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Developing a Stakeholder-Assisted Agile CONOPS Development Process

Ali Mostashari,[1,] * Sara A. McComb,[2] Deanna M. Kennedy,[2] Robert Cloutier,[1] and Peter Korfiatis[1]

[1]*School of Systems and Enterprises, Stevens Institute of Technology, Hoboken*, NJ 07030
[2]*Department of Industrial and Systems Engineering, Texas A&M University*, 3131 TAMU, *College Station*, TX 77843

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ABSTRACT

Concepts of Operations (CONOPS) are documents describing the characteristics and intended usage of proposed and existing systems. They provide information about the requirements and future desired states the project aims to achieve. We reviewed 22 recent CONOPS from government and private sector institutions to ascertain the current approach to CONOPS development. Based on the CONOPS review and research literature, we highlight three key areas, stakeholder involvement, shared mental models, and visualization, through which the development process may be improved. Moreover, we suggest that the development process itself may be transformed into an agile process that addresses current shortcomings in the key areas. To do so, we propose an agile CONOPS development process conducted through three iteration-driven phases and present corresponding research and commercial tools that may be leveraged at each phase. As such, putting this agile process into effect may reduce development time, improve effectiveness, and change the perception of the CONOPS from a burdensome documentation procedure to an invaluable resource throughout the system lifecycle. © 2011 Wiley Periodicals, Inc. Syst Eng 15: 1–13, 2012

Key words: CONOPS; agile systems engineering; shared mental models; visualization; stakeholder involvement; agility, modeling; conceptual phase; requirements process

1. INTRODUCTION

A Concept of Operations (CONOPS) is a document describing the characteristics and intended usage of a proposed or existing system from the viewpoint of its users. Its purpose is to communicate the quantitative and qualitative system characteristics to all stakeholders and serve as a basis for stakeholder discussions about the system. Moreover, the CONOPS can help reach a "meeting of the minds" before the requirements process begins. Generated effectively, it may convey a clearer statement of intent than the requirements themselves.

Normally, a CONOPS is produced when the task has one of three objectives: (1) develop a new system or product, (2) modify/upgrade/change an existing system or product, or (3) create an operational strategy which may also include end of life activities. CONOPS development should occur during the concept stage [ISO/IEC, 2008] of the system development lifecycle. This may be between milestone A and milestone B for a US Department of Defense (DoD) program, or during the business development phase of a commercial program. The most traditional use of a CONOPS has been to describe complete, physical systems. They may also be useful when the characteristics of one, complex aspect of a system are

*Author to whom all correspondence should be addressed (e-mail: ali.mostashari@stevens.edu; mccomb@tamu.edu; d_kennedy@tamu.edu; robert.cloutier@stevens.edu; pkorfiat@stevens.edu).

needed, such as the security for a large scale project [Ammala, 2000] or for nonphysical projects such as software-intensive systems [Fairley et al., 1994]. Finally, as missions change, system requirements change, or derived requirements arise that affect the operation use of the system, the CONOPS should be updated.

Researchers and developers have opposing views regarding the generation of a CONOPS. Many researchers believe that the development and use of operational concepts at the start of large projects is essential [Gabb, 2001; Jost, 2007]. Indeed, 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 [Gabb, 2001] and be maintained throughout the engineering life cycle [Jost, 2007]. Despite the fact that documenting requirements can be overwhelming, the CONOPS should not be left out of the system development project at any time [Jost, 2007] as it is a complete kernel for any system development project that will scale into a multilevel, multipeer process of a complex adaptive system [Nelson, 2007]. To make the document more manageable, it can be broken down into subdocuments that may be useful at different stages of the life cycle and for different audiences [Gabb, 2002].

Alternatively, developers may view the CONOPS as a burden to the development process rather than an enabler due to the extensive documentation requirements [Gabb, 2001; Jost, 2007]. One potential reason for this characterization is that the CONOPS are often generated in the form of lengthy text-intensive documents, which are essentially a static representation of the user's desires at one point in time. Moreover, the document creation process offers little opportunity to visually observe behavior, interact with the analyst, communicate in real time, or develop a shared understanding of the problem/mission and its likely solution approaches. This scenario is particularly problematic for agile systems engineering, where development times are short and the need to adapt the outcome to continuous changes is paramount.

