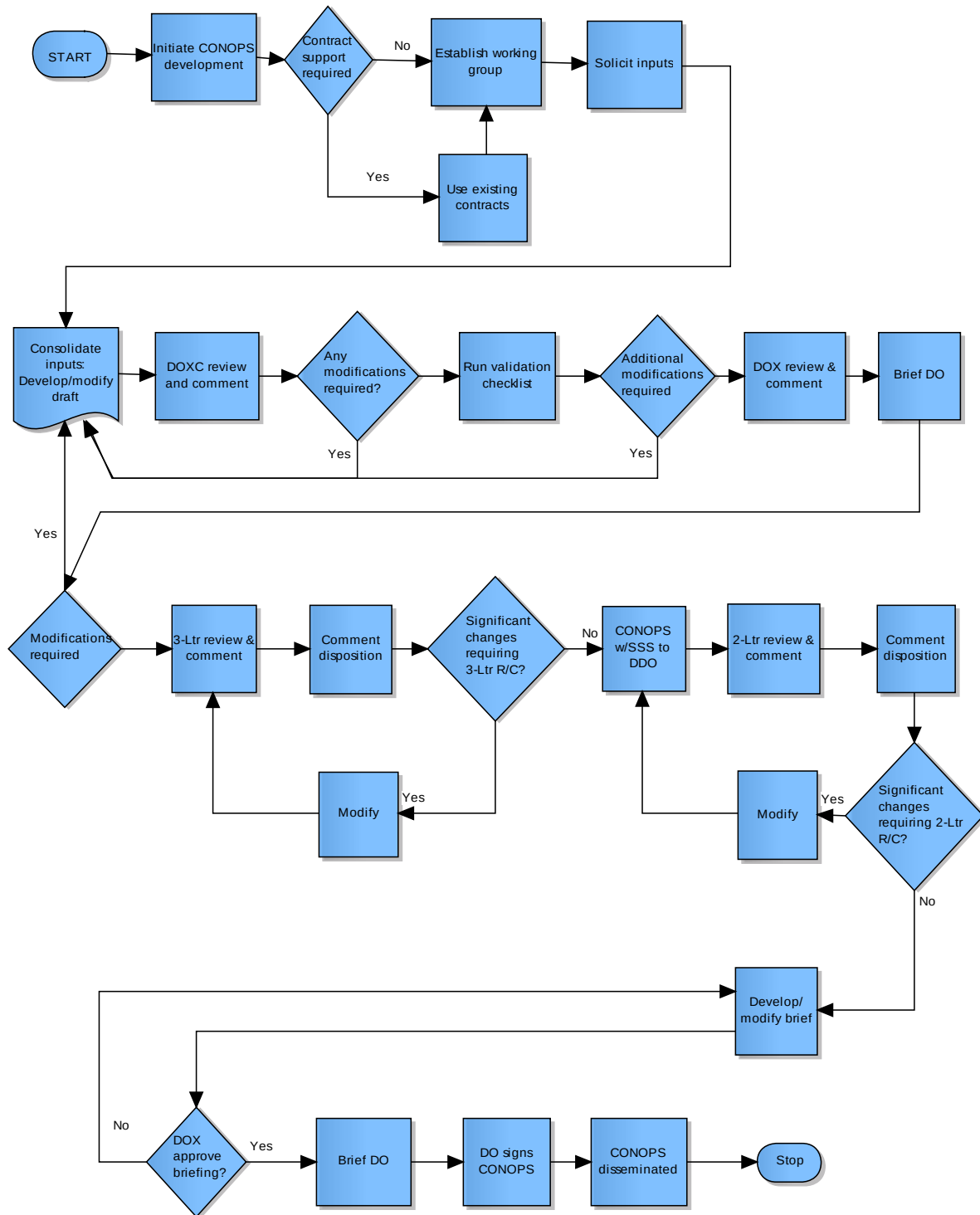


Figure 7: Air Force Space Command CONOPS Development Process

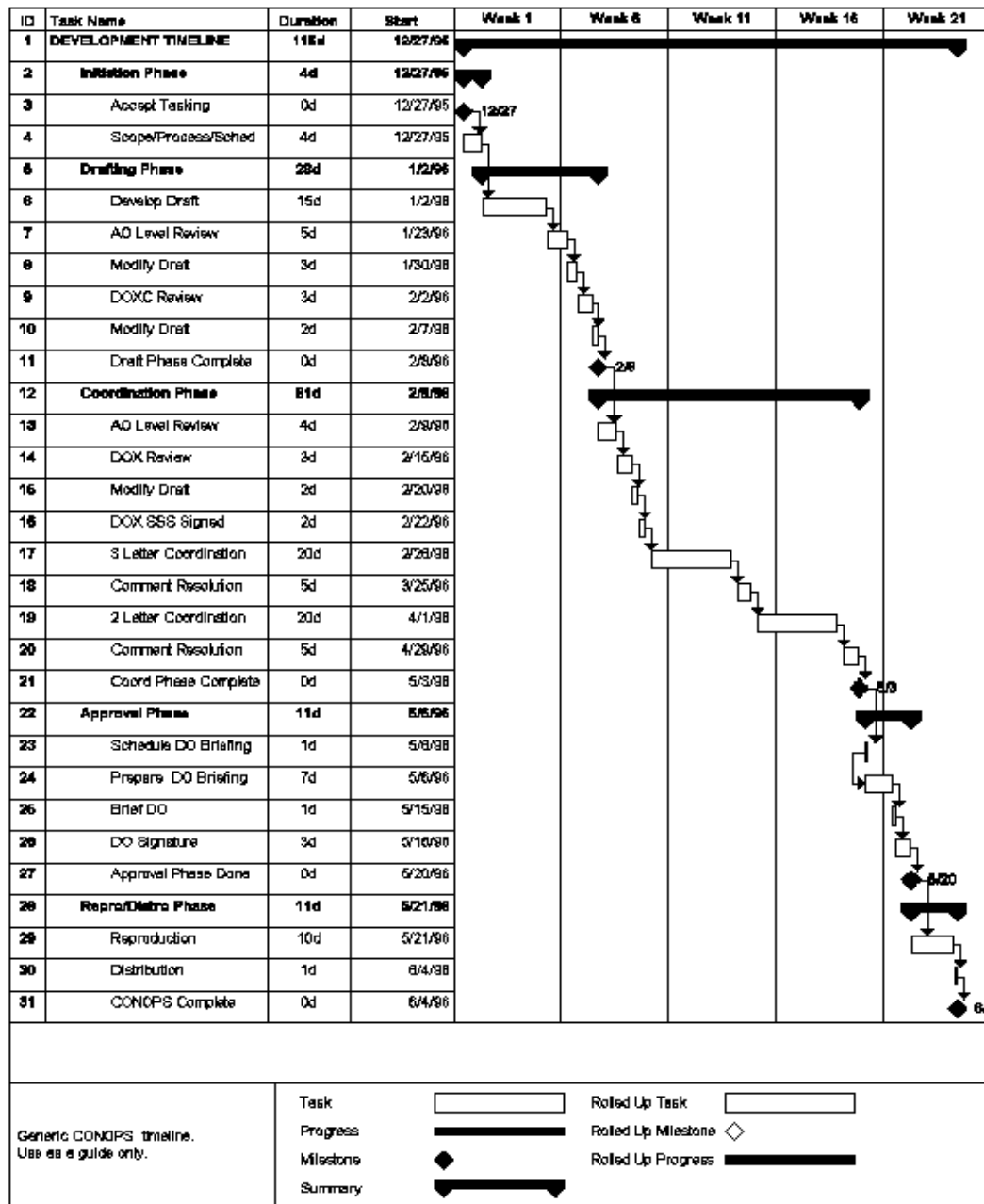


Figure 8: Air Force Space Command CONOPS Process Translated into a Schedule

3.5.2 EXAMPLES OF KEY PRACTITIONERS IN DIFFERENT DOMAINS

In the private sector, a CONOPS² is not usually created in a formal document at the initiation of a program, but rather evolves over the program lifecycle either through tribal knowledge within the project organization, or piecemeal in a number of product and project related documents. A formal CONOPS is usually written late in the development cycle after a system is up and running and just before initial deployments (often Beta quality products) are made. This CONOPS is usually written as a transfer of knowledge between engineering, product management and the service organization which is responsible for the installation and maintenance of the system. One project phasing approach used in the computer industry consists of internal alpha releases of products to test functionality and performance; followed by limited external Beta releases that test the manufacturing, delivery and installation processes; followed by ramped up full scale production. Since a formal CONOPS is not usually created and validated until late in the development cycle, operational issues are often found late.

The artifacts from CONOPS work that are completed early in the development cycle often find their way into Product Requirements documents or Product Architecture and Design documents, often as a high-level overview description of operation primarily to provide context for the product, architecture or design details. An evolving view of the operation of the system is usually developed by interactive discussions between the architects, designers and verifications/validation teams. Occasionally this information is documented in development and test plans. In any case, the CONOPS is generally an informal, evolving set of specifications. Disconnects between the evolving system operation and the original intent of the product marketing organization, or business team occur and can be quite expensive in terms of product delay, product functionality and quality issues, and development inefficiencies.

The following are a few examples of programs with widely varying results. It should be noted that a formal CONOPS was not created in any of these cases, but rather shared mental models about the operation were created through discussion and disseminated in a number of different documents.

² Note, the term 'CONOPS' is not used in the private sector, but is used here to avoid confusion.

3.5.2.1 SUN MICROSYSTEMS “SERENGETI” SERVER DEVELOPMENT

In 2001, Sun unveiled a new line of mid-range servers, code named “Serengeti”, based on the UltraSPARC III microprocessor. This included 8-way, 12-way and 24-way rack mounted systems. This was very much an engineering driven development process and the product evolved based largely on technical tradeoffs rather than value attributes. While the system did not meet its aggressive schedule, it was technically a sound product. Unfortunately, none of these systems had the same form factor as the hugely successful 14-way Enterprise 4000 (introduced in 1996) and the 4500 (introduced in 1999). As a result, Sun lost the opportunity to capitalize on an extremely large upgrade opportunity. While attempts were made to create a server with the form factor of the 4000 and 4500 using Serengeti parts, this was an effort that came too late. In this case, not having a concept of operations which included the value of a common form factor for the upgrade of systems resulted in a dramatic loss of value for the delivered system.

3.5.2.2 SUN MICROSYSTEMS “EAGLE” SERVER DEVELOPMENT

In an attempt to avoid the engineering driven issues of Serengeti, the server development code-named “Eagle”, based on the UltraSPARC V microprocessor, and incorporated the development of a Product Requirements Document into the development process. Unfortunately, this was a long and protracted process due to a large extent on conflicts of interests within the organization. In particular, there was a lack of clarity on how value would be created in the market, and an unwillingness to make tradeoffs which depended on this knowledge. In addition, those who were responsible for creating the requirements did not have the authority to independently arbitrate on behalf of their host functional organizations. The difficulty in finding available time from those with the appropriate level of authority resulted in delays in meetings and interactive decision making. As a result, decisions were made very slowly, if at all. The net result was that after significant delays the program was canceled in 2004. The gap in products was filled with systems from another manufacturer. While many of the ideas and some of the technology from the Eagle program were carried forward to a follow-on program based on the “Rock” microprocessor, this program was also delayed and canceled in 2009.

3.5.2.3 THINKING MACHINES VECTOR UNIT PROJECT

In 1990, a project was initiated to increase the floating-point performance of the CM-5 supercomputer by a factor of at least 10x to be deployed in volume in less than 2 years. This project included the development of new hardware, OS extensions, run-time system modifications, math-library development and new application code. There was great clarity on the value of the project for the CM-5 customers. A number of concepts

for the product were explored and discussed across the company. Being a start up, there were a limited number of internal stakeholders all of whom also had the authority to make decisions for their organizations. Rather than creating textual descriptions of the evolving concepts, executable models were created which provided the necessary representations of the concept, architecture and implementation to the appropriate stakeholders and development and support personnel including hardware, software, application and service support staff. Commitments were made between each organization as the concepts evolved and were translated into the architecture and implementation. The new result was that the system was delivered within two years, performed as expected and had a very long life in the field (over 10 years in some installations).

3.5.2.4 RIO GRANDE STUDIOS

Rio Grande Studios is a fully digital studio located in Albuquerque, NM. When dealing with investors for a new project, they create a 10-12 minute "movie" of the project in 7-10 days with 2-3 people. It is built using software that leverages a module library of items that can be put into motion. Figures 9 and 10 are examples of the types of capabilities available in Storyboard Lite. Useable objects include landscape, people and objects. The software then puts the scenario into motion. Other popular tools used include Autodesk Maya, and FrameForge Pre-viz Studio³. While the software requires skilled animators, the same is true for any modeling environment today. One does not sit down to a CAD program without extensive training.

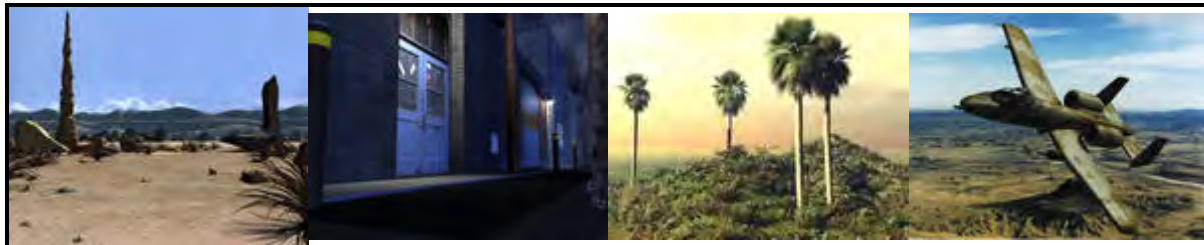


Figure 9: Computer Generated (CG) Graphics⁴

The purpose of the short movie is to develop a shared vision of where the larger project is going. The stakeholders of this shared vision include the director, the screenwriter, major investors, producer, and even the key cast.

³ <http://www.frameforge3d.com/newsite/>

⁴ <http://venicedna.com/>

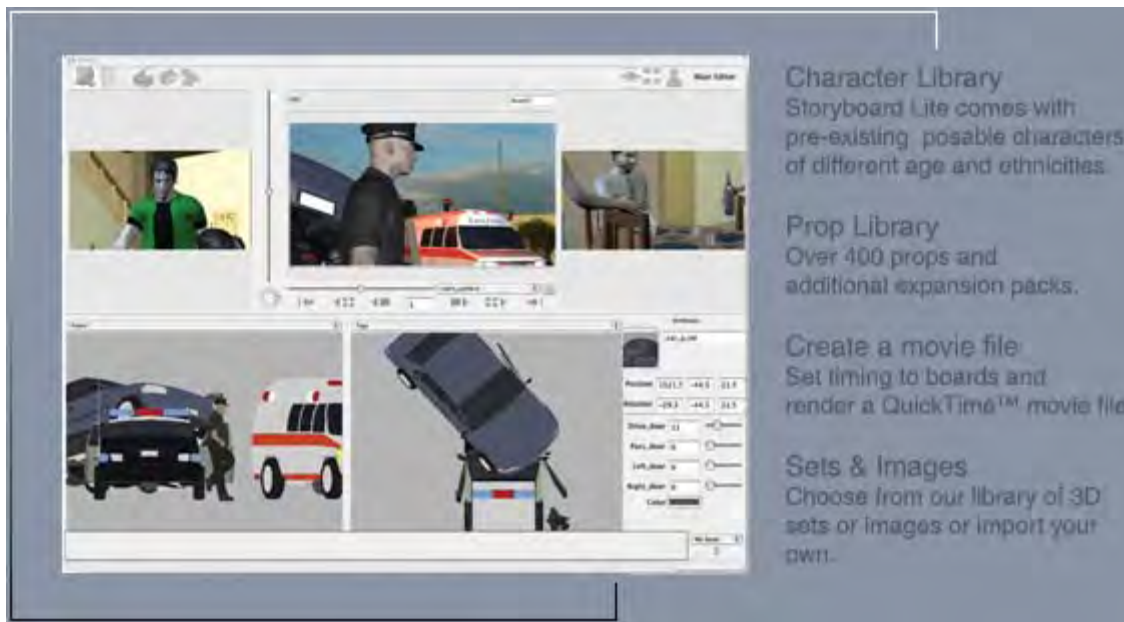


Figure 10: Software for Creating Movies from Modules – Storyboard Lite⁵

3.5.2.5 INNOVATION & DESIGN COMPANIES

There are a number of successful innovation and design organizations such as IDEO, Frog Design, Applied Minds and the like which specialize in the business of creating design concepts for customers in a number of diverse fields. While each of these companies have distinctly different personalities, each of them rely upon getting a deep understanding of the value proposition through interaction with the end customers and/or questioning their customer's understanding, active brainstorming sessions with multidisciplinary experts who are accustomed to working together, and rapid prototyping of ideas. This approach addresses many of the challenge areas for CONOPS development.

First and foremost, these firms strive to understand the ultimate value proposition from the end users perspective. Second, they translate conceptual decisions into easily perceivable attribute often through the use of rapid prototyping. Next, they augment the ability to form shared mental models amongst people with diverse capabilities and backgrounds by forming studios or teams of people that work well together and have formed the means for effective communication. Finally, they are outside firms and are largely devoid of the conflicts of interest that often plague organizations – they are only looking for the solution that creates the most value. However, this independent view

⁵ <http://www.zebradevelopment.com/index.php>

can be compromised by who in the customer organization is judging the success of the project. At the end of the day though, market success determines the success of the projects, and the innovation and design companies with the most successful projects tend to flourish and those that don't often fail.