In this paper, we propose a three-stage agile CONOPS development process that supports the early phases of an agile systems engineering approach. The process incorporates insights from model-based systems engineering, requirement elicitation, shared mental models, negotiation and decision analysis tools, modeling tools, description languages, GUI generators, and collaboration environments. It allows for concurrent and sustained stakeholder involvement, facilitates shared mental model development, and streamlines the process of rapidly adapting the CONOPS when changes in needs and/or requirements arise across all stages of the development process.

2. CURRENT CONOPS DEVELOPMENT PROCESSES

Two international standards and one DoD Data Item Document (which we group into the category of standards for this paper) provide guidance regarding the content of a CONOPS:

- IEEE 1362-1998—IEEE guide for CONOPS document [IEEE, 1998]
- ANSI/AIAA G-043-1992—guide from American National Standards Institute [AIAA, 1993]
- DI-IPSC-81430—DoD data item description for CONOPS document.

In Table I we provide an overview of these three recommended formats for comparison.

To better understand how these standards are applied, we reviewed 22 representative strategic, operational, and product-centric CONOPS. A summary of the stated objective, type of CONOPS, document length, the process/approach used to develop the CONOPS (where available), and the length of the process (where available) are provided in Table II. Our review yielded several interesting insights:

- Less than 75% of the CONOPS researched actually list or identify specific mission needs.
- Nearly a third had no description of the background describing the current system, situation, or context in which it was embedded.
- Little attention was paid to other stakeholders who do not directly interact with the system, including acquisitions staff, government personnel, and regulatory agencies.
- Stakeholder assessment was not included in any of the standards; several of the CONOPS reviewed, however, did include stakeholder involvement, but not until later stages of development.
- Personnel related issues (e.g., personnel needs, personnel activities, personnel types, and personnel profiles) were rarely discussed.
- Less than 20% of the CONOPS examples identified associated risks of the system and its development.

With respect to the process, we also found that for a CONOPS adhering to all the steps outlined within the standards, its development process could take as long as 30 months. In other cases, when the bare minimum elements were selected, the CONOPS was finished within 3 months. In most cases the CONOPS development process was performed by a core CONOPS team and the draft sent out for review to the relevant stakeholders. The bulk of the time in the CONOPS development process appears to be the result of waiting for reviews and iterating among the CONOPS team members and the various stakeholders. The time required may be attributable to the text-based nature of the CONOPS, which makes editing a time-consuming and challenging process.

Finally, in most cases the CONOPS appear to have been produced to fulfill documentation requirements rather than to serve as a strategic/tactical system-planning tool. Table III shows the least used elements [Cloutier et al., 2009] in the reviewed CONOPS.

Considering the low number of CONOPS that identified critical CONOPS elements such as modes of operation, system interfaces, and personnel needs, one might arrive at the conclusion that the authors of many of the reviewed CONOPS did not consider the CONOPS as a vehicle mediate among members of the user, other stakeholder, and developer communities in a manner that facilitates designing a system holistically and in an integrated fashion.