3.6 IDENTIFIED CHALLENGES IN CREATING CONOPS

Several common challenges can be derived from the conducted research and interviews. Despite the negative impact and high level of risk incurred by not having a consistent view of the CONOPS for a system throughout the lifecycle, it is difficult to create an effective one due to a number of important challenges. One of the major challenges is that the development of a CONOPS often involves making tradeoffs in a large, highly dimensional, complex trade space with stakeholders from multiple disciplines. This is a difficult task for the following reasons:

1. **Value Proposition:** There is generally a great deal of uncertainty in the value proposition for the system due to changing market and competitive conditions. Thus, it is challenging to translate system attributes into realizable value.
2. **Translation of Concept Decisions into System Attributes:** Even with a common understanding of the value proposition space, it is often very difficult to translate a myriad of concept decisions into the impact on the attributes of the system that are pertinent for the creation of value.
3. **Shared Mental Model Capability:** With a group of stakeholders from multiple disciplines, it may be very difficult to create consistent shared mental models or even to have the ability to determine the existence of inconsistencies in the mental models that do exist. Unfortunately, these inconsistencies are often found much later in the system lifecycle.
4. **Human Dimension:** The human dimension generally manifests itself as conflicts in how the relative costs and benefits of a decision are distributed to the stakeholders. This is an area where reward systems and organizational structures are extremely influential. Another aspect of the human dimension is the delaying effect. This may manifest itself in the form of engaging in delaying tactics as a method to avoid conflict, or to stall a decision because the key stakeholders and/or decision makers have differing opinions.
5. **Process Nonlinearity:** The prevalent practice of developing CONOPS has attempted to apply a linear approach to an inherently nonlinear process.

4 ADDRESSING THE CONOPS CHALLENGES

In this section, we present an agile CONOPS process and a graphical CONOPS system. Together, these two components address the aforementioned challenges in a number of ways as we demonstrate in the following:

1. **Value Proposition:** Our CONOPS process allows the CONOPS team and stakeholders to revisit the original concept, conduct risk analyses, evaluate trade-offs, etc. at multiple points throughout the process. At each of these points, current market and competitive conditions can be incorporated to ensure that the value proposition is realized.
2. **Translation of Concept Decisions into System Attributes:** Our graphical CONOPS system will facilitate translating concept decision into system attributes. The graphical interface we envision will provide the CONOPS team and stakeholders with the ability to visualize both the concept and the system attributes, and more importantly, compare them.
3. **Shared Mental Model Capability:** The capability to create shared mental models is enhanced through both our CONOPS process and graphical CONOPS system. The process is designed to help all participants attain shared mental models about the desired future state during the Conceptual Phase, by incorporating the views of all stakeholders throughout the process, and by negotiating to resolve conflicts in real time. The system will include visualization tools (e.g., concept maps, Systemigrams) that facilitate shared mental model development.
4. **Human Dimension:** By incorporating stakeholders into the CONOPS process, conflict and delay tactics can be minimized. For instance, CONOPS documents will not wait on stakeholders' desks until they have the time to evaluate them since the stakeholders will be actively participating in real time. Through this active participation, stakeholders may be compelled to reach consensus as they feel ownership in the process.
5. **Process Nonlinearity:** The proposed CONOPS process incorporates multiple feedback and feed-forward loops that allow the participants to reconsider their current activities based on earlier decisions and/or new information.

4.1 AGILE CONOPS PROCESS

We propose the following three-stage process for agile CONOPS development:

- Stage 1) Conceptual Phase
- Stage 2) Specification Phase
- Stage 3) Design and Implementation Phase

While in theory these stages are the standard phases used in current CONOPS processes, our process is reliant upon stakeholder input throughout the process (vs. at the end), formally emphasizes the conceptual phase (vs. embedding it as a component of the specification phase), and incorporates feedback and feed-forward loops to ensure that the original intention is not lost (vs. a primarily linear approach that may diverge significantly as the process evolves). In addition to these improvements, we have designed a robust process that is applicable to a wide-array of CONOPS, across disciplines, and throughout a product/process life-cycle.

4.1.1 STAGE 1 – CONCEPTUAL PHASE

Figure 11 shows the conceptual phase and related tools and methods. The CONOPS process essentially begins with a perceived need that is expressed either through formal channels (top-down) or informal channels (bottom-up). It ultimately results in a decision to proceed with a CONOPS for a new system, for modifications/upgrades of an existing system or for establishing operational strategy. The core team can then use stakeholder participation heuristics and frameworks such as the PLP (Participation Level Points) heuristic and the SPK (Stake Power Knowledge) framework introduced in Appendices A and B to identify the optimal level of participation and the relevant stakeholders for collaborative development of the CONOPS. The needs, interests and perspectives of the stakeholders can then be mapped using initial surveys and interviews. In joint sessions with all stakeholders the problem definition is refined and the desired state future state of the system is mapped. Once this iterative process has resulted in a shared mental model, the desired future state is refined at a conceptual level and the group can proceed to the specification phase. The conceptual phase is an important phase as many organizations rush into the specification phase without a clear agreement on the situational analysis. Table 8 also shows the set of tools and methods that can be leveraged at this stage to increase the effectiveness of the process.

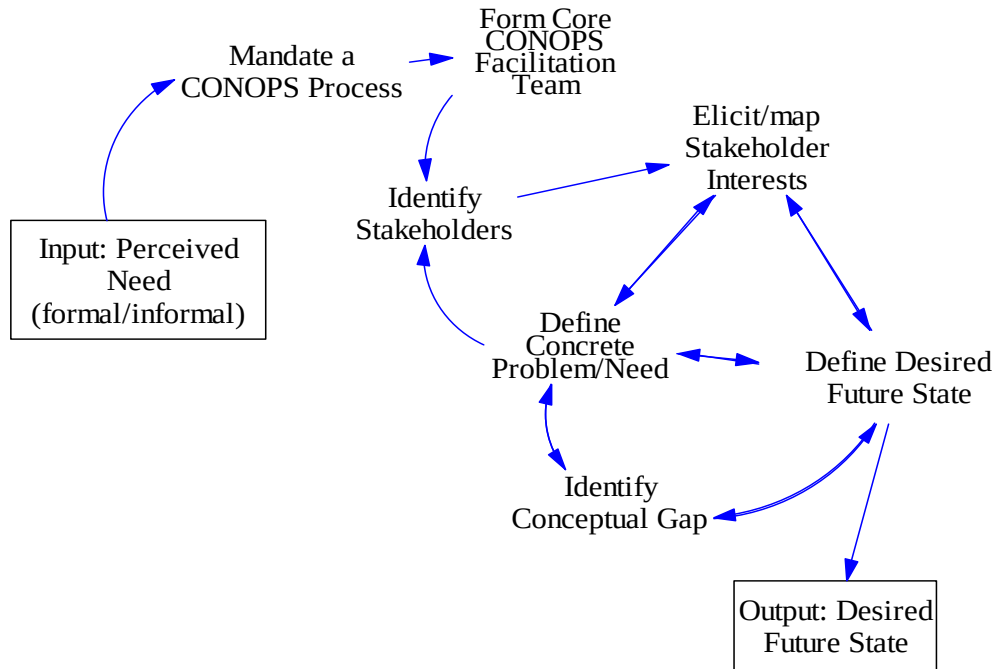


Figure 11: Stage 1 Conceptual Phase

Table 8: Stage 1 Conceptual Phase Process Steps, Tools, and Methods

CONOPS Process Steps	Tools	Methods
Mandate CONOPS	Web-based Templates	Objective Statement
Form CONOPS Core Team		SPK Framework
Identify Stakeholders	Web-based Heuristic	SPK Framework
Elicit Stakeholder Inputs	Surveys, Interviews	Discourse Integration, Contextual Analysis, Data Analysis
Conceptual Situational Analysis (Define problem/define desired state/identify gap)	Visual Tools (Modular/lego, storyboarding, causal loop diagrams etc.)	Brainstorming, Consensus seeking, Shared Mental Models, traditional research methods etc.

4.1.2 STAGE 2 – THE SPECIFICATION PHASE

Taking the output from Stage 1 and identifying any new stakeholder groups that need to be involved, stakeholder requirements are mapped and a trade-off analysis is conducted to assess the feasibility of the requirements serving as a basis for negotiations between the user community, the developers and the decision-makers on desired future specs and their prioritization. Comparing the desired future specs with existing specs/capabilities allows the participants to identify the gaps, gather technical data, conduct risk analyses on features of the desired future state and finalize the detailed

specs/requirements of the desired future state of the system. A variety of methods such as discourse integration, contextual analysis, data analysis, utility theory, multi-attribute Trade-off analysis, Consensus Seeking Negotiations, Group Brainstorming, Consensus seeking, Shared Mental Models, Traditional Research methods, Risk Analysis etc. can be leveraged at this stage to get to the final spec/requirements output for the desired future system. Figure 12 and Table 9 show this iterative process and the tools and methods that can be used at each step of the process.

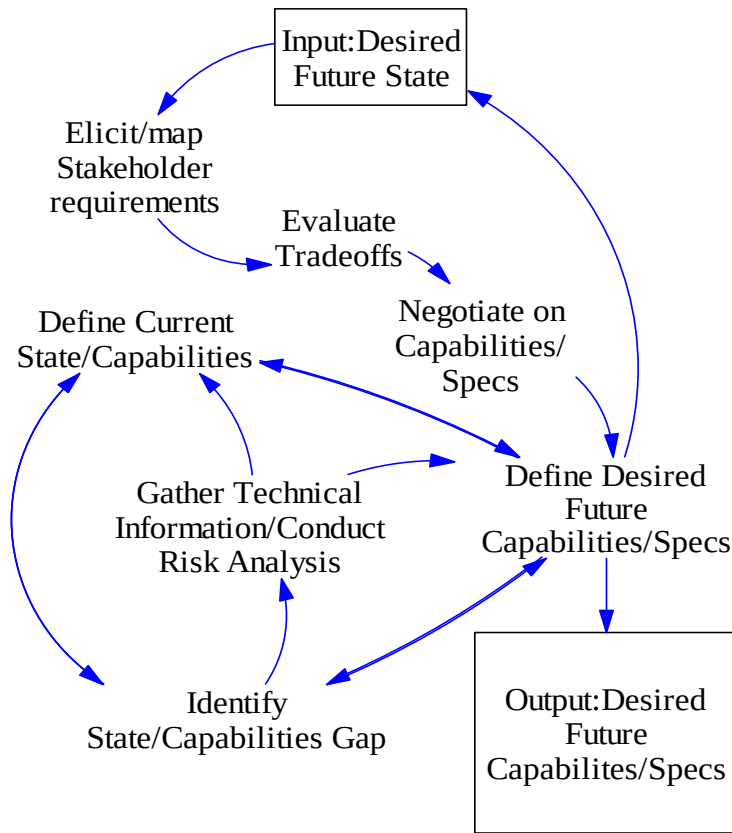


Figure 12: Stage 2 Specification Phase

Table 9: Stage 2 Specification Phase Process Steps, Tools, and Methods

CONOPS Process Steps	Tools	Methods
Elicit/Map Stakeholder Technical Requirements	Surveys, Interviews, Face-to-face discussions	Discourse Integration, Contextual Analysis, Data Analysis, Utility Theory
Evaluate Tradeoffs (Capab/Specs)	Multi-attribute Decision-support Tools	Multi-attribute Trade-off analysis
Negotiate on Capabilities/Specs	Model-based Negotiation Tools	Consensus Seeking Negotiations
Technical Situational Analysis (Define current sit/define desired cap-specs/identify gap/risk analysis and information gathering)	Visual Tools (Modular/Lego, storyboarding, simulation tools etc.)	Brainstorming, Consensus seeking, Shared Mental Models, traditional research methods, risk analysis etc.

4.1.3 STAGE 3 – DESIGN AND IMPLEMENTATION PHASE

In the final stage the inputs from the specification phase serve as a basis to identify the detailed system components and interfaces needed to achieve the desired capabilities and identify the exact team that will manage and implement the development/deployment/usage of the system. Using tradeoff analysis to identify priorities in the design and implementation of the desired future system, the overall system architecture and a management and implementation plan can be negotiated among the stakeholders. This again is an iterative process and the cycles end when stakeholders converge on an agreement for the two outputs. Figure 13 and Table 10 show the process steps for this stage and the relevant tools and methods that can be leveraged.

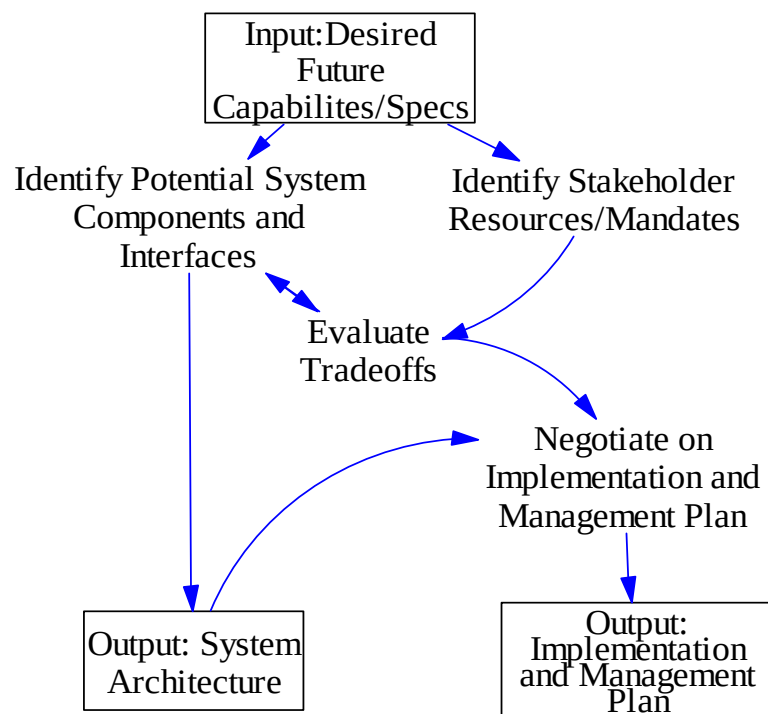


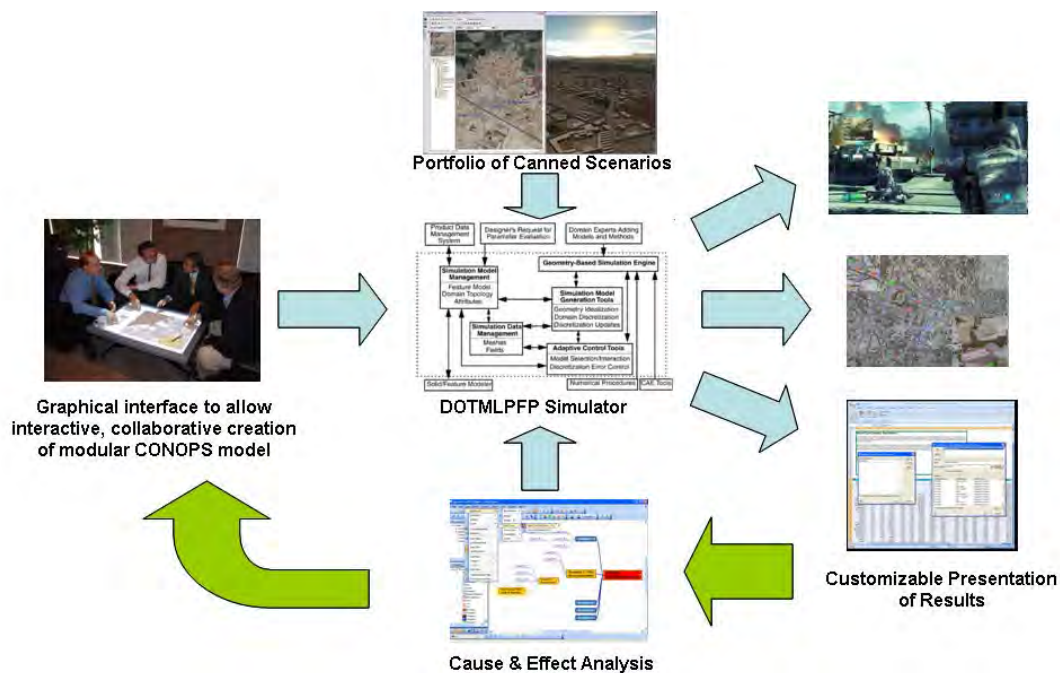
Figure 13: Stage 3 Design and Implementation Phase

Table 10: Stage 3 Design and Implementation Phase Process Steps, Tools, and Methods

CONOPS Process Steps	Tools	Methods
Identify Stakeholders Resources/Mandates	Surveys, Interviews, Face-to-face discussions	
Identify System Components	System-specific and Technical Models	Brainstorming, Consensus seeking, Shared Mental Models, traditional research methods, risk analysis etc.
Evaluate Tradeoffs (Components, Implementation and Management Plan)	Multi-attribute Decision-support Tools	Multi-attribute Trade-off analysis
Negotiate Implementation and Management Plan	Model-based Negotiation Tools, Project Management Software	Consensus Seeking Negotiations, Project Management

4.2 GRAPHICAL CONOPS SYSTEM

While there are a number of interesting and exciting technologies available today to assist in developing a graphical CONOPS, no tools or integrated systems exist that are specifically created for this expressed purpose. We propose developing the Graphical CONOPS System shown in Figure 14. A number of technologies are available to create such a graphical CONOPS tool, and they are discussed in the following sections.

**Figure 14: Representation of Graphical CONOPS System**

4.2.1 USER INTERFACE

A Graphical Concepts of Operation can be created by dragging and dropping CONOPS primitives onto a common visualization palette and defining the interconnections between the primitives via a user interface. Along with a set of standard CONOPS primitives, the users can also be provided with a set of easily customizable primitives, CONOPS patterns, and various test scenarios. CONOPS developments would both leverage previous work and create new models, patterns and test scenarios that may be used for future CONOPS development, both updates and for new systems.

The user interface could involve a small group working on a single Surface Computing (MS) table touch table in which everyone shares the same view (perhaps with a small window for a personalized view). Alternately, each person could use a single mouse (e.g., MS Multipoint) with a large monitor, or could work with the own monitor (with a personalized view) and keyboard with networked PCs with a shared large monitor. Multiple sites can be networked together (albeit with some restrictions to handle potential latency issues) to provide for a distributed development experience. The important aspect of this is that each participant can freely and independently make changes to a single CONOPS model, while sharing a common view and perhaps having a customized local view as well.

The primitives can be represented by smart blocks, such as Siftables, or simple graphical objects. The different strengths associated with each of the interconnections between CONOPS primitives can be represented using interaction modeling technologies, such as those used for physical chemistry to create a model which effectively provides a minimal energy state. The primitives and interconnections are coupled with simulation models and analysis procedures. Creation of a Graphical CONOPS model via the user interface leads to the creation of the integrated simulation and analytical model representing the system under consideration.

4.2.2 3D/2D VIEWING & USER IO

Logo was at one time the tool of choice for elementary education to introduce students to the concept of computer programming using a simple language to cause a tethered “turtle” to move around a room. Over the years, the language has matured to become a serious agent-based programming language. StarLogo TNG⁶ is such a tool. An agent-based program is constructed by assembling lego-style primitives into an executable computer simulation (Figure 15).

⁶ <http://education.mit.edu/drupal/starlogo-tng>

Another potential technology for viewing CONOPS is the Microsoft's Surface Computing touch table (or a number of other similar implementations) mentioned above. This would allow a number of people to simultaneously interact with graphical building blocks to construct a CONOPS. In addition, this could be extended to multiple sites and distributed collaboration with the networking of a number of tables.



Figure 15: StarLogo TNG Modeling Environment

Templates, or patterns, could be used to quickly create new combinations or variants of existing CONOPS. Tapping the blocks could be used to dive deeper into the hierarchy, squeezing could allow you to pop up in the hierarchy.

A less expensive technology to that of Surface Computing, is the Multipoint software development kit (SDK) which can be downloaded to assist in the development process. Using mice as the primary interface will certainly enforce a simple interface with the program. One of the challenges, of course, is avoiding conflicts on the screen (the SDK allows the support of rules, privileges, hierarchy, etc. for collision situations), and keeping it a constructive operation. A collaborative etiquette would need to be developed. Another potential technology is Hubnet⁷ which is integrated with NetLogo.

⁷ <http://ccl.northwestern.edu/netlogo/hubnet.html>

4.2.3 PRESENTATION OF INFORMATION

This system can provide a number of different views, both 2D and 3D. The 2D views can be of an entire system or of a particular layer in a system hierarchy. Moving to a 3D view, various layers in the hierarchy can be presented. What is represented in a particular layer can be selected by each user which enables them to view the system from a number of different vantage points. With multiple screens, a number of participants can each interact with, build and modify the system simultaneously, each from their own perspective. A global view could be presented to all on the large screen on a wall while each participant interacts on their own PC/laptop. An example of such a flexible digital dashboard can be seen in Figure 16, which shows the Composable Digital Dashboard developed at Texas A&M University for situational common operating picture in emergency response situations. Another example of a visualization platform is the EWall system, developed by MIT to assist in group cognitive processes.



Figure 16: Composable Digital Dashboard for Common Operating Picture of Emergency Response Scenario

Finally, each user can have personalized information relevant for the stakeholders that he/she represents on his/her view. This information can be customized to provide users with what they need to see, while the information pertaining to the global good can be viewed on a global screen.

It should be noted that both the CONOPS structure and the simulation outcomes can be personalized for each of the viewers. It might be interesting for the various stakeholders to swap screens and see how the world looks from the others perspectives. Perhaps this could be a mandatory practice during the CONOPS development process.

4.2.4 INFORMATION MAPPING

Information mapping is a technique for analyzing, organizing, and presenting information that is dependent upon the needs and purposes for which the information is being collected. It is routinely used for activities including information visualization, knowledge management, graphic design, etc. The results are considered easy to comprehend, use, and recall⁸.

4.2.4.1 SYSTEMIGRAMS

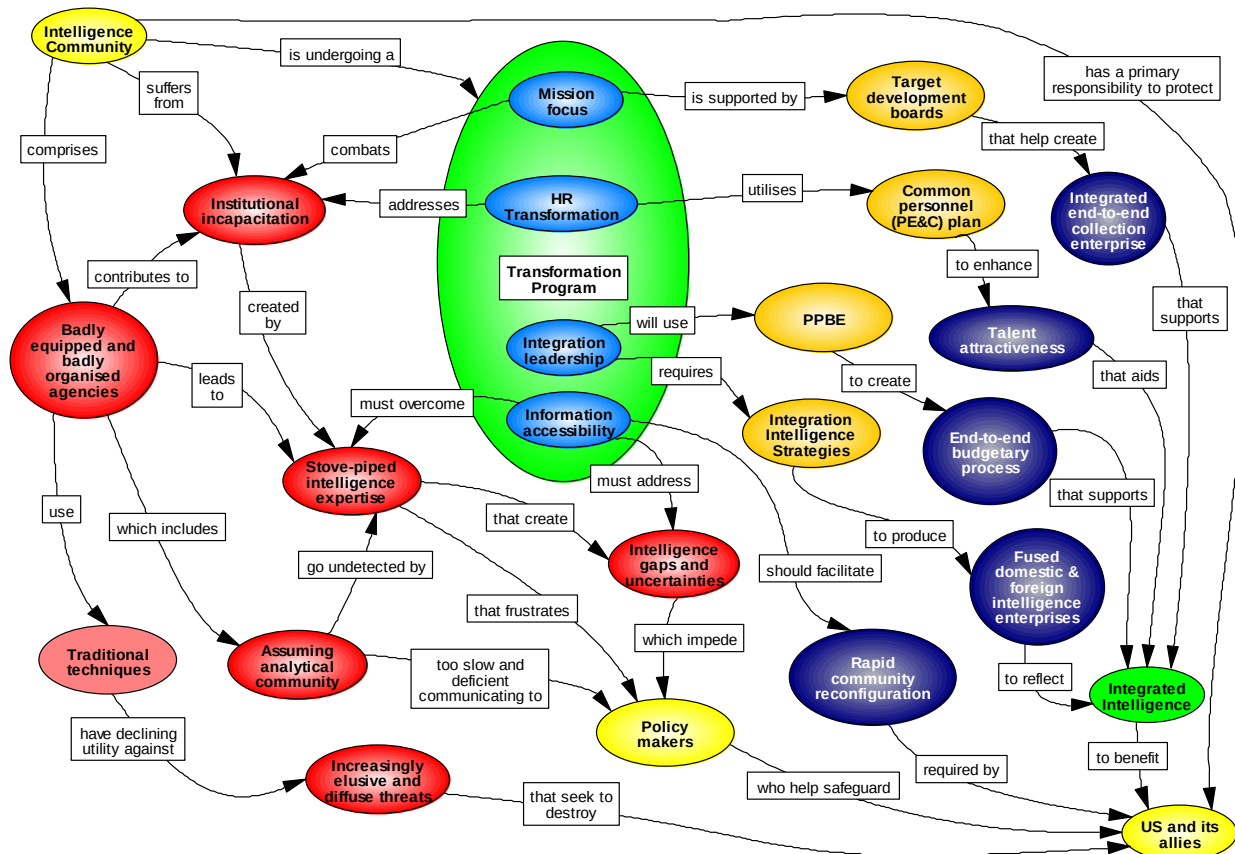
Systemigram is a portmanteau word taken from systemic and diagram. The systemigram is an approach to graphically tell a story, and is very useful in creating a shared understanding of the problem at hand. It is a structured translation of the words and meanings that is reminiscent of sentence diagramming that used to be taught in elementary school, but is much more powerful and easily understood.

The primary sentence (mainstay) which supports the purpose of the system will read from top left to bottom right. Ideally there should be 15-25 nodes (less can make for a trivial system description; more can create clutter and illegibility). Nodes must contain noun phrases, and links should contain verb phrases (to reduce trivial links). There should be no repetition of nodes, and no cross-over of links.

When creating a systemigram, the author works with subject matter experts to dialogue the CONOPS. It is important for the author to remember that the model (systemigram) is really 'theirs' (belongs to the client). All the author does is to present a fresh perspective on their system descriptions with hopefully some added value.

Figure 17 is a representation of an intelligence community, developed by Dr. John Boardman.

⁸ Information mapping. (2009, June 23). In *Wikipedia, The Free Encyclopedia*. Retrieved 18:30, October 24, 2009, from http://en.wikipedia.org/w/index.php?title=Information_mapping&oldid=298063480

Figure 17: Intelligence Community Systemigram⁹

4.2.4.2 MINDMAPS

A mind map is a picture which represents ideas, captured as a combination of words and cartoons around a central thought or concept. It was developed by Tony Buzan in the '70's, and he coined the term "Mental Literacy". Figure 18 is a mind map for creating mind maps.

Mind maps are used to help visualize thoughts or notes as they are developed, providing multiple senses stimulus to improve understanding and recall. Practitioners are encouraged to use multiple colors, graphics, etc. For the more computer minded, there are tools such a Mind Manager¹⁰ and Personal Brain. Figure 19 is a project scope definition example from Mind Manager.

⁹ <http://www.boardmansauser.com/thoughts/systemigrams.html>

¹⁰ <http://www.mindjet.com/>

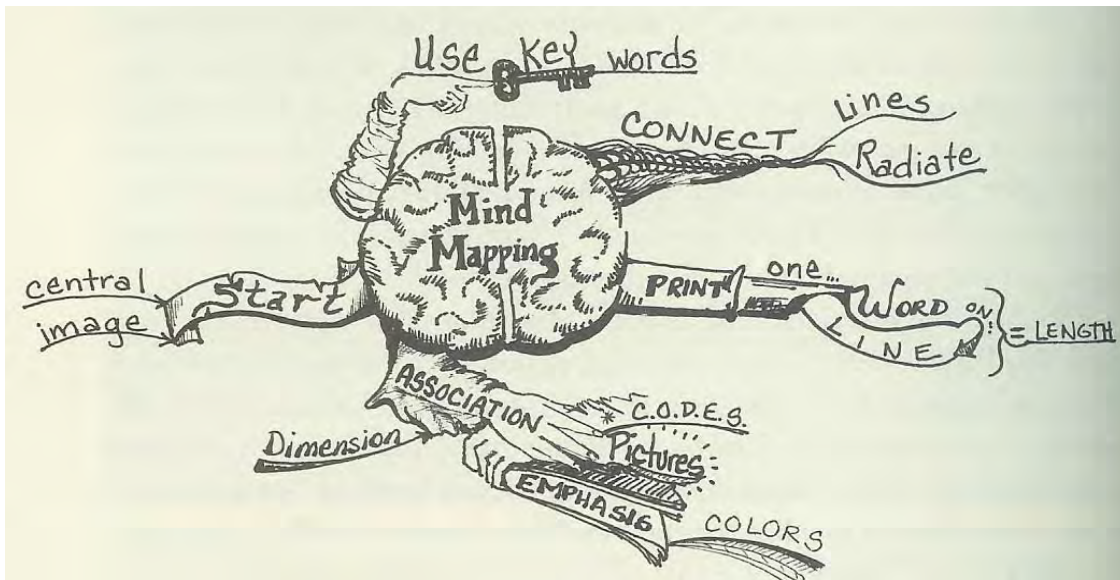
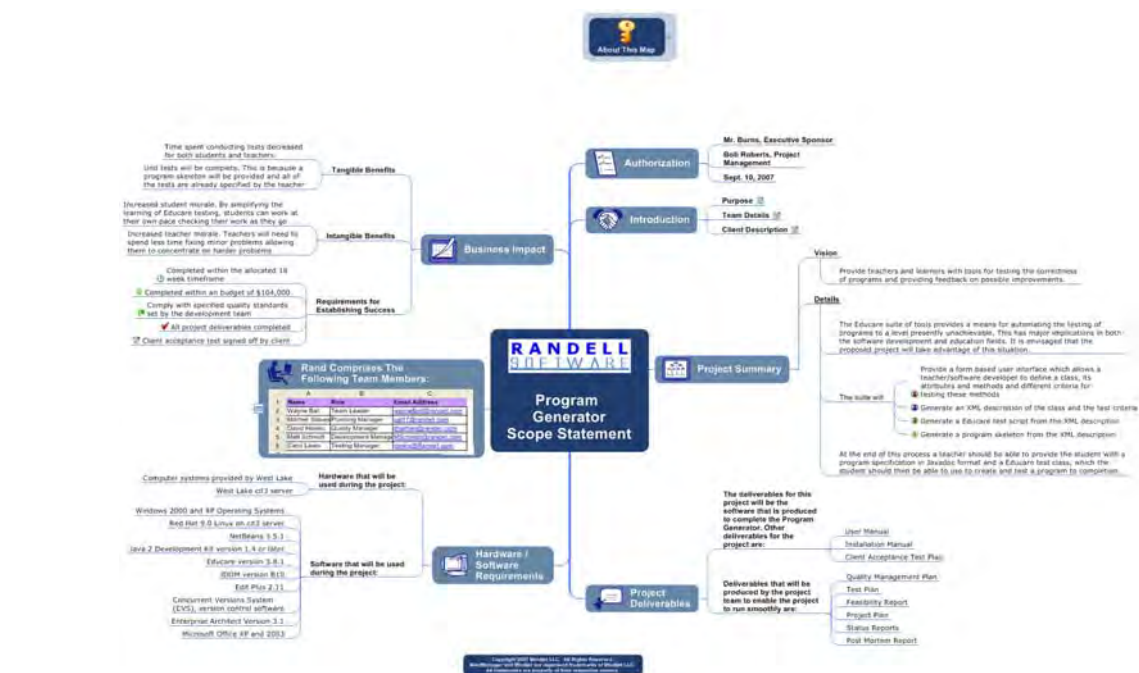
Figure 18: Mind Map on how to Mind Map¹¹¹¹ Michael J. Gelb, How to Think Like Leonardo Da Vinci, p 174,183.

Figure 19: Example Mind Map from Software

4.2.4.3 CONCEPT MAPS AND STORYBOARDING

Concept maps allow for the graphical representation of concepts using nodes to represent information pieces, and arcs to represent the linkages between the nodes of information. They are often used to develop and document mental models. Much of the research to date has focused on structural similarity when the nodes are given to the study participants. Concept maps may be a valuable tool for CONOPS if stakeholders are allowed to provide their own nodes in at least 3 ways. Specifically, they will: (1) help the stakeholders develop a common language, (2) facilitate making linkages among key concepts, and (3) enable the establishment of shared mental models.

Concept maps could be used to help create, communicate, and refine CONOPS information. The tool helps to represent the information visually, integrate it with storyboard sketches, refine it through interaction with other stakeholders, and finally export the information in a form directly usable by developers. Currently it is possible to create two dimensional and three dimensional animated storyboards using Photoshop, AfterEffects, 3D Studio Max or Maya that animate realistic, technically and physically accurate, modern-day military scenarios for CONOPS presentations.

4.2.4.4 TREE MAPS

Tree maps display hierarchical (tree-structured) data as a set of nested rectangles. Each branch of the tree is given a rectangle, which is then tiled with smaller rectangles representing sub-branches. A leaf node's rectangle has an area proportional to a specified dimension on the data. (In the illustration, this is proportional to a waiting time). Often the leaf nodes are colored to show a separate dimension of the data¹².

When the color and size dimensions are correlated in some way with the tree structure, one can often easily see patterns that would be difficult to spot in other ways. A second advantage of treemaps is that, by construction, they make efficient use of space. As a result, they can legibly display thousands of items on the screen simultaneously.

4.2.4.5 MAP OF THE MARKET

The Map of the Market is an example of a treemap. The map is a graphical representation which tracks the stock market action for over 500 US based stocks. Developed by Martin M. Wattenberg, a scientist and artist known for his work with data visualization, it is based on a modified treemap algorithm. Each rectangle on the map

¹² <http://en.wikipedia.org/wiki/Treemap>

represents an individual stock. If the color is green, the stock is up. The larger the box, the larger the market capitalization that stock represents. This becomes a quick and easy way to see what sectors and stocks are causing the stock market to move. A snapshot of this graphical representation can be found in Figure 20.

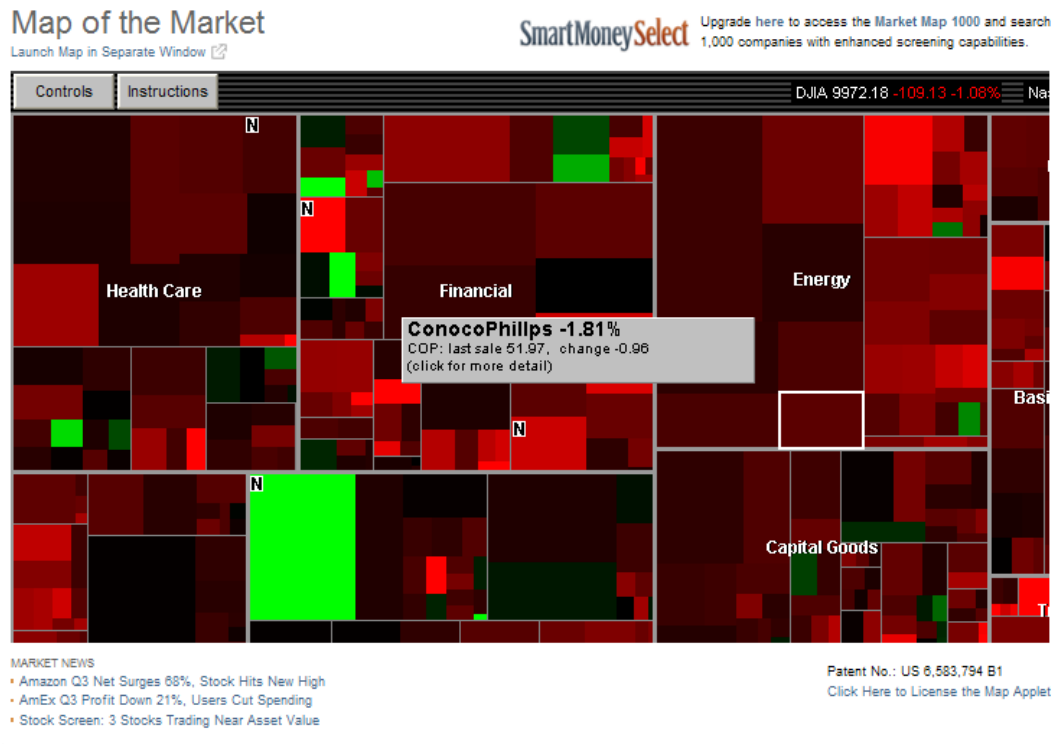


Figure 20: Map of the Market

4.2.5 CONOPS SIMULATION ENGINE

The CONOPS simulation engine will have the ability to run forward and backwards in time, with specified amounts of accuracy, as well as a given amount of predetermined time-steps (generally specified in terms of amount of storage allocation and fidelity). It will also be possible to set trap conditions to stop execution and trace back on the events that caused the trap condition to occur. This tracing mode will be useful in determining event causality.