Table I. Comparison of CONOPS Standards

IEEE 1362-1998 CONOPS Document Outline	DI-IPSC-81430 CONOPS Elements (DoD)	ANSI/AIAA G-043-1992 Operations Concept
Scope	Scope	Scope
Identification	Identification	System identification
Document overview	System overview	Purpose
System overview	Document overview	Overview
Referenced documents	References	Referenced Documents
Current system or situation	Title, revision, and date of all documents referenced	User-Oriented Description
Background, objectives, and scope	Current System or Situation	How mission accomplished
Operational policies and constraints	Background, objectives, and scope	Strategies
Description of the current system or situation	Operational policies and constraints	Tactics
Modes of operation for the current system or situation	Description of current system or situation	Policies
User classes and other involved personnel	Users or involved Personnel	Constraints
Support environment	Support concept	Who users are and what the users do
Justification for and nature of changes	Justification for Change	When and in what order operation takes place
Justification of changes	Justification for change	Personnel profile; organizational structure
Description of desired changes	Description of needed changes	Personnel interactions; activities
Priorities among changes	Priorities for change	Operational process models; sequence, interrelationships
Changes considered but not included	Changes considered but not included	Operational Needs
Concepts for the proposed system	Assumptions and constraints	Mission of personal needs derived from requirements of the system
Background, objectives, and scope	Concepts for New/Modified System	System Overview
Operational policies and constraints	Background, objectives, and scope	Scope
Description of the proposed system	Operational policies and constraints	Users
Modes of operation	Description of the new or modified system	Interfaces
User classes and other involved personnel	Users or involved personnel	States and modes
Support environment	Support concept	Capabilities
Operational scenarios	Operational Scenarios	Goals and objectives
Summary of impacts	One or more operational scenarios that illustrate the role of the new or modified system, its interactions with users, its interface to other systems, and all states or modes identified	System architecture
Operational impacts	Summary of Impacts	Operational Environment
Organizational impacts	Operational	Support Environment
Impacts during development	Organizational	
Analysis of the proposed system	Impacts during development	
Summary of improvements	Analysis of Proposed System	
Disadvantages and limitations	Advantages	
Alternatives and trade-offs considered	Disadvantages	
Notes	Alternatives and tradeoffs	

3. OPPORTUNITIES TO IMPROVE THE CONOPS DEVELOPMENT PROCESS

Based on our review of the current standards and guidelines for developing a CONOPS and multiple existing CONOPS, we identified a number of opportunities in which the CONOPS process could be improved. This paper focuses on three of those areas that could be improved and made agile. To realize the benefits purported by researchers, the CONOPS development process should:

- Involve relevant stakeholders in all phases of the CONOPS development process.
- Embed visualization within a CONOPS development tool to facilitate agility through the display of complex data and the ability to easily make modifications, by large numbers of stakeholders with varying roles.
- Assist shared mental model formation throughout the development process by leveraging an integrated toolset that enables stakeholder participation.

We examine each of these opportunities for improvement in the following subsections.

3.1. Stakeholder Involvement

The CONOPS development process should require active stakeholder participation from the beginning of the process, not just after a static document has been written. While this notion is commonly understood, it is often overlooked in practice [Roberts and Edson, 2008]. In many of the CONOPS we reviewed, we found stakeholders were involved after the preliminary CONOPS was created rather than during the process as we are advocating herein. Even two CONOPS that made specific reference to stakeholder involvement during CONOPS development only did so through stakeholder interviews and workshops, for the purpose of generating a list of desired capabilities [Lacroix et al., 2002] and defining customer needs [Booz Allen Hamilton, 2005]. Both of these CONOPS teams used this early input from stakeholder interactions to develop the CONOPS, but then left the stakeholders out of the process until after the initial CONOPS draft was generated.

The types of stakeholders that may be involved in a CONOPS development process are numerous and varied. Typically, a stakeholder can include any group or individual

Table II. Summary of CONOPS Reviewed

Stated Objective	Type of CONOPS	Document Length	CONOPS Process/Approach	Process Length
Boeing: Air Traffic Management Capacity Drive Operational Concept [Haraldsdottir, Schwab,andAlcabin, 1998]				
Describes system mission, functions, and available resources for developing operational concept for the US National Airspace System, and presents a logical functional structure for the overall system that ties together functions, resources and subsystems	Operational Strategy	10 pp	Unknown	Unknown
Boeing and Lockheed Martin: System and Software Test Track [Boeing and Lockheed Martin, 2009]				
Describes system characteristics of the Systems and Software Test Track from a user's viewpoint. Meant to capture user needs and express those needs in the users' terminology.	Modification to Existing System	47 pp	Built from the results of the Systems and Software Test Track Phase 1 contracted efforts with The Boeing Company and Lockheed Martin	Unknown
Business Transformation Agency: Business Enterprise Architecture (BEA) [Business Transformation Agency, 2007]				
Describes an improvement strategy for the BEA	Modification to Existing System	16 pp	Unknown	Unknown
City of Lincoln, Nebraska: Automated Vehicle Location [Mixon/Hill Inc., 2005]				
Describes current system state, establishes need for change, and describes proposed system. Designed for the system owners, system users, system developers, and system providers.	Modification to Existing System	55 pp	Unknown	Unknown
EPA: Financial System Modernization Project [Booz Allen Hamilton, 2005]				
Articulates vision and high-level requirements for the system, where users describe their expectations of the new system. Captures the results of conceptual analysis process. Used as input to a software requirements specification, as part of solicitation materials for acquiring new system, and to development of a formal, testable financial management system.	Modification to Existing System	147 pp	Office of the Chief Financial Officer (OCFO) is overseeing the CONOPS process, and revises based on stakeholder comments.	9 months
INCOSE: Systems Engineering Education Community (SEEC) [Ring and Wymore, 2000]				
Useful to prospective customers of the SEEC for validation that the concept responds to their needs or solicitation of improved expressions of needs; stimulating consideration of novel concepts pertinent to the SEEC; as a baseline for functional analysis and other steps in the process of systems engineering; as a baseline for interrelating the related work.	Operational Strategy	42 pp	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
NASA/NIA: Health Monitoring and Maintenance Systems Products [Darr, 2005]				
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	Modification to Existing System	146 pp	Initial Draft by CONOPS Team and Revisions based on Comments by Stakeholders	26 months
National Archives and Records Administration: Electronic Archive [Integrated Computer Engineering, 2004]				
Serves as a vehicle to communicate the high-level quantitative and qualitative characteristics of the system to the user, buyer, developer, and other stakeholders.	Modification to Existing System	86 pp	Initial development by a CONOPS development team utilizing existing documents and use-cases to extract user requirements. Draft provided to relevant stakeholders for comment. Final CONOPS issued after integration of comments.	30 months
NOAA: Integrated Ocean Observing System Data Management and Communications [NOAA, 2008]				
Defines approach of the NOAA IOOS Program to the DMAC subsystem, and socializes the concept with stakeholders, allowing them to better define and coordinate their own efforts to revise/build observation and modeling/analysis subsystem components of the national IOOS	Operational Strategy	74 pp	CONOPS draft used as a stakeholder review process document	Unknown
NOAA: Integrated Weather Forecast Process [Johnston and Ladd, 2004]				
Describes framework for an improved, standardized, and relevant CWSU operation in support of the NAS. Serves as guide for follow-on efforts to establish staffing requirements, procedures, as well as determining changes to related documentation.	Operational Strategy	5 pp	A functional audit of CWSUs and an audit assessment identified each of these as areas of needed improvement."Tiger Team" assembled to develop CONOPS for enhancing CWSU weather services.	~ 12 months
NOAA: Geostationary Operational Environment Satellite (GOES) [NOAA and NASA, 2008]				
Describes process for preparing for the procurement of the next-generation GOES series to continue its mission and to clarify the requirements.	Modification to Existing System	64 pp	Unknown	30 months

Table II (continued)