The simulation engine will normally run in interpreted mode, such that the simulation can be stopped, changes can be made (within a finite range) and the simulation can be started again without a lengthy recompilation. One mode of operation is to run a set of test scenarios and upon failure, trace back to the root cause, make the necessary corrections and run from that point forward to determine if the problem is fixed or it causes other failures. The development of test scenarios can be likened to Test Driven

Development (TDD) or the development of requirements. As the team gains experience with the CONOPS, the test scenarios can be updated and enhanced to better illustrate the desired behavior.

Another interesting aspect of the simulation coupled CONOPS would be to create a retrospective study of how the system designers reacted after seeing the performance of their proposed configuration (it will help the cognitive scientists gather first hand data on their preferences, utilities, etc). This might allow one to see blind spots in group behavior in which a repetitive set of responses are made without other productive approaches. The system would have access to all of the information input into the system, and audio/video information could be recorded as well. The system could very well be used as a trainer for personal and team development.

4.2.5.1 SIMULATION ENGINES

It is believed that simulators can be broken into two distinct classes – Immersive Experience and Simulators.

An Immersive Experience environment can be thought of as one which provides the user (game player) with the ability to have an immersive experience that mimics real life. These tend to be physics-based systems that simulate a human operating a machine (flight simulator, tank battle, etc.), or human avatars. These can be systems with a single player, one with a single player and computer controlled other agents, or multiple agents. Second life and the many multi-player gaming environments are examples of these.

The behaviors of the agents tend to be simplified and the effort is placed in creating a realistic environment in which the player can engage. In the second type, the effort is in creating an accurate simulation of complex processes and the realism of the environment is secondary.

Immersive environments tend to be very impressive. They can be very high definition and photorealistic, but may require significant time, effort and cost. Proving that one can create an interactive environment which models sufficiently complex systems quickly and to the required level of fidelity is likely to be where the challenge lies in these systems.

Simulators are not intended to provide a real-life experience for a player, but rather provide a simulation of how a component or system might behave. This has the advantage that rate of time change is a variable that can be modified dependent on the desired results. Finite-element analysis, weather modeling, etc. are examples of these. Other examples are system simulators which include both hardware and software subsystems and components.

For graphical CONOPS, it is likely that the simulator type of visualization is most appropriate, with the focus on ease of changing the behaviors and interactions between the agents. The AADL language appears to be aimed at this target in the modeling of HW/SW systems. Little Jil from UMass is targeted at doing this for the modeling of processes. Other languages, such as SysML, UML, and the like may also be appropriate for graphical CONOPS.

4.3 SALIENT FEATURES OF OUR ANSWER TO THE CONOPS CHALLENGES

The CONOPS Process and Graphical Operation we have presented address the challenges we identified through our assessment of CONOPS documents and interviews with practitioners familiar with the CONOPS process. They have several salient features that include:

1. Involving relevant stakeholders in all phases of the CONOPS development.
2. Developing a system that facilitates easy visualization and agile modifications by large numbers of stakeholders with varying roles.
3. Assisting shared mental model development throughout the three process stages by leveraging an integrated toolset that enables stakeholder participation.

4.3.1 STAKEHOLDER INVOLVEMENT

Agile CONOPS development requires active stakeholder participation from the beginning, not just after the fact. While this notion is commonly understood, it is often overlooked in practice. In much of the research we conducted, stakeholders were involved *after* the preliminary set of CONOPS documents were completed rather than *during* the process as we propose. If the right stakeholders are chosen and incorporated into the process, the advantages are:

- Users, developers and other stakeholders can discuss the conceptual need for a system, negotiate requirements, and coordinate design, development and implementation in an interactive manner.
- Stakeholders can help the CONOPS team decide which steps can be skipped in the CONOPS process without compromising quality.
- The CONOPS can be developed much faster in a few joint sessions conducted in person or through virtual meetings.
- The risks with systems implementation and costs can be better estimated having most of the relevant stakeholders at the table.
- A shared mental model emerges during such meetings that can help the success of the system during development and implementation.

- Feelings of ownership evolve within a wider community across the organization(s).

4.3.2 AGILITY AND VISUALIZATION

While text based CONOPS have been traditionally used, they have several limitations when used in multi-user, distributed settings. For example, editing text documents collectively and interactively is difficult. Furthermore, text based CONOPS cannot be easily tailored to be of use to different roles within the system. A graphical CONOPS can have the following advantages:

- Ease of access to various sections by different stakeholders
- Simultaneous editing possibility for various stakeholders in interactive sessions
- Ease of reaching a shared mental model among stakeholders
- Modular, easily modifiable format
- Can be mined later to create standard text documents
- More intuitive for later referencing

4.3.3 SHARED MENTAL MODELS

Shared mental models play a critical role in all stages of the CONOPS process. Shared mental models, however, are not generic. Rather, they contain specific content that is dependent upon the purpose of the particular phase, or even of the particular step in the phase. For example, much of the *Conceptual* phase requires developing an action-oriented plan where task-relevant content must be shared in order to ensure that all perspectives are accounted for in the description of the desired future state.

Alternatively, the various negotiation steps within the *Specification* and *Design and Implementation* phases may be considered cognitive conflict tasks (McGrath, 1984). As such, shared mental models addressing each team member's/stakeholder's point of view may be necessary to devise a feasible plan suitable to all parties. For a more comprehensive description of shared mental models, see Appendix C. Regardless of the content, the CONOPS process we developed will help expedite the creation of shared mental models. Quickly creating shared mental models will benefit the CONOPS process in several ways including:

- Establishing consistent perspectives that will govern activities throughout the various stages
- Reducing the overall time to develop CONOPS
- Minimizing problems due to misunderstandings that often occur toward the end of CONOPS
- Ensuring that the customers get the product/process that meets their expectations

5 RECOMMENDATIONS FOR FUTURE RESEARCH

The following are a set of the greatest challenges to the implementation of the graphical CONOPS system. Each of these areas represents primary areas for future research. The sections below describe some of the work that can be done in a modular approach.

5.1 DEFINING THE BUILDING BLOCKS FOR A GRAPHICAL CONOPS

To rapidly build a graphical CONOPS using some form of automated tools, a collection of primitives and building blocks, and a composition language are critical. An open question is how many primitive types are required to model an appropriately detailed CONOPS and at what level of complexity should they be constructed for optimal use. If a reasonably small number of primitives are created, will there be an unacceptable amount of work necessary to build them up to represent useable concepts? Can the interfaces be standardized sufficiently to permit the use of on-the-fly use? The CONOPS analysis indicated 3 different classes of CONOPS: 1) Development of a New System, 2) Modification/ Upgrade/ Change to Existing System/Product, and 3) Operational Strategy (which may also include end of life activities). However, the interviews indicated a different set of CONOPS classes: Products, Continual Services, and Customized Responses. Will each of these classes of CONOPS require different primitives or are they likely to be similar? Further research should be conducted to address this question.

The tasking in sections 5.1.1 and 5.1.2 could be done iteratively, decomposing one class of CONOPS first, and understanding the necessary primitives, semantics and building blocks before moving to another class of CONOPS - each iteration building on the previous iteration. The investigation could also be parsed by CONOPS domains if desired.

5.1.1 CONOPS DEFINITION, DECOMPOSITION, & PRIMITIVE DEVELOPMENT

The first step of creating a graphical CONOPS toolbox would be to identify and create a base set of core primitives which would then become the building blocks for more complex functions and actions. To do this, a consistent taxonomy of CONOPS terms and definitions should be created. This collection of terms and definitions will then be used to define core primitives and objects, their attributes and actions, in a generic and reusable form for a tool based approach. This would entail the decomposition of a representation CONOPS and the development of a set of primitives necessary to most efficiently and effectively model it. Examples of initial primitives may include move,

communicate, engage, observe, decide, change, etc. Core objects will include items such as vehicle, person, organization, etc. Each of these will have definable attributes and actions.

The use of OWL (Web Ontology Language) tool should be considered as part of this effort to provide information interchange into and out of the ontology as requirements emerge.

5.1.2 CONOPS PRIMITIVES LANGUAGE SUPPORT

Next, a small set of representative CONOPS would be decomposed to determine the additional semantics and syntax to tie the primitives into a language that will form the basis for simulation. This would entail an investigation of potential computing languages to represent the graphical CONOPS, while understanding the capabilities of potential design, debug and simulation support. In addition, this would include potential language and tool extensions.

5.2 MENTAL MODEL CONTENT

Further investigation is needed to ascertain the mental model content most appropriate for each phase of the agile CONOPS process. It is believed that multiple mental models will exist simultaneously and the most relevant ones will be task dependent. By conducting cognitive task analysis on the aforementioned small set of representative CONOPS, we can (1) understand the cognitive demands of the CONOPS process, (2) determine similarities and differences across the set of CONOPS studied, (3) identify a set of shared mental models that will aid the team in expediting the agile CONOPS process, and (4) work closely with the graphical CONOPS developers to ensure that the interface is designed in a manner that facilitates the development of the identified shared mental models.

5.3 PROOF OF CONCEPT DEMONSTRATOR

It is believed that it should be possible to create a proof of concept that will demonstrate a graphical CONOPS capability to a sufficient level using an existing tool such as StarLogo TNG or Microsoft Surface Table, or even Siftable Blocks. This would be a proof of concept of the primitives/building block approach to visualizing a CONOPS. An example of this approach is to decompose a portion of a CONOPS such as the Noncombatant Evacuation Operation: Red Cross Rescue Scenario CONOPS into block primitives as described above. Once defined, a proof of concept simulation could be built and demonstrated.

It would be necessary to determine which technology would be used to accomplish this task early. It is probably less important which technology is used, and more important to produce demonstrator to further the learning on graphical CONOPS and its usage.

5.4 ABILITY TO DEVELOP SHARED VISION

In the arena of shared vision, it remains to be proven that users working with the approach proposed in this study will be able to create a shared vision in less time than using conventional methods. Games can be enlisted as metaphors to see how well this might be accomplished. Having the ability to see outcomes through one's own lens and that of the overall group might make it easier for people to make the necessary tradeoffs for the common good. The ability to develop shared vision should be evaluated through the use of early prototyping and experiments.

This effort can be accomplished using both students and practitioners to acquire the necessary knowledge and data. Additional work will be necessary to design the scenarios and experiments to provide useful and meaningful data.

5.5 ON THE FLY SIMULATION

One challenge is the ability to create integrated concept simulation models based on the primitives, semantics, and syntax using a graphical CONOPS language. Another key challenge would be to change the model on the fly and restart simulations. A key constraint on the modular simulation environments is that all the potential interfaces between the modules are pre-envisioned. However, if new connections that are not previously envisioned are created the outcome of the simulation may not be predictable.

For instance, ThinkCAD (the homegrown LISP-based tool that was used at Thinking Machines) was restricted in the sense that functionality could be changed on the fly during simulation (discussed in the next section), but structure could not. However, there was much that could be done even within these constraints. For example, one could change the policies by which decisions are made and go back in history and rerun. So, much can be done even without the ability to change structure during execution.

The primary issues these environments seem to run into are I/O compatibility and maintaining logical consistency. The key future research question for on the fly simulation of graphical CONOPS is the ability to allow an on-line logic checker, in addition to an interpreter or a dynamic compilation capability, to permit creation of new configurations.

This will be one of the most challenging of the tasks, and is dependent on the previous research tasks.

6 CONCLUSIONS

While concepts of operations (CONOPS) are still generated in a textual format, the growth of complexity in the systems and system of systems we use today will make it ever more difficult to grasp mentally. As a simple example, a modern day smartphone today can have in excess of 8 million lines of code (LOC) in the operating system, and over 22 million LOC of application code.

Today's smartphone will serve as a phone, speakerphone, a communicator, portable file storage, a camera, MP3 player, personal information manager, Internet browser, game platform, and GPS device.

That phone will interface with cell towers via a cellular radio, Bluetooth devices via a Bluetooth radio, other USB devices, WiFi connectivity, connection to GPS satellites, and may have an InfraRed (IR) interface. The software will interface with applications on a desktop (Calendar synchronization), file exchange, music player, SMS, FM radio receiver, and Internet access to cloud computing. It will have a camera that is able to take pictures, and then send that picture via email, SMS, or to a connected device.

And yes, it has an interface to the user – a human user – and any two individuals may reason about the same task in totally different ways. Part of the interface can be implemented using hardware in the form of mechanical buttons, and some interfaces will be implemented in software through virtual buttons and displays.

A textual CONOPS does not do a smartphone justice in describing the many ways the phone will be used by the individual. This problem is further compounded as one considers more and more complex systems, with more and more users. But, if one does not create a textual CONOPS, what should be used in its place?

This report demonstrates there is no tool currently available to facilitate an alternative at this point. There are technologies that can be applied toward the desired capability however. This report should form the basis for any further research in developing a graphical CONOPS tool to assist in the visualization of CONOPS.

Finally, the authors would like to acknowledge the contributions of the following individuals: Gunnar Feldman, Research Assistant; Keith Hall, Research Assistant; and Mary Bone, Research Assistant.

APPENDICES

APPENDIX A: THE PLP HEURISTIC

Virtually all Complex Large-Scale Engineering Systems have a multitude of stakeholders and would benefit from some level of stakeholder participation in the CONOPS design process. The core CONOPS team needs to identify what level of stakeholder participation is necessary for the particular system. As a heuristic tool, we have developed the PLP (Participation Level Points) heuristic (shown in Table 11), which links system/stakeholder characteristics with participation levels. The premise of the PLP heuristic is that some problem/system characteristics increase the desired level of stakeholder participation.

The PLP heuristic provides a direction, not an answer. As such, it is always wiser to err on the side of higher stakeholder participation than to settle for lower stakeholder participation levels. If the PLP of a system is 4 or higher, stakeholder participation in the conceptual CONOPS development stage is necessary. If the PLP of a system is lower than 4, then it probably makes more sense to have the core team develop the CONOPS and send it out for review by stakeholders. Given that the different questions in Table 11 do not necessarily carry the same weight in different contexts, decision-makers need to use their own judgment to judge whether this heuristic is appropriate for their particular system.

Table 11: The PLP Heuristic

Step 1: Examine System Characteristics	Yes	No
Is the system in question spread over multiple divisions/entities?	1	0
Does the problem affect a multitude of heterogeneous stakeholder groups (developers, users, managers, others outside the organization)?	1	0
Has the informal discussion of the proposed system highlighted the potential for disagreements on requirements/objectives?	1	0
Are cost distribution issues among different organizational important?	1	0
Is all the funding necessary for building/managing the system available to the project developers?	0	1
Is there significant uncertainty in the impact of design decisions on system performance?	1	0
Are there significant intraorganizational and interorganizational political aspects to the system in question?	1	0
Is the bringing together of users, developers and other concerned stakeholders feasible logistically?	1	0
Participation Level Points (PLP)	Sum	
Step 2: Determine Level of Participation in the CONOPS process	PLP	
Inclusion of Stakeholders in all Phases of CONOPS development	7-8	
Inclusion of Stakeholders in Conceptual and Requirements Phases of CONOPS developments	6	
Inclusion of Stakeholders in Conceptual Phase of CONOPS development	4-5	
Development of CONOPS by core team with stakeholder commenting	2-3	
Development of CONOPS by core team	0-1	

APPENDIX B: THE SPK FRAMEWORK FOR STAKEHOLDER IDENTIFICATION

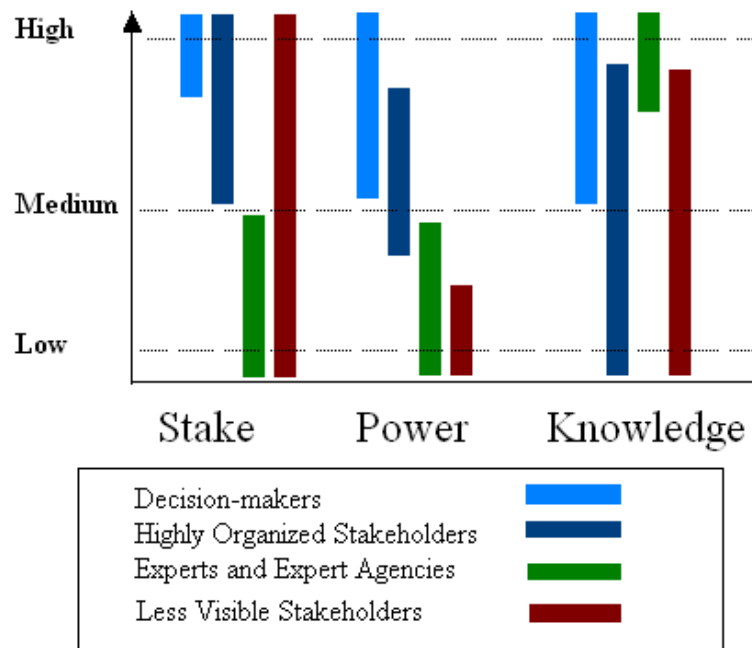


Figure 21: The SPK Framework

Engineering systems development often impact a multitude of stakeholders, some obvious, some less so. Given the limitations on how many stakeholders can physically participate in a collaborative CONOPS process, it is necessary to identify the critical stakeholders for such a process.

Effective stakeholder identification is therefore imperative to determine who will be directly or indirectly affected, positively or negatively, by a project or a system management plan, and who can contribute to or hinder its success. It is important for the project sponsor/system manager to be comprehensive in identifying and prioritizing all relevant stakeholders, including those that are not usually present at the table (Susskind and Larmer, 1999). Those identified will then need to be consulted to varying degrees, depending on their impact potential on the system, as well as their potential to contribute to the policy process through knowledge, resources or compliance with implementation. We categorize stakeholders based on their influence/power, stake, and knowledge.

- **Decision-makers, Managers and Principal Users (High Stake, High Power, and Differing levels of knowledge):** Management or leadership within organizations and high-leverage systems users that have a mandate to manage some part of the system or are primary users of the system. These are the people

who usually create a demand for a new system or a system change process based on their perceived needs.

- Stakeholders with financial/political influence (**High Stake, Medium to High Power and Differing Levels of Knowledge**): These include affected industry, private corporations, landowners, labor unions, nationally recognized and highly organized NGOs and other groups with strong political influence.
- Knowledge-producers (**Low Stake, Low Power, High Knowledge**): Scientists, Engineers and Consultants working in the academia, technical consulting firms, local, state and federal science agencies and scientific and technical offices of government agencies and scientific arms of NGOs that have a stake in the process, but have no specific mandate.
- Other affected Stakeholders (**High Stake, Low Power, Differing Levels of Knowledge**): These include smaller groups of stakeholders directly or indirectly affected by system management strategies or the proposed project. These can include less organized neighborhood groups, local environmental groups, small business owners etc., depending on the type of system or project that is initiated.

The SPK framework provides a rough mental guideline for the stakeholder classification process. Stakeholders can be assessed on their stake, power and knowledge (expert or local) on the decision. Stakeholders with high stakes in the collaborative process, even if they lack any power or knowledge can add legitimacy and community acceptance. Stakeholders with high knowledge can add to the scientific/technical /contextual validity of the analysis, while stakeholders with power (that is mandate or resources) can increase the viability of the process. Stakeholder with lower stake, power and knowledge can be involved through feedback systems, information websites, media releases and outreach campaigns.

Of course it is important to realize that such a categorization, while useful as a rough map, should not be the exclusive criteria for selecting stakeholders for participation, given that even smaller actors can sometimes be effective in undermining a process.

APPENDIX C: SHARED MENTAL MODELS (SMM)

Mental models are simplified characterizations humans create of their worlds (Johnson-Laird 1983). They are comprised of content and any relationships or structure among the content (Mohammed et al. 2000). Individuals use them to describe, explain, and predict their surroundings (Rouse and Morris 1986). When team members interact, their mental models converge, resulting in a scenario where the individual team members' mental models become similar to, or shared with, that of their teammates' mental models (McComb 2007; McComb and Vozdolska 2007). The resulting shared mental models can be defined as "knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behavior to demands of the task and other team members" (Cannon-Bowers et al. 1993). These shared mental models have been routinely linked to better team performance (McComb, 2008). As such, shared mental models are a critical construct for consideration when examining teams facing operational tasks that require agility such as mission planning, business processes, and intelligence analysis.

When left to develop naturally, the content of shared mental models may not always represent scenarios that will positively impact team performance. For instance, evidence suggests that when team members agree that they are cooperating, their performance deteriorates, indicating that they may be functioning in a groupthink mode where they do not question each others' ideas (McComb, 2007). Under these circumstances, teams may benefit from a strategically designed tool to guide their activities and their conversations. Team communication, in particular, may play an integral role in the mental model convergence process (Kennedy & McComb, in press). While information processing and mental model updating are internal processes, the communication of information occurs external to the team member and, therefore, represents an observable and manipulatable component of the convergence process.

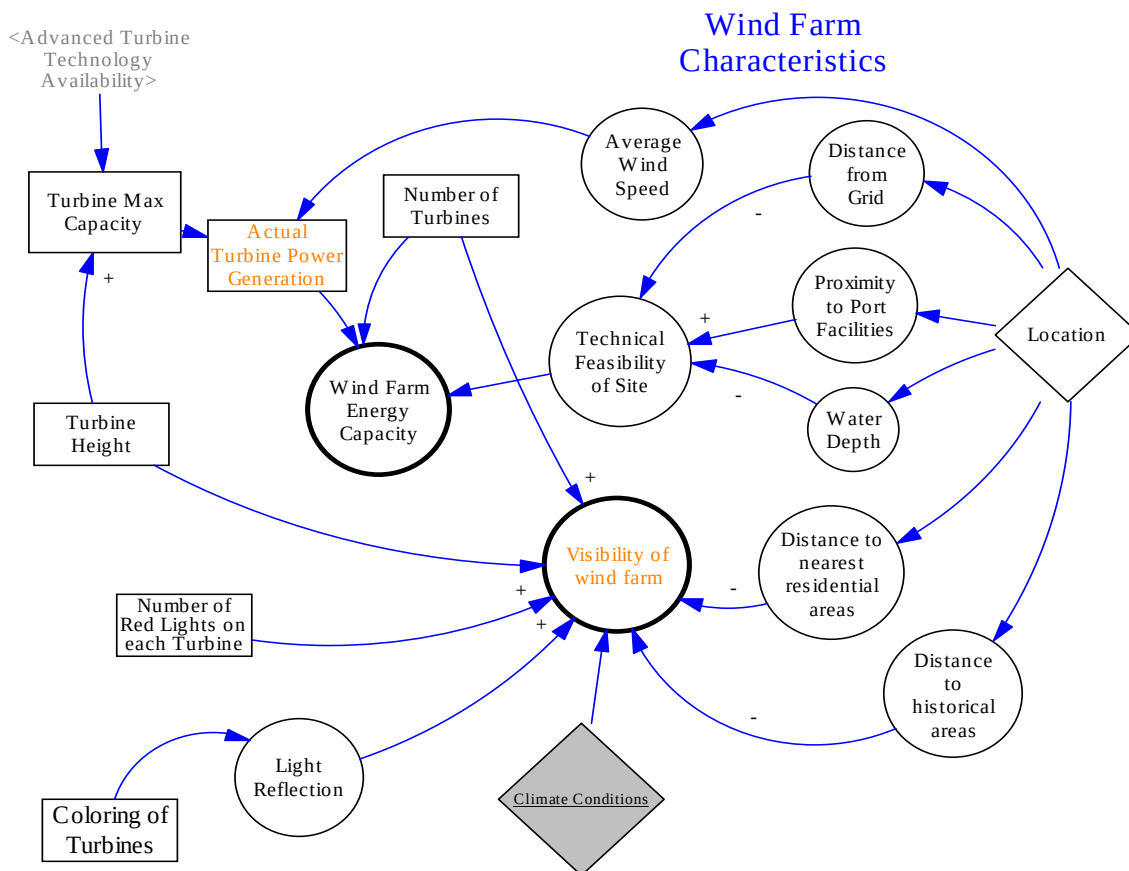
The way in which communication needs to be facilitated, however, is dependent upon the (1) type of task being undertaken by the team and (2) the point in the team's life cycle. First, communication content is driven by the type of task being undertaken. For example, Kennedy and McComb (2007) found that teams working on an intellectual task (i.e., a task with a correct answer that is technically difficult and not necessarily intuitive (McGrath, 1984)) focused their conversations on teamwork behaviors needed to organize themselves. As such, Kennedy and McComb (2007) investigated mental model convergence about, for example, how the team would approach solving the task and how they would allocate work among themselves to complete the task. Alternatively, the focus of the team's task may be on generating an action-oriented plan (McGrath, 1984). McComb et al., (2009) examined teams charged with creating a rescue plan for trapped workers on a hostile island. Team members were assigned specific roles, given contextual information about the mission, enemy, and island, and capability information about personnel, transport, and timing options. The teams had to

assimilate this information to make a plan that drew upon specific capabilities under the control of the team. Thus, communication exchanges were focused on sharing the information provided and, through these communication exchanges, the team members' mental models about the task converged.

Second, the convergence process is entwined in the team development process in such a way that the topics of conversation are dependent upon the purpose of the team at a particular point in time. Indeed, mental model convergence may occur, to various degrees, across all stages of development (McComb, 2007). Upon convergence of their mental models, team members will use them to guide their taskwork. The cognitive shift to taskwork will occur automatically as the team members' familiarity with the mental model content increases (Dutton, 1993; Yoo & Kanawattanachai, 2001). The team will work on their taskwork until a time when one or more mental models need revision to accommodate changes in the circumstances surrounding the team (Smircich, 1983). In other words, periodic mental model maintenance may be necessary. When maintenance is needed, each individual team member may shift to an individual focal level where they can orient themselves to the new information available and re-differentiate the information they have (including the new information just attained) before re-integrating all the information back to the team focal level. Kennedy and McComb (2009) found evidence through their examination of communication exchanges of reconvergence and how the timing of reconvergence impacts team outcomes. Thus, monitoring and facilitating team communication processes can assist in all aspects of the mental model convergence process.

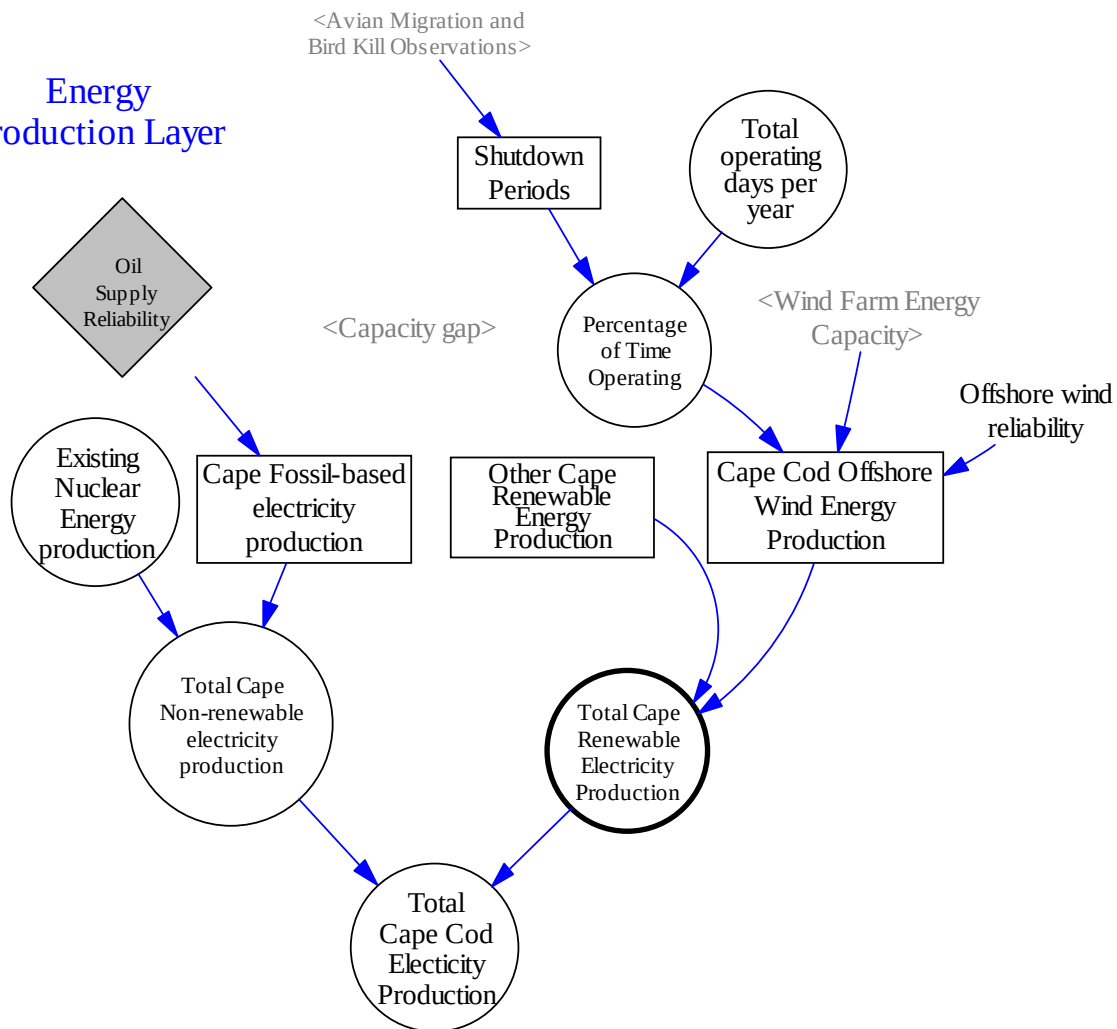
APPENDIX D: SAMPLE GRAPHICAL REPRESENTATION OF THE CONCEPTUAL CONOPS PHASE FOR AN OFFSHORE WIND ENERGY PROJECT

(Source: Mostashari, 2005)



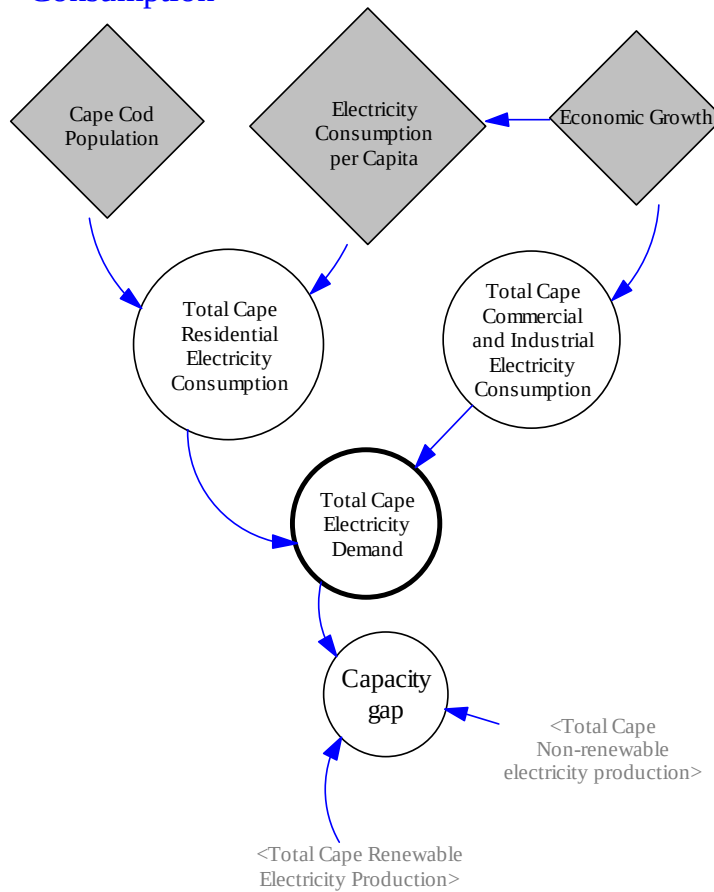
Major Uncertainties (H=High M=Medium L=Low)	- Visibility of Wind Farm (M-H)
Sources of Disagreement	- Visibility of Wind Farm (Strong) - Actual Turbine Power Generation (Weak)
Quantitative Tools/Models	- Visibility Simulations from different areas on shore - Electricity Generation Model under Varying Wind Conditions
Qualitative Tools/Frameworks	- Aesthetics assessment through simulations for residents - Visitor opinion surveys for historical areas and national parks

Energy Production Layer



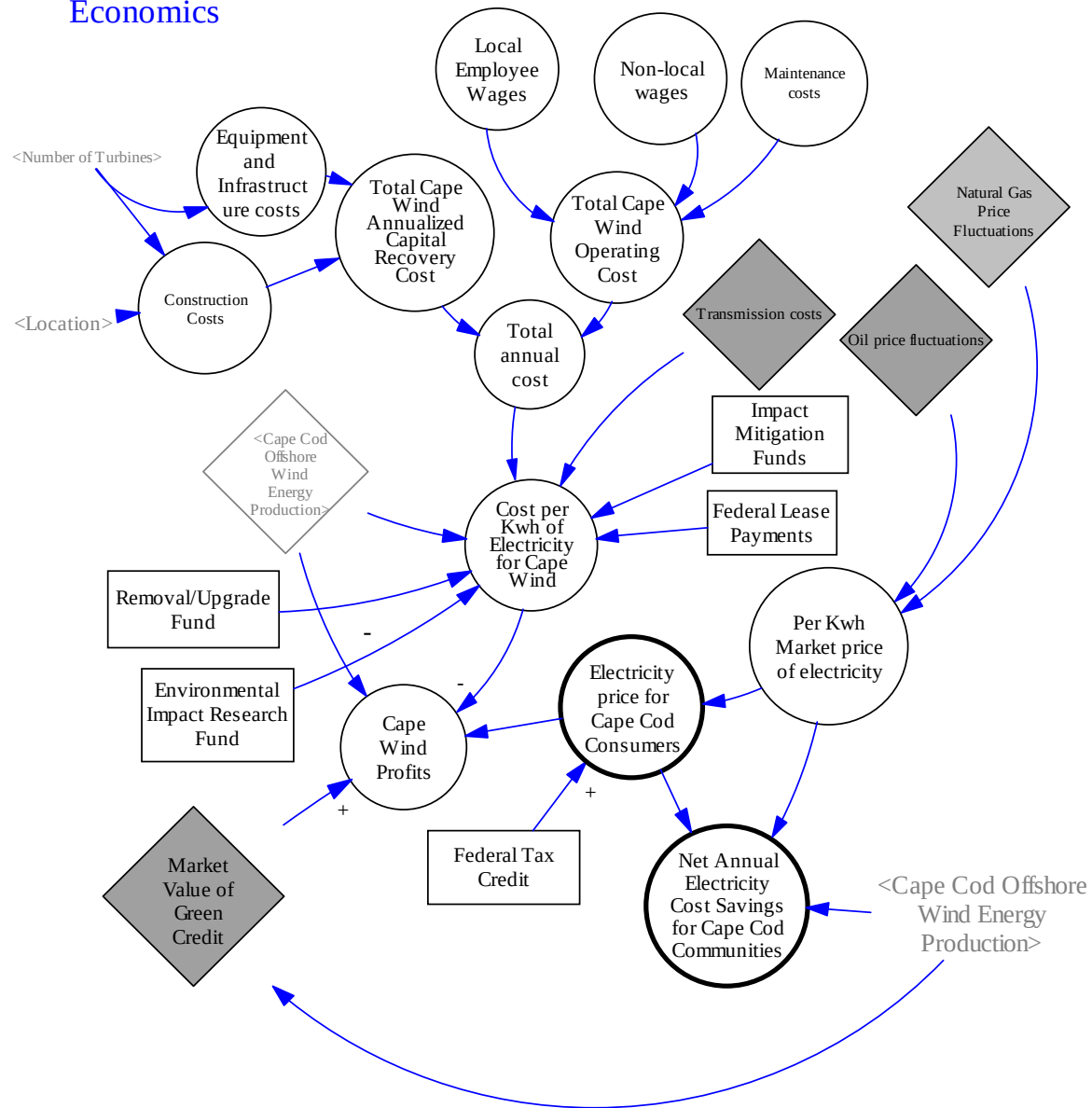
Major Uncertainties (H=High M=Medium L=Low)	- Cape Cod Offshore Wind Production (M) - Wind Energy Reliability (M) - Effect of oil supply reliability on fossil-based electricity production (M)
Sources of Disagreement	- Cape Cod Offshore Wind Production - Other Cape Renewable Energy Production
Quantitative Tools/Models	- Sensitivity analyses for oil supply fluctuations (volume and price) - Wind Energy Electricity Production Models