Stated Objective	Type of CONOPS	Document Length	CONOPS Process/Approach	Process Length
NOAA: River Forecast Center [Lynott, 2005]				
1) explores possibility of using a grid processing tool in the RFCs, 2) addresses RFC operational deficiencies, 3) provides added system functionality, 4) meet the need for a nationally supported tool that can be utilized by all RFCs to prepare the Quantitative Precipitation Forecast, and 5) improves the efficiency of the work performed at the RFCs	Modification to Existing System	17 pp	Unknown	6 months
NATO: Missile Early Warning System [Gilibert and Thevenot, 1997]				
Assists development of a more effective ABTM system	Modification to Existing System	8 pp	Unknown	Unknown
State of Maine: Incident Communications Interoperability [Maine State Office of Information Technology, 2007]				
Provides guidance to public safety agencies and non-traditional responders for developing and employing on-scene interoperability through an effective Incident Communications program. Focused on incident communications requirements and the role of interoperability	Operational Strategy	8 pp	Unknown	Unknown
United Nations: U.N. System Response in an Influenza Pandemic [UN System Influenza Coordinator, 2008]				
Defines ways in which all elements of the UN System should collaborate with each other in addressing the major challenges that are likely to be posed during different phases of a severe influenza pandemic	Operational Strategy	9 pp	Unknown	Unknown
United States: Grants.gov Improvement [Grants.gov, 2007]				
Identifies extended system capabilities to handle increasing numbers of agencies and grants listed, increasing numbers of applicants, growing numbers of search requests, accommodating multiple browsers, and adapting the use of a software forms package.	Modification to Existing System	23 pp	Unknown	Unknown
US Air Force: Air Force Smart Operations [US Air Force Smart Operations, 2009]				
Articulates what is required throughout the Air Force to continue to assure asymmetric air, space and cyberspace capability. Represents the recognition that AFSO21 applied will result in processes that are standardized, effective, efficient and responsive in meeting demands - ultimately improving combat capability.	Operational Strategy	34 pp	Unknown	Unknown
US Air Force: Civilian Force Development [US Air Force, 2006]				
Offers a cohesive plan for the civilian force development of the Air Force.	Operational Strategy	18 pp	Mandate-based	Unknown
US Marine Corps: Logistics Command and Control System [US Marine Corps, 2004]				
Describes conceptually how CLC2S will be used and operated, identify standard processes and procedures, and delineate additional opportunities for extended use and functionality.	Operational Strategy	21 pp	Written by Mr Jerome McGovern of Impact Resources Technologies (process unknown)	Unknown
US Navy: Deep Diving Submarine [Lacroix, 2002]				
Provides insight into the capabilities that an NR-2 platform or system might incorporate and help define operational capability requirements based on a prioritization of those capabilities and the missions they would support.	Modification to Existing System	28 pp	Convened three conferences, where subject matter experts contributed to defining mission profiles required. Profiles provided the basis for prioritizing design-driving capabilities. Used “group systems” decision making support approach.	Unknown
World Batch Forum: Pharmaceutical Plant Production Information Technology [Karlsson and Wauthier, 2001]				
Describes method to integrate miscellaneous IT packages bridging control systems and business systems.	Operational Strategy	16 pp	First major release during design phase. After defining OCD scope and structure with the core team, a conference was organized where process groups gathered to describe their part of the process.	Unknown
World Intellectual Property Organization: Intellectual Property Management [World Intellectual Property Organization, 2005]				
Describes the classification and reclassification process of the reformed IPC 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.	Modification to Existing System	39 pp	Unknown	Unknown

Table III. Least Commonly Used CONOPS Elements in Reviewed CONOPS

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			

who may be affected by or accountable for a system [de Weck, 2009]. By this definition, stakeholders should clearly include the users and developers of a system, but can also include individuals who perform acquisition, contracting, testing, maintenance, life-cycle support, logistics, management, manufacturing, regulation, and analysis, as well as any additional individuals or organizations that are affected or affect the system's operations. Moreover, the owners of any interfacing systems should also be considered stakeholders, and therefore, included in the CONOPS process. The potential stakeholders involved in a CONOPS development should be determined through consensus between the system customers and developers based on the system boundaries, anticipated operations, and expected operational environment.

If the right stakeholders are chosen and incorporated into the CONOPS development process, the advantages include:

- The CONOPS can be developed much faster via a few joint sessions conducted in person or through virtual meetings.
- The stakeholders can help the CONOPS development team decide which steps to skip in the process without compromising quality.
- The risks associated with system implementation and costs can be better estimated having most of the relevant stakeholders at the table.
- Feelings of ownership evolve within a wider community across the organization(s).

3.2. Visualization

Although text based CONOPS have been traditionally used, they have several limitations when the process includes multiple users distributed across time and space. For example, editing text documents collectively and interactively is difficult. Furthermore, text-based CONOPS cannot easily be tailored to meet the specific needs of various constituencies within the system.

In recent years, several development efforts have been undertaken to incorporate graphical visualization into conceptual models. The following discussion describes three such efforts. First, Chen et al. [2008] established a means of creating meta-data of geographic conceptual scenarios that are based on 3D icons. Second, Keel [2007] created EWall, a visual analytics environment for the support of distributed collaboration where "virtual transactive memory" can be created and managed by the team members. Finally, Thronesbury, Molin, and Schreckenghost [2009] proposed the use of a storyboarding tool for building CONOPS for new systems that would allow increased stakeholder involvement and continued use throughout the development cycle. Building on these approaches suggests that a sophisticated, yet user-friendly, tool may be used to facilitate CONOPS generation graphically (vs. textually). Such a system might have a modular structure that is simple to modify and a layout that is intuitive to navigate. Deploying a graphical CONOPS development tool in the field should have several advantages, including:

- 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.
- The learning curve to become proficient with the graphical CONOPS development system will be very quick.
- All participants will have ready access to all aspects of the CONOPS for simultaneous editing during joint sessions, reviewing decisions made at later points in time, and automatically generating standard text documents that are tailored to specific uses.