Energy Consumption



Major Uncertainties (H=High M=Medium L=Low)	- Energy Demand Assessment (L)
Sources of Disagreement	- Cape Cod Long-term Electricity Demand (Weak)
Quantitative Tools/Models	- Energy demand modeling

Energy Economics



APPENDIX E: CONOPS ELEMENTS/ COMPONENT AND CONOPS PROCESS APPROACH

CONOPS Project	Type of CONOPS	CONOPS Process/Approach	Process Length
Electronic Records Archives	Modification/ Upgrade/ Change to Existing System/Product	1. Initial development of CONOPS by a CONOPS development team utilizing existing documents and use-cases as a way to extract user requirements. 2. Document provided to relevant stakeholders for comment 3. Final CONOPS document issued after integration of comments	30 months
Incident Communications Interoperability	Operational Strategy	N/A	N/A
Health Monitoring And Maintenance Systems Products	Modification/ Upgrade/ Change to Existing System/Product	Initial Draft by CONOPS Team and Revisions based on Comments by Stakeholders	26 months
Financial System Modernization Project	Modification/ Upgrade/ Change to Existing System/Product	Office of the Chief Financial Officer (OCFO) is overseeing the CONOPS process, and revises based on stakeholder comments.	9 months
Systems Engineering Education Community (Seec)	Operational Strategy	EMWG held an International Workshop, in January, 1999 and produced a Review Draft form in mid-1999 and was accepted as an EMWG working paper in the January, 2000 workshop. A summary paper was included in the INCOSE 2000 Conference Proceedings.	12 Months

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Missile Early Warning System	Modification/ Upgrade/ Change to Existing System/Product	N/A	N/A
CONOPS Project	Type of CONOPS	CONOPS Process/Approach	Process Length
Un System Response In An Influenza Pandemic	Operational Strategy	Not available	Not available
Grants.Gov CONOPS	Modification/ Upgrade/ Change to Existing System/Product	Not Available	Not Available
Civilian Force Development	Operational Strategy	Mandate-based	Not Available
Geostationary Operational Environmental Satellite (Goes)	Modification/ Upgrade/ Change to Existing System/Product	N/A	30 months
Business Enterprise Architecture (Bea)	Modification/ Upgrade/ Change to Existing System/Product	N/A	N/A
Integrated Ocean Observing System Data Management And Communications	Operational Strategy	CONOPS draft used as a stakeholder review process document	N/A

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APPENDIX F: ANNOTATED BIBLIOGRAPHY

While it is traditional to include a references section, we have chosen to provide an annotated bibliography of the materials that were investigated for this study. The advantage of an annotated bibliography is that it provides a short annotation about the content of the document that goes beyond the title. It is hoped this will provide the reader with better information in determining the relevance of the cited document to the task at hand.

American Institute of Aeronautics and Astronautics. **ANSI/AIAA Guide for the Preparation of Operational Concept Document, G-043-1992. ANSI/AIAA G-043-1992.** 1993.

The ANSI/AIAA Standard for Operational Concept Documents.

Ammala, Darwin. **A New Application of CONOPS in Security Requirements Engineering.** *CrossTalk: The Journal of Defense Software Engineering*. August 2000. Normally used for describing full systems, CONOPS can also be used to address one single aspect-such as security in a large-scale project. This paper reports on a recent Navy contract effort, which demonstrated this use of the CONOPS. This paper will describe and analyze the results of this effort.

Bizkevelci, Sezin and Cakmak, M. A. **Technology management model application in concept approval decision - case study: Concept of operations and mission need assessment for a defence system.** 2008.

This paper is a continuation of Research & Development Project Selection Model and Process Approach in Defense Industry Related Programs: First Phase Concept Approval Decision study, which was presented in PICMET07, a defence industry application is realized. The application contains the first three steps of Concept Approval Decision Phase. First of all, Concept of Operations is formed, then Mission Need Statements are defined and finally first leg of Mission Need Analysis, which is called Functional Area Analysis, is realized for a generic defence system as an example. This is a part of a case study and it is aimed to demonstrate the applicability of the theoretical study proposed in PICMET07.

Boardman, John; Sauser, B.; John, L. and Edson, R. **Conceptagon: A framework for systems thinking and systems practice.** *IEEE International Conference on Systems, Man and Cybernetics*. October 2009.

This paper, building on the body of Systems Thinking knowledge and cognizant of the key problem-solving systems methodologies, presents a new framework, the Conceptagon, and illustrates its use by describing its application to a case study drawing on the United States Department of Defense Biometrics Enterprise.

Booz Allen Hamilton. **Concept of Operations (CONOPS) Environmental Protection Agency Financial System Modernization Project.** October 26, 2005.

The CONOPS is framed by EPA's business requirements and by the objectives set forth

by the Office of Management and Budget's (OMB's) Financial Management Line of Business (FM LoB).

Business Transformation Agency. **Concept of Operations for Business Enterprise Architecture (BEA) Requirements.** September 14, 2007.

This CONOPS identifies and describes the following concepts, relative to BEA development, that enable the BEA to address the two types of requirements or gaps/improvements: a "top down and bottom up" ;approach to BEA development aimed at delivering the right balance of strategic and tactical information within the BEA, making it possible to address the strategic and tactical requirements and federate the BEA with relevant component and system architectures; a governance model and supporting process to manage the priorities.

Cannon-Bowers, J. E.; Salas, E. and Converse, S. **Shared Mental Models in Expert Team Decision-Making. Individual and Group Decision-Making: Current Issues.** Lawrence Erlbaum Associates: Hillsdale, NJ. 1993.

The purpose of this chapter is to describe how the notion of shared mental models can advance our understanding of teamwork and team decision making, and to delineate the implications of adopting such a position. In order to accomplish this, several relevant bodies of research reviewed, including literature regarding team performance, team decision making, and mental model theory. Following this, a case is made that, when teamwork is conceptualized in terms of shared mental models, it provides an effective means to understand this rather elusive phenomenon. Finally, the implications of adopting the shared mental model perspective in terms of team decision making and training for team decision making are discussed

Chen, Min; Lu, G.; Wen, Y.; Tao, H. and Su, H. **Study on the Modelling of Geographic Conceptual Scenario Based on 3D Icons. XXXVII. Part B4, Commission IV.** July 3-11, 2008.

There are many problems in conceptual modeling process, such as difficulties in modeling conception sharing, expressing and simulating the processes via a visual method, and so on. To solve those problems, expression meta data of geographic conceptual scenario is established based on 3D Icons, a visual conceptual modeling approach is put forward to realize expression and construction of geographic conceptual models interactively. By the experiments, it has shown that our research can accelerate practicality of geographic conceptual modeling and deepen its theoretic meanings.

Cloutier, Robert. **Model Driven Architecture for Systems Engineering. Conference on Systems Engineering Research.** April 4-5, 2008.

Model Driven Architecture (MDA) includes a model based approach for software architecture and design as well as a set of key principles intended to improve software interoperability, reusability, portability, maintainability, and reliability. This paper reviews the key MDA principles as defined by the Object Management Group, and then discusses their potential applicability to the systems engineering discipline, along with the potential benefits to systems architecture and system design concepts of large scale systems development. The paper will identify potential MDA practices that could

significantly advance the practice of systems engineering, to include the application of system design patterns to system architecture.

Cloutier, Robert. **Model Driven Architecture for Systems Engineers - Why Should We Care.** *Telelogic Users Conference*. 2006.

Model Driven Architecture, or MDA, is an Open Management Group (OMG) framework and standard with the goal of leading “the industry towards interoperable, reusable, portable software components and data models based on standard models¹”. When one reads the MDA literature, it is full of IT language and examples relevant to software development. So, why then should the systems engineering community be interested in this approach? Can the approaches outlined by the MDA approach be used to perform systems architecting/systems engineering? What does it mean to create a compute independent model (CIM) or platform independent model (PIM) in terms of systems engineering? Finally, is this approach of any value to the systems engineering discipline, and how can TAU help? This paper will attempt to address those questions.

Cloutier, Robert and Verma, D. **Applying the concept of patterns to systems architecture.** *Systems Engineering*. 10,2. April 6, 2007.

This paper provides a discussion of patterns and their potential applicability to complex system architecting. The relevance and applicability of patterns to systems architecting is then examined. Research with regard to developing a pattern form for documenting patterns for systems architecting is presented, and this is demonstrated on a command and control pattern, using both IDEF0 and UML. The application of this pattern within a functional architecture is then explored. Finally, recommendations for the development and management of a systems architecting and architecting pattern repository are offered.

Cloutier, Robert and Verma, D. **Applying Pattern Concepts to Enterprise Architecture.** *Journal of Enterprise Architecture*. 2,2. May 2006.

This article reviews some of the relevant research and application related to the use of patterns, reviews how other disciplines are using patterns, and discusses research that has been done on applying patterns to the practice of architecting complex system (enterprise) architectures. Examples of architecture patterns are presented and discussed, and a methodology and rationale for documenting architecture patterns is presented.

Cohen, Sholom. **Guidelines for Developing a Product Line Concept of Operations. Product Line Practice Initiative.** August 1999.

An organization develops its CONOPS to establish the desired product line approach that it wishes to take. These guidelines recommend a detailed description of the selected approach and possible presentation of alternatives. The resulting CONOPS documents the decisions that define the approach and the organizational structure needed to put the approach into operation.

Commander Air Force Space Command. **Development and Use of Conceptual Documents.** 10-606. 1996.

This Instruction implements AFPD10-6 Mission Needs and Operational Requirements, by providing guidance and procedures for developing and processing Air force Space

Command (AFSPC) conceptual documents. It provides general guidance regarding the development and use of the various types of conceptual documents in support of AFSPC's mission areas and systems.

Darr, Stephen. **NASA Aviation Safety & Security Program (AvSSP) Concept of Operation (CONOPS) for Health Monitoring and Maintenance Systems Products.** *NIA Report # 2006-04*. September 2005.

This document describes current and proposed practices in the areas of fire detection, fire suppression, health status monitoring and maintenance, to include maintenance resource management in the broader context of continuous airworthiness maintenance.

Department of Defense. **Operation Concept Description.** *DI-IPSC-81430*. 1994.
Department of Defense Operation Concept Description Standard.

DiMario, Michael; Cloutier, R. and Verma, D. **Applying Frameworks to Manage SoS Architecture.** *Engineering Management Journal*. 20,4. December 2008.

This article addresses some of the reasons why the management approach for systems development should be different than that for SoS development and offers a methodology for implementing the widely accepted Zachman Framework to facilitate the managing of SoS architectures.

Dutton, J.E. **Interpretations on Automatic: A Different View of Strategic Issue Diagnosis.** *Journal of Management Studies*. 1993.

Models of strategic decision-making and environmental scanning typically assume that decision-makers diagnose issues actively, using conscious and intentional effort to identify and to interpret potentially significant events, developments and trends. This article establishes that conditions in organizations put decision-makers 'on automatic' in their diagnosis of strategic issues, with direct implications for the process and content of strategic action. Implications for theory and practice are established.

Eden, C. **On the nature of cognitive maps.** *Journal of Management Studies*. 29,3. May 1992.

A discussion into the development and use of cognitive maps.

El Haouzi, Hind and Thomas, A. **A Methodological Approach to Build Simulation Models of Manufacturing Systems with Distributed Control.** 2005

International Conference on Industrial Engineering and Systems Management. May 16-19, 2005.

Our study focuses on simulation of industrial systems with distributed control. We propose a structured approach to build the simulation models. This approach is based on methodology ASDI (analysis-specification-design-implementation) and it is independent of any platform or software tool. We will illustrate the use of this approach in an assembly line manufacturing application.

Engineering Talk. **Bentley uses Aesthetica simulation software.** Updated March 5, 2009. Accessed March 15, 2009. <http://www.engineeringtalk.com/news/ias/ias115.html>.

Bentley Motors has implemented Icona's perceived quality simulation software, Aesthetica, at its design and manufacturing plant in Crewe, England.

Fairley, Richard E.; Thayer, R. H. and Bjorke, P. **The Concept of Operations: The Bridge from Operational Requirements to Technical Specifications.** *The First International Conference on Requirements Engineering*. April 18-22 1994.

This paper describes the role of a Concept of Operations (CONOPS) document in the specification and development of a software-intensive system. It also describes the process of developing a CONOPS, its uses and benefits, who should develop it, and when it should be developed. The CONOPS described in this paper is compared to other forms of operational concept documents. A recommended format for the CONOPS document is presented in the paper.

Gabb, Andrew P. **Operational Concepts - Some Variations.** *Systems Engineering, Test & Evaluation Conference*. October 2002.

This paper describes different types of operational concept documents (OCDs) that may be used at different times in a project. While several guidelines exist for the development of OCDs, none distinguish between the different stages of a project at which an OCD may be developed, nor the different purposes and audiences of the various OCDs. This paper discusses some of the possible OCD variants and also examines the differences in content of the different variants.

Gabb, Andrew P. **Front-end Operational Concepts - Starting from the Top.** *Eleventh Annual International Symposium of the International Council of Systems Engineering*. July 1-5 2001.

This paper addresses the need for, use and development of operational concepts at the start of large projects. The front-end operational concept, derived in consultation with the system's potential users and other stakeholders, should serve as the driving document for the acquisition and supply of the system. However, there is often uncertainty about what such a document should contain, how it should be developed, and its relationship to other project documents. The paper addresses these issues, as well as the evolution of the Operational Concept throughout the life of the project.

Gilibert, Herve and Thevenot, R. **CONOPS of HALE UTA in an InfraRed Early Warning mission for Theater Missiles Defense.** *AGARD MSP Symposium on "System Design Considerations for Unmanned Tactical Aircraft (LITA)"*. October 7-9, 1997.

This paper presents the concept of High Altitude Long Endurance UTA equipped with InfraRed sensors for Tactical Ballistic Missiles (TBM) detection and tracking.

Grants.gov. **Concept of Operations Grants.gov System.** April 17, 2007.

The Grants.gov Concept of Operations (CONOPS) document describes the desired characteristics of the Grants.gov system from the users' viewpoint. This document also addresses Grants.gov requirements for operation and maintenance (O&M) of the system. This CONOPS briefly discusses the Grants.gov system, its components, and all associated systems that impact Grants.gov operation.

Greer, William. **Next Generation Modeling of Operational Effects.** *Science and Technology for Chem-Bio Information Systems*. October 28, 2005.

Extend and improve the CBRN warfare effects on military operations methodologies and

transition demonstrated technologies to the Joint Operational Effects Federation (JOEF) program.

Haraldsdottir, Aslaug; Schwab, R. W. and Alcabin, M. S. **Air Traffic Management Capacity-Driven Operational Concept Through 2015.** *2nd USA/Europe Air traffic Management R&D Seminar.* December 1-4, 1998.

This paper describes an approach to developing an operational concept for the US National Airspace System. The paper illustrates this approach by defining an operational concept that is driven by system capacity as the primary performance goal, including a logical system transition path from the current system to a higher throughput system for 2015. In addition, this paper proposes a preliminary design process for the NAS that guides the system architecture design through a careful flowdown of performance requirements and operational and technology trades.

Herald, Tom and Verma, D. **Concept of Operations Development Considerations for a Highly Networked System.** *Fourteenth Annual International Symposium of the International Council on Systems Engineering.* June 20-24, 2004.

Since a new Net Centric System (NCS) is often made up of existing systems plus the development of new state-of-the-art and emerging-technology systems, there is potential to provide an early system analysis from the bottoms-up and integrate with the stakeholder tops-down needs. This source of information is the existing constituent system Concept of Operations (CONOPS) documents. However, how can these be effectively used? This paper focuses on a reasonable implementation in direct support of the NCS Systems Engineer with the tops-down and bottoms-up mapping for effectively feeding the NCS-level CONOPS document development process.

Hlupic, Votka and Paul, R. J. **Guidelines for selection of manufacturing simulation software.** *IIE Transactions.* 31,1. January 1, 1999.

This paper provides guidelines for selecting manufacturing simulation software according to the intended purpose of software use. The basic criteria to be examined in the software evaluation process are listed together with the level of their importance for particular types of users.

IEEE. **IEEE Guide for Information Technology - System Definition - Concept of Operations (CONOPS) Document.** *IEEE Std 1362™-1998 (R2007).* 1998.
IEEE CONOPS Standard.

Integrated Computer Engineering. **Concept of Operations for Electronic Records Archives.** 2004.

This Concept of Operations (CONOPS) document provides a conceptual overview of the proposed ERA system. The CONOPS is intended to support the evolution of a fully integrated, modernized, and functional system where records of the Federal Government will be available to the public in perpetuity. Moreover, the CONOPS is a living document and will be coordinated in a collaborative manner with industry, public, and Government stakeholders to ensure the viability of the concepts represented.

Jain, Rashmi. **Knowledge Acquisition: From Concept to Competencies.** *International Journal of Intelligent Defence Support Systems.* (unpublished)

Jain,Rashmi and Chandrasekaran,A. **A Systems Approach to Design: Research and Some Results.** *Asia-Pacific Conference on Systems Engineering*. September 22-23, 2008.

A systems approach to design means designing from a holistic perspective. It is an approach focused on understanding the functionality for which the system is designed for by keeping the focus on its need, context, and its intended lifecycle. This paper is focused on the need and current challenges of teaching engineering students a systems approach to design. The paper proposes definitions of five core concepts of a systems approach to design. These concepts are context, abstraction, trade-off, inter-disciplinarily, and value. The paper also includes discussion on the findings of a survey of students and faculty on these fundamental concepts of system design.

Jain,Rashmi;Sheppard,K.;McGrath,E. and Gallois,B. **Promoting Systems Thinking in Engineering and Pre-Engineering Students.** *American Society for Engineering Education Zone 1 Conference Proceedings*. 2008.

This paper describes vertically-integrated curriculum innovation, in which graduate-level coursework spawned a pilot program to embed systems in a core engineering design course for undergraduates with its resulting adoption and extension to a core design thread, and a resulting high school curriculum development and dissemination effort which has followed. These efforts have also prompted educational research to develop the academic underpinnings of the relatively under-developed scholarly foundations of systems engineering.

Johnson-Laird, P.N. **Mental Models: Towards a Cognitive Science of Language, Inference, and Consciousness.** Cambridge, MA: Harvard University Press. 1983. *Mental Models* offers nothing less than a unified theory of the major properties of mind, including comprehension, inference, and consciousness. In spirited and graceful prose, Johnson-Laird argues that we apprehend the world by building inner mental replicas of the relations among objects and events that concern us. The mind is essentially a model-building device that can itself be modeled on a computer. This book provides both a blueprint for building such a model and numerous important illustrations of how to do it.

Johnston,Kevin and Ladd,J. **A Concept of Operations for an Integrated Weather Forecast Process to Support the National Airspace System.** *11th Conference on Aviation, Range, and Aerospace*. October 4, 2004.

The intent of this CONOPS, of which an overview is provided in this paper, is to describe a framework for an improved, standardized, and relevant CWSU operation in support of the NAS. The CONOPS serves as a guide for follow-on efforts to establish staffing requirements, specific procedures and directives, as well as determining required changes to appropriate planning, requirements, and training documents.

Jost,Alan C. **CONOPS: The Cryptex to Operational System Mission Success.**

CrossTalk: The Journal of Defense Software Engineering. October 2007.

As engineering firms start to design any number of systems for a variety of customers and end users, the number and variety of system documentation can be overwhelming. Among this pile of documentation, the Concept of Operations (CONOPS) stands out as a

critically important engineering document that should be created at the beginning of the system development and maintained throughout the engineering life cycle. This article discusses the CONOPS and if it truly is necessary in addition to all of the other documentation available.

Karlsson, Goran and Wauthier, S. **Operational Concept Document: A process based integration of production IT solutions in a pharmaceutical plant.** *World Batch Forum North American Conference*. April 2001.

The operational concept document is a result of the analysis of the manufacturing process and the functions completed by the miscellaneous IT packages that bridge the gap between the pieces of equipment and the business systems. This presentation will describe the method used to perform this analysis and present the lessons learned through the application of that method in a secondary manufacturing plant greenfield project.

Karplus, W. J. **System identification and simulation: a pattern recognition approach.** *Proceedings of the Fall Joint Computer Conference*. December 5-7, 1972.

Recent years have seen continuing and increasingly-intensive attempts to extend the art of simulation to areas which heretofore were considered too complex and too difficult to lend themselves to conventional modeling and simulation techniques. The extension of simulation techniques developed in application areas such as control system design, electro-mechanical systems, etc., to these new areas has often been disappointing, if not completely unsuccessful. This is due to the difficulty in constructing a sufficiently-valid mathematical model---a model which can be used for prediction with a reasonable amount of confidence. It is well-known, of course, that even under the best conditions, inverse problems such as system identification problems, do not have unique solutions. That is, inevitably an infinite number of possible models will satisfy a specified set of excitation/response relationships. Where the identification process is further handicapped by uncertainties as to system structure and inadequate experimental data, the pertinent question is often not: "How good is the model?" but rather: "Is there any point to modeling at all?"

Keel, Paul E. **EWall: A visual analytics environment for collaborative sense-making.** *Information Visualization*. 6, 1. Spring 2007.

We introduce EWall, an experimental visual analytics environment for the support of remote-collaborative sense-making activities. EWall is designed to foster and support 'object focused thinking', where users represent and understand information as objects, construct and recognize contextual relationships among objects, as well as communicate through objects. EWall also offers a unified infrastructure for the implementation and testing of computational agents that consolidate user contributions and manage the flow of information among users through the creation and management of a 'virtual transactive memory'. EWall is designed to enable individual users to navigate vast amounts of shared information effectively and help remotely dispersed team members combine their contributions, work independently without diverting from common objectives, and minimize the necessary amount of verbal communication.

Kennedy, Deanna M. and McComb, S.A. **Team Mental Model Re-Convergence: The Effect of New Information and the Mental Model Convergence Process during Collaborative Activities.** *INGroup Conference*. 2007.

During collaborative activities, new information may arise that requires adjustments to, and reconvergence of, mental model content. Herein, we analyze textual data collected during team experiments to explain the mental model convergence process when new information is interjected. Further, we examine how reconvergence about mental model content impacts team effectiveness.

Kennedy, Deanna M. and McComb, S.A. **Examining the Mental Model Convergence Process through Team Communication.** *Theoretical Issues of Ergonomic Science*. (in press).

Mental model convergence is a macrocognitive process critical to team development. Yet, little is known about how the convergence process occurs in a team domain. To date, researchers have examined convergence at specific points in time after performance episodes. While this approach has moved the field forward, research is needed that captures the dynamics of the convergence process as it occurs during collaborative activities. To facilitate this needed research, we present a framework for examining mental model convergence via communicated mental model content. Our framework is theoretically based on relevant research in cognitive science and communication, as well as more recent team mental model research. By explicitly establishing the theoretical connection between mental model convergence and team communication, we extend the extant research that links communication and team cognition and address a gap in the team mental model literature regarding how to examine the mental model convergence process over time.

Lacroix, F. W.; Button, R. W.; Johnson, S. E.; Chiesa, J. and Wise, J. R. **A Concept of Operations for a New Deep-Diving Submarine.** 2002.

The NR-1 is the Navy's only nuclear deep-diving research submarine capable of scientific and military missions. Its nuclear reactor will be exhausted in 2012; therefore, the NR-1 must be refueled or retired before then. As part of its considerations in this regard, the Navy is developing a concept of operations (CONOP) for a possible replacement platform, initially designated the NR-2.

Lanner Group Limited. **Ford Engine Assembly Line Simulation Tool.** 2001.

A massive amount of planning and investment goes into every new engine that Ford Motor Company design. In today's highly competitive climate, the speed to market for new products is crucial in maintaining competitive advantage. Ford have been using WITNESS since the mid-1980s to speed up the design of their engine manufacturing facilities. In that time many engine assembly lines have been simulated, with the model results being used to justify design decisions.

Larson, Wiley; Sellers, J.; Kirkpatrick, D.; Thomas, D. and Verma, D. **Applied Space Systems Engineering.** McGraw Hill, 2009.

Law, Averill M. and McComas, M. G. **Simulation of manufacturing systems.** *Proceedings of the 30th conference on Simulation*. Winter 1997.

This paper discusses how simulation is used to design new manufacturing systems and to improve the performance of existing ones. Topics to be discussed include: manufacturing issues addressed by simulation, simulation software for manufacturing applications, techniques for building valid and credible models, and statistical considerations. A comprehensive example will be given in the conference presentation.

Linebarger, John M.; Spain, M. J. D.; McDonald, M. J.; Spencer, F. W. and Cloutier, R. J. **The Design for Tractable Analysis (DTA) Framework: A Methodology for the Analysis and Simulation of Complex Systems.** *International Journal of Decision Support System Technology*. 1,2. April-June 2009.

The Design for Tractable Analysis (DTA) framework was developed to address the analysis of complex systems and so-called “wicked problems.” DTA is distinctive because it treats analytic processes as key artifacts that can be created and improved through formal design processes. After using the Systems Modeling Language (SysML) to frame the problem in the context of stakeholder needs, DTA harnesses the Design Structure Matrix (DSM) to structure the analysis of the system and address questions about the emergent properties of the system. The novel use of DSM to “design the analysis” makes DTA particularly suitable for addressing the interdependent nature of complex systems. The use of DTA is demonstrated by a case study of sensor grid placement decisions to secure assets at a fixed site.

Lynott, Kevin. **NOAA’s National Weather Service Concept of Operations River Forecast Center (RFC) Analysis and Gridded Forecast Editor Improvement.** July 19, 2005.

This document defines the River Forecast Center (RFC) analysis and gridded forecast improvement operational concept. This document includes a description of the current system, a justification for the proposed change, a description of the proposed system, and a summary of anticipated changes.

Madni, Azad M.; Lin, W. and Madni, C. C. **IDEON: An extensible ontology for designing, integrating, and managing collaborative distributed enterprises.** *Systems Engineering*. 4,1. 2001.

The major challenges facing organizations are: (a) achieving seamless integration of enterprise design, management and control processes and supporting applications; (b) ensuring interoperability between new and legacy business applications; and (c) adapting business strategies and ongoing operations to changes in the external and internal environments. The latter requires integrated planning and execution of enterprise processes. This paper presents IDEONTM, a unified, extensible enterprise ontology that has been designed in response to these needs. Two specific applications of IDEONTM are presented along with the specific extensions for each application.

Madni, Azad M.; Madni, C. C. and Garcia, S. K. **Cognitive Model-enabled Simulation-based Training of Aerospace Operations Center Operators.** *AIAA Infotech@Aerospace*. September 26-29, 2005.

The Aerospace Operations Center (AOC) is a weapon system for the command and control of joint forces in the dynamic battlefield as we go into the future. The training of command and control (C2) personnel, who man the AOC, continues to lag because of personnel turnover and lack of cost-effective “anytime, anywhere” training tools. The

challenge in today's compressed personnel assignment cycle is to develop training that satisfies an operator's individual and collaborative decision making needs, and to provide that training in a manner that rapidly raises the learner's proficiency to a level that enables the learner to perform effectively in the operational environment. Simulation-Based Training (SBT) is the approach of choice to achieve these objectives. This paper presents ProcessTrain™, a cognitive model- inspired SBT system that is both cost-effective from a development perspective and scalable in terms of supported users and simulated entities.

Madni, Azad M.; Samet, M. G. and Freedy, A. **A Trainable On-Line Model of the Human Operator in Information Acquisition Tasks.** *IEEE Transactions on Systems, Man and Cybernetics*, 12,4. 1982.

A trainable model of the human operator in information acquisition tasks is described. The purpose of this model, called the adaptive information selector (AIS), is to select and present textual messages automatically to users in computer-based tactical systems. The AIS was implemented and tested in a simulated environment. The results demonstrated the model's capability to 1) converge on distinctive information processing strategies exhibited by different operators; and 2) effectively present messages in their order of priority for each operator. The AIS is potentially useful in performing information distribution functions in command and control systems and in aiding the performance of personalized searches of large data bases.

Maine State Office of Information Technology and Maine Emergency Management Agency. **State of Maine CONOPS For Incident Communications Interoperability.** March 19, 2007.

This Concept of Operations Plan (CONOPS) provides guidance to public safety agencies (traditional first responders) and non-traditional responders for developing and employing on-scene interoperability through an effective Incident Communications program.

McComb, Sara A. **Mental Model Convergence: The Shift from Being an Individual to Being a Team Member.** *Multi-Level Issues in Organizations and Time*. 2007.

Mental model convergence occurs as team members interact. By collecting information and observing behaviors through their interactions, team members' individual mental models evolve into shared mental models. This process requires a cognitive shift in an individual's focal level. This chapter presents a framework describing the mental model convergence process that draws on the extant research on group development and information processing. It also examines temporal aspects of mental model convergence, the role of mental model contents on the convergence process, and the relationship between converged mental models and team functioning. Preliminary evidence supporting the framework and the important role that converged mental models play in high-performing teams is provided. The chapter concludes with a discussion of the implications of this mental model convergence framework for research and practice.

McComb, Sara A. **Noncombatant Evacuation Operation: Red Cross Rescue Scenario.** (unpublished)
Hypothetical Rescue Scenario documentation.

McComb, S.A. **Shared Mental Models: The Convergence of Mental Model Content and Structure. Collaboration and Knowledge Interoperability**. London: Ashgate Publishing. 2008.

The purpose of this chapter is to examine shared mental models research and the role of shared mental models in the macrocognitive processes of teams. To this end, the chapter begins with a brief overview of shared mental models terminology and empirical research results demonstrating their essential role in effective team functioning. The next section describes my mental model convergence conceptualization and provides preliminary evidence of mental model convergence. I then turn my attention to mental model measurement and offer some suggestions for advancing this critical aspect of mental model research. Finally, I examine the relationship between macrocognitive processes and shared mental models. The chapter ends with implications for research and practice relating to the study of shared mental models.

McComb, Sara A.; Green, S. G. and Compton, W. D. **Team flexibility's relationship to staffing and performance in complex projects: An empirical analysis**. *Journal of Engineering and Technology Management*. 24,4. 2007.

We examine the role of flexibility in project team effectiveness. Specifically, we hypothesize that (1) it will mediate the relationship between staffing quality and effectiveness and (2) its relationship with team effectiveness will be moderated by project complexity, where more flexibility will be required when projects are complex. Hypotheses are tested using data collected from 60 cross-functional project teams. Implications for research and practice are discussed.

McComb, Sara; Kennedy, D.; Haas, R.; Warner, N. and Letsky, M. **Examining Temporal Patterns of Mental Model Convergence: Implications for Distributed Teams Interacting in an Electronic Collaboration Space**. (*working paper*) 2009.

We examine the effects of an electronic collaboration space, designed specifically to foster information processing, on teams' cognitive processes.

McComb, Sara A. and Vozdolska, R.P. **Capturing the Convergence of Multiple Mental Models and Their Impact on Team Performance**. *Southwestern Academy of Management Conference*. March 13-17, 2007.

We examine the relationship between shared mental models and team performance by introducing a new method for capturing shared mental models over time that is domain-independent and readily applicable to the field. We examined seventy-two teams of three undergraduate students during two sessions. These teams completed a scheduling task that required them to work interdependently. Our results indicate that (1) the method we introduce captures mental model convergence over time, (2) multiple shared mental models, which are not domain dependent, exist simultaneously and have differing effects on team performance, and (3) the content of the mental model moderates the shared mental model-team performance relationship. Implications for research and practice are discussed.

McGrath, J. E. **Groups: Interaction and Performance**. Englewood Cliffs, N.J.: Prentice-Hall, Inc. 1984.

In this volume, McGrath examines the existing group literature, describes various methodologies for studying groups, and presents a typology of tasks. His primary focus is

on groups as vehicles for performing tasks. Therefore, much of the volume is devoted to describing eight categories of tasks and the research that has been conducted on groups engaged in those tasks. The typology, which McGrath labels The Group Task Circumplex, is a useful tool for differentiating among types of activities undertaken by groups and teams.

McIntyre, Cynthia. **U.S. Manufacturing - Global Leadership Through Modeling and Simulation.** *High Performance Computing Initiative*. March 4, 2009.

This is today's headline: The Collapse of Manufacturing, and many U.S. manufacturers and their supply chains are in crisis. In this time of crisis, the U.S. has the technological tools to maintain our competitive edge and global leadership in manufacturing, but we risk our manufacturing leadership position if we fail to utilize the game-changing tool of high performance computing (HPC) for modeling, simulation, and analysis.

Miller, S. and Pegden, D. **Introduction to manufacturing simulation.** *2000 Winter Simulation Conference Proceedings*. 2000.

The article presents an overview of simulation in manufacturing design and scheduling. A review of the modeling considerations in both application areas is provided. Finally, a number of example applications are presented to illustrate the concepts.

Mixon/Hill, Inc. **StarTran Automated Vehicle Location System Concept of Operations. Response to City of Lincoln StarTran RPF 05-053.** November 2005.

This document provides a Concept of Operations (CONOPS) for the City of Lincoln, Nebraska's StarTran AVL system. The CONOPS document is designed for the system owners, system users, system developers, and system providers. It describes the current system state, establishes the need for system change, and describes the proposed system in terms of features and functionality.

Moertl, Peter; Beaton, E. and Viets, K. **En Route Merging and Spacing Preparation concept of operations.** *IEEE/AIAA 27th Digital Avionics Systems Conference, 2008*.

This paper describes a concept of operations for improving the merging and spacing operations as aircraft approach and transit into the terminal area that implements the NextGen concept for en route and arrival operations.

Mohammed, S.; Klimoski, R.; and Rentsch, J.R. **The Measurement of Team Mental Models: We Have No Shared Schema.** *Organizational Research Methods*. 3. 2000.

This article seeks to promote the advancement of empirical research on team mental models by (a) highlighting the conceptual work that must precede the selection of any measurement tool, (b) delineating measurement standards for group-level cognitions, and (c) evaluating a set of techniques for measuring team mental models. Pathfinder, multidimensional scaling, interactively elicited cognitive mapping, and text-based cognitive mapping are critiqued and compared according to their treatment of content and structure, as well as their psychometric properties. We conclude that these four techniques hold promise for measuring team mental models and illustrate the variability in measurement options. However, careful attention to the research question and research context must precede the selection of any measurement tool.

NASA. **Project Management: Systems Engineering & Project Control Processes and Requirements. 4.1.3 Operational Concept Development.** March 2004.

This document provides a description of the basic processes and general practice for the development and operation of all projects managed at the Lyndon B. Johnson Space Center (JSC).

Nelson, Gary G. **The CONOPS in a Self-Similar Scale Hierarchy for Systems Engineering.** *Conference on Systems Engineering Research.* 2007.

The standardized CONOPS differs from a partial, non-standardized, but widely used "CONOPS". This paper proposes that the CONOPS is a complete kernel for any system development thread and scales into a multi-level, multi-peer process of enterprise evolution. Self-similar versions of the CONOPS are the nodules in a scale hierarchy that is the fundamental architecture of complex adaptive enterprises. This architecture applies to risk management in a collective of agents contending over limited information and other resources. This "CONOPS-centric" approach should displace fragmented and linear approaches to complex systems. This concept has firm precedence and the real puzzle is why the CONOPS is so neglected and abused.

Nichols, Ernie. **Developing a concept of operations: enabling improvement.** *IEEE Proceedings Aerospace Conference.* 7. 2001.

INTELSAT, an international telecommunications satellite business, is in the midst of developing and maintaining a Concept of Operations as a link between the work it does and the vision, mission and strategy of the company. This paper will provide a short historical summary of the beginning of INTELSAT'S Concept of Operations and how it has evolved. It will show how work processes and the deliverables they produce relate to policy, mission, strategy, and objectives. The focus of the discussion will be how the creation and maintenance of a Concept of Operations creates value throughout the organization.

NOAA. **Integrated Ocean Observing System Data Management and Communications Concept of Operations.** October 2008.

This document describes the initial high-level concept of operations (CONOPS) for the DMAC subsystem. The focus of the document is to define the functions and services that IOOS stakeholders desire the DMAC to perform. It does not address the technology or architecture of how it will perform those functions and services.

NOAA. **NOAA Global Earth Observation Integrated Data Environment (GEO-IDE) Concept of Operations.** September 13, 2006.

NOAA's GEO-IDE is envisioned as a "system of systems" – a framework that provides effective and efficient integration of NOAA's many quasi-independent systems, which individually address diverse mandates in areas of resource management, weather forecasting, safe navigation, disaster response, and coastal mapping among others.

NOAA and NASA. **Geostationary Operational Environmental Satellite (GOES) Concept of Operations.** February 2008.

A CONOPS for the upgrading of the joint NOAA/NASA GEOS System to improve the nation's ability to monitor and forecast weather and environmental phenomena.

Pace, Peter. **Joint Operations Concepts Development Process**. *CJCSI 3010.02B*. 2006.

This instruction provides guidance for joint concept development and synchronizes the efforts of the joint concept community in the DOD capabilities-based approach to transformation. Joint concepts link strategic guidance to the development and employment of future joint force capabilities and serve as “engines for transformation” that may ultimately lead to doctrine, organization, training, materiel, leadership and education, personnel and facilities (DOTMLPF) and policy changes. This instruction defines the specific joint concepts known as the Joint Operations Concepts (JOPsC) family. It describes how these concepts are developed and managed, prescribes specific concept templates, introduces the Joint Concept Steering Group (JCSG), and describes joint experimentation as it relates to assessment of the JOPsC family.

Patrashkova, Ralitza R. and McComb, S. A. **Exploring why more communication is not better: insights from a computational model of cross-functional teams**.

Journal of Engineering and Technology Management. 21,1-2. March - June 2004.

Recent evidence suggests that communication and performance in cross-functional new product development (NPD) teams are curvilinearly related, but fails to pinpoint the reasons for this relationship. We developed a computational model to study the communication activities of cross-functional new product development teams. Our simulation confirms the recent evidence and offers insights into the underlying reasons for the curvilinearity. We provide guidelines regarding when the top performance occurs, for both frequency and duration of synchronous and asynchronous communication. Further, we perform a series of post-hoc analyses to examine the reasons for the curvilinearity of the communication-performance relationship. The work concludes with a discussion of the theoretical and practical applications of the results.

Patrashkova, Ralitza R.; McComb, S. A.; Green, S. G. and Compton, W. D. **Examining a curvilinear relationship between communication frequency and team performance in cross-functional project teams**. *IEEE Transactions on Engineering Management*. 50,3. 2003.

In this work, we postulate that both high and low levels of team communication can impede team performance, thus leading to a curvilinear relationship between team performance and team communication. To test this hypothesis, the relationships between face-to-face, e-mail, and telephone communication and team performance were examined for 60 cross-functional project teams.

Peterman, Mike. **Simulation Nation: Process simulation is key in a lean manufacturing company hungry for big results**. *Quality Digest*. May 2001.

As companies continue to look for more efficient ways to run their business, improve work flow and increase profits, they increasingly turn to lean manufacturing, which is used by best-in-class operations to improve their processes, achieve their goals and gain a competitive edge. Process simulation has become an increasingly important and integral tool as businesses look for ways to strip nonvalue-adding steps from their processes and maximize human and equipment effectiveness, all parts of lean manufacturing. The beauty of process simulation is that, while it complements and aids in lean manufacturing, it can also stand alone to improve business processes.

Richards, Nicole and Edson, R. **System Concept of Operations: Standards, Practices and Reality.** *11th Annual NDIA Systems Engineering Conference.* 2C7. October 20-23, 2008.

Presentation given at NDIA SE Conference aimed at: Exploring Industry Use of CONOPS, Defining a quality CONOPS, Developing Evaluation Criteria for CONOPS goodness.

Ring, Jack. **Concept of Operations: Purpose and Practice.** (*unpublished*)

This material is intended to guide authors of a CONOPS artifact toward successful fulfillment of their commitments. The reader will find guidance regarding the What, How, Who, When, Where and Why of CONOPS preparation, user support, and value assessment as well as the authors' self-reflections on their handiwork.

Ring, Jack and Wymore, A. W. **Overview of a CONOPS for an SE Education Community.** *Tenth Annual International Symposium of the International Council on Systems Engineering.* July 16-20, 2000.

This paper summarizes a concept of operations (CONOPS) for a Systems Engineering Education Community (SEEC). An SEEC enables those involved in performing systems engineering to improve systems engineering. An SEEC is envisioned as a vehicle for competency and proficiency growth by all practitioners of systems engineering as well as the vehicle for measuring, quantitatively, both the supply and demand sides of the SE learning community.

Rouse, W.B. and Morris, N.M. **On Looking into the Black Box: Prospects and Limits in the Search for Mental Models.** *Psychological Bulletin.* 100. 1986.

This paper explores a wide range of issues associated with research on mental models. Based on a functional perspective, mental models are defined as the mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states. Specifically, this paper reviews the ways in which different domains define mental models, characterize the purposes of such models, and attempt to identify the forms, structures, and parameters of models.

Sapre, Omkar. **Bentley Systems upbeat on Indian Market.** Updated November 17, 2008. Accessed March 15, 2009.

<http://economictimes.indiatimes.com/articleshow/3720769.cms?prtpage=1>.

When Volkswagen (VW) starts production at Pune next year, it will be one of its fastest built factory. The German carmaker built its facility using virtual 3D tools developed by Bentley Systems, the US-based infrastructure software solutions company.

Scotti, Richard S. and Gambhir, S. **A Conceptual Framework for a Customer-centered System Development Lifecycle Model.** *Sixth annual International Symposium of the International Council on Systems Engineering.* July 7-11 1996.

This paper is divided into two parts. The first contains a survey of various system development lifecycle models, including the Waterfall, Spiral, and Evolutionary Models. The second part introduces a conceptual framework for a new approach to complex, large-scale system developments based upon a customer focus throughout the system development lifecycle. This customer-focused approach utilizes automated Concept of

Operations (CONOPS) and group dynamics techniques to allow greater understanding of end-user 'actual' needs by system designers via more productive interactions. This approach is based on the development and use of detailed user objectives and critical success factors prior to and separate from their mapping into basic and derived system requirements. It provides a means for capturing previously obscure requirements within the user environment and mindset.

Siemens ITS. **STARNET Concept of Operations**. 2006.

This Concept of Operations document is intended to be read by transportation operations and planning personnel at STARNET stakeholder agencies, and by any contractors hired to assist with design, implementation, operation, or maintenance. As with nearly all documents used in the management of STARNET, this document will be used throughout the life of the system and will be updated as needed. During the planning and design stage of STARNET, it reflects the stakeholders' vision for how the system will be used and the role of various support measures. After the initial system is operational, this document will be updated to reflect how the system is actually used, to describe the support measures actually in place, and to help plan expansion or enhancements.

Silva,L.;Ramos,A. L. and Vilarinho,P. M. **Using simulation for manufacturing process reengineering-a practical case study**. *Simulation Conference Proceedings, 2000. Winter*. 2,2. December 10-13, 2000.

This paper presents a simulation study carried out to solve a problem of manufacturing process reengineering. The relevant operational performance measures were analyzed in order to allow for the proposal of a set of changes to the actual manufacturing operations.

Smircich, L. **Organizations as Shared Meanings**. *Organizational Symbolism*. pp. 55-65. Greenwich, CT: JAI Press. 1983

The overall purpose of this paper is to illustrate how organizations exist as systems of shared meanings and to highlight the ways in which shared meanings develop and are sustained through symbolic processes. The paper is derived from an ethnographic study of the executive staff of an Insurance Company. It describes the system of meaning the group members used to make sense of their experience and traces its emergence from their interaction and its influence on their further interaction. The paper shows how such symbolic processes as organizational rituals, organizational slogans, vocabulary, and presidential style contribute to, and are part of, the development of shared meanings which give form and coherence to the experience of organization members.

Smith,Brian. **Developing and Using a Concept of Operations in Transportation Management Systems**. *FHWA-HOP-07-001*. 2005.

This document is intended to serve both as a comprehensive introduction to the Concept of Operations and a reference document for professionals involved in developing and using a Concept of Operations for Transportation Management Systems.

Software Engineering Institute. **Concept of Operations for the CMMI**. *Carnegie Mellon University*. January 15, 2001.

This Concept of Operations (CONOPS) for the CMMI product suite includes the

background and description of the CMMI, the process for using the CMMI, the scenarios for use, the process for maintenance and support and the approach for adding new disciplines. It is intended that the CONOPS not only describe the use of the proposed product suite, but also be used to obtain consensus from the developers, users and discipline owners on the required infrastructure to develop, implement, transition and sustain the CMMI product suite.

Spiegel, Rob. **Manufacturing by Computer Simulation.** *Automation World*. October 2004. Recent advances in factory simulation are pushing the technology beyond its core use for modeling automation to also provide help in areas ranging from training and product design to warehouse management and supply chain planning.

The Boeing Company and Lockheed Martin Corporation. **CONOPS for the Systems and Software Test Track.**

This document has been built from the results of the Systems and Software Test Track Phase I contracted efforts with The Boeing Company and Lockheed Martin. This document communicates the user needs and the expectations of the proposed system.

Thompson, Ted. **Development of Operating Concepts.** *Fifth annual International Symposium of the International Council on Systems Engineering*. July 22-26, 1995. Systems engineering techniques, especially requirements collection and management, are well described in the literature but appropriate methods of determining and documenting operator requirements are not as widely discussed. The Canadian Airspace System (CAS) is a large, complex systems engineering task. This paper discusses the methods used by Transport Canada to elicit, review, discuss and document the operating concepts for the future evolution of the CAS.

Thronesbery, Carroll; Molin, A. and Schreckenghost, D. L. **Assisting CONOPS with Storyboards.** *Houston Human Factors Society Meeting*. April 24, 2009.

A Concept of Operations Storyboard Tool was developed to assist authors in building a concept of operations for a new system, refining it with stakeholders, and using it to support subsequent development activities. We illustrate some of these use cases to show this product-oriented workflow assistance as well as some of the more basic storyboard support. The Storyboard Tool was developed iteratively, testing successive prototypes by using the tool to support ongoing research and development projects at NASA Johnson Space Center. In addition to describing and illustrating the tool, we present lessons learned about integrating sketches and descriptions for clearer communication, the benefits of organizing descriptive information as structured data, and assisting the process of concept development. We also discuss supporting the role of human factors in systems engineering and the value of iterative development for systems with innovative human task support.

Thronesbery, Carroll; Molin, A. and Schreckenghost, D. L. **Concept of Operations Storyboard Tool Refinements Based on Practical Experiences.** *IEEE Aerospace Conference*. 2008.

A storyboard tool has been prototyped that supports authoring, evaluating, and exporting a concept of operations and its illustrations. A requirements engineering prototype has uncovered new requirements to communicate the intended use of the

storyboard tool. New designs include an elaborated help system, vertical linking of related information, and a work plan guide. A work plan guide reveals how authors can use the storyboard tool for the specific needs of the current project. We discuss the original approach and design along with the newly discovered requirements and designs to respond to them. Finally, we present lessons learned that we think may be applied to a wide range of software development projects.

Thronesbery,Carroll;Molin,A. and Schreckenghost,D. L. **A Storyboard Tool to Assist Concept of Operations Development.** *2007 IEEE Aerospace Conference*. March 3 - 10 2007.

We describe progress in developing a software tool to help create, communicate, and refine concept of operations (CONOPS) information. Information found in a CONOPS document is central to our tool. While there are some helpful documents prescribing CONOPS format, there is little direct assistance to express the concept of operations. We describe a tool to help author this information, integrate it with storyboard sketches, refine it through interaction with other stakeholders, and finally export the information in a form directly usable by developers. We have developed a demonstration prototype that performs the core functions of CONOPS definition. We discuss the results of this prototyping effort and plans for expanding the tool functions.

Tibbitts,Beth. **Flexible simulation of a complex semiconductor manufacturing line using a rule-based system.** *IBM Journal of Research and Development*. 37,4. 1993. Rule-based systems have been used to produce fast, flexible simulation models for semiconductor manufacturing lines. This paper describes such a rule-based simulator for a semiconductor manufacturing line, and the language in which it is written. The model is implemented in ECLPS (Enhanced Common Lisp Production System), also known as a knowledge-based or expert systems language. It handles very large models (thousands of data elements, or more) well and is very fast. Subsequent changes improved the speed several orders of magnitude over that of an older version of the model, primarily through use of a preprocessor to eliminate duplicate and redundant data, and by enforcing data typing to take advantage of special techniques for very fast processing of extremely large matches (hashed indices).

UN System Influenza Coordinator and Pandemic Influenza Contingency Team. **Concept of Operations for the UN System in an Influenza Pandemic.** September 19, 2008. The CONOPS serves as an overarching framework into which the pandemic preparedness plans of different UN agencies, country teams and missions are expected to fit in the event of a Human Influenza Pandemic.

Unknown. **What is a CONOPS anyway?** February 26, 2002.

A presentation made to the WMA Chapter of INCOSE on February 26, 2002 about CONOPS.

US Air Force. **Force Development CONOPS Civilian.** January 2006.

The Civilian Force Development Concept of Operations (CONOPS) is part of a series of transformational, strategic level Air Force (AF) CONOPS. It outlines a cohesive plan for developing the civilian component of the Total Force The strategy is to blend the skills,

knowledge, and experience of all components of the Total Force -- officer, enlisted and civilian - active, Guard or Reserve -- to leverage strengths to maximize mission success.

US Air Force. **Air Force Smart Operations for the 21st Century CONOPS. Working Draft Version 6.3.**

Air Force Smart Operations for the 21 Century (AFSO21) is our Air Force's dedicated effort to maximize value and minimize waste in all of our environments – operational, support, and otherwise; to fully integrate continuous improvement into all we do across the Air Force. AFSO21 is our standard concept and approach to immediate and long-term improvement. This CONOPS articulates what is required throughout the Air Force to continue to assure asymmetric air, space and cyberspace capability by focusing on the processes behind our core, governing and enabling processes in the Air Force.

US Department of Health and Human Services: Centers for Medicare & Medicaid. **Concept of Operations (CONOPS). System Lifecycle Framework Documentation.** January 2005.

US Department of Health and Human Services: Centers for Medicare & Medicaid Guide to CONOPS development.

US Department of Justice: JMD: Information Resources Management. **The Department of Justice Systems Development Life Cycle Guidance Document.** 2003.

Systems Development Life Cycle (SDLC) emphasizes decision processes that influence system cost and usefulness. This SDLC establishes a logical order of events for conducting system development that is controlled, measured, documented, and ultimately improved.

US Department of Transportation: Federal Highway Administration. **Concept of Operations. SE Guidebook for ITS.**

Objective, Description, Context of Process and FAQ's about US DoT's Federal Highway Administration CONOPS Documents.

US Department of Transportation: Federal Highway Administration. **Concept of Operations Template. SE Guidebook for ITS.**

Example of format and template of the US DoT Federal Highway Administration's CONOPS Documents.

US Marine Corps. **Common Logistics Command and Control System Concept of Operations.** April 19, 2004.

The purpose of this document is to provide a concept of operations (CONOPS) for the Common Logistics Command and Control System (CLC2S). The document will describe conceptually how CLC2S will be used and operated, identify standard processes and procedures required for the system to be implemented, and delineate additional opportunities for extended use and functionality.

Uygun,Özer;Öztemel,E. and Kubat,C. **Scenario based distributed manufacturing simulation using HLA technologies.** *Information Sciences.* 179,10. April 29, 2009.

This paper presents an overview of distributed manufacturing simulation as well as of information representation in distributed manufacturing simulation using high level

architecture (HLA) and its object model template (OMT). The concept is explained with a scenario which is provided to better address the object class structure, interaction class structure, attribute, parameter and data type tables.

van Gaasbeek, James R. **Operational Concepts**. *11th Annual NDIA Systems Engineering Conference*. 3D2. October 20-23, 2008.

This presentation will address the nature of the operations concept, how it is developed and by whom, and how it is used in the development, deployment, operations and support of a new or upgraded system.

Verma, Dinesh and Pennotti, M. **Fundamentals of Systems Engineering. Graduate Course Notes**. *Stevens Institute of Technology*. 2009.

Volzdoska, Ralitz; McComb, S. A. and Kennedy, D. M. **Optimizing Team Performance through Communication: The Role of Team Size, Interdependence and Communication Media**. *Third International Conference on Maintenance and Facility Management*. September 27-28, 2007.

This paper extends previous research that established a curvilinear relationship between team communication and performance by identifying the impact of team size, interdependence level, and media choice on this relationship. Using a communication-performance model we vary team size and interdependence levels across asynchronous, mixed, and synchronous media. Implications are discussed.

World Intellectual Property Organization. **Concept of Operations for the Reformed IPC**. *IPC/CE/36/11, Annex X*. February 18, 2005.

The purpose of CONOPS is to describe the classification and reclassification process of the reformed IPC (International Patent Classification) in sufficient detail to allow all industrial property offices to understand how the maintenance of the classification data of the core and advanced levels will be carried out.

Yoo, Y. and Kanawattanachai, P. **Developments of Transactive Memory Systems and Collective Mind in Virtual Teams**. *International Journal of Organizational Analysis*, 9,2. 2001.

In this study, we examine the developments of transactive memory systems and collective mind and their influence on performance in virtual teams. Building on an emerging body of socio-cognitive literature, we argue that transactive memory systems and the collective mind are two important variables that explain team performance. We tested our hypotheses with a longitudinal data set that was collected from 38 virtual teams of graduate management students from six universities in four countries over eight weeks. The results suggest that the influence of team members' early communication volume on team performance decreases as teams develop transactive memory systems and a collective mind. The results further suggest that the development of a collective mind represents a high-order learning in team settings.

Young, Eric C. **The U.S. Navy's Role in Executing the Maritime CONOPS for U.S. Homeland Security/Defense**. *Naval War College. Masters Thesis*. 2002.

The proposed U.S. HLS/D maritime CONOPS comprises Prevention, Defense, and Response phases and discusses how best the Navy may perform the relevant maritime

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tasks in each phase. Maritime tasks include: deterring enemy threats against the homeland; defending against enemy attacks; supporting civil authorities; security cooperation and contingency response with Canada and Mexico; and command and control coordination.

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