3.3. Shared Mental Models

Shared mental models play a critical role in all stages of the CONOPS development process. Mental models are simplified characterizations humans create [Johnson-Laird, 1983] that help them to describe, explain, and predict what is happening in their surroundings [Rouse and Morris, 1986]. As team members interact, their mental models become similar to, or shared with, their teammates' mental models [McComb, 2007]. Teams that possess shared mental models have routinely attained higher levels of performance [McComb, 2008]. As such, they must be considered when examining

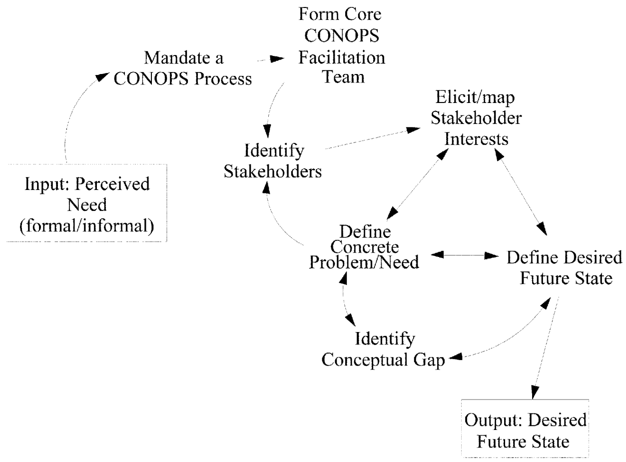

Figure 1. Stage 1: Conceptual phase.

teams facing operational tasks that require agility such as mission planning and intelligence analysis.

Shared mental models are not generic. Indeed, the knowledge embedded in them may be about "tasks, situations, response patterns, working relationships" as well as "internalized beliefs, assumptions, and perceptions" relevant to their current activities [Klimoski and Mohammed, 1994: 426]. Moreover, individuals possess multiple mental models simultaneously that may, or may not, be relevant to the particular activities transpiring at a given time. For example, at the initial stages of CONOPS development, shared mental models about the purpose(s) of the proposed system must be developed to ensure that all perspectives are accounted for in the description of desired future states. Regardless of the content, a CONOPS development process that facilitates the expedited creation of shared mental models will be beneficial in several ways, including:

- Consistent perspectives across all participants may be established and should govern activities throughout the various stages of the CONOPS development process.
- Overall time to develop a CONOPS may be reduced.
- Problems due to misunderstandings that often occur during development and implementation may be minimized.
- Customers may get the product/process that meets their expectations.

4. AN AGILE CONOPS DEVELOPMENT PROCESS

Based on our review of current CONOPS development processes and the opportunities for improving it that resulted from that review, we propose the following three-stage, stakeholder-assisted process for agile CONOPS development. The stages are (1) Conceptual, (2) Specification, and (3) Design and Implementation.

While in theory these stages mirror the standard phases that comprise the current approaches we reviewed, our process is different in three distinct ways. First, our process is reliant upon stakeholder input throughout the process (vs. at the end). Second, we formally emphasize the conceptual stage (vs. embedding it as a component of the specification phase). Finally, we incorporate feedback and feed-forward loops to ensure that the original intention is not lost (vs. a primarily linear approach that may diverge significantly from the original intention as the process evolves). In addition to these improvements, we have designed a robust development process such that CONOPS may be applied more broadly, to a wide array of systems projects, across disciplines, and throughout a product/process life-cycle. We describe our process in the following subsections.

4.1. Stage 1—Conceptual Phase

Figure 1 shows the conceptual phase and Table IV also shows the set of tools and methods that can be leveraged at this stage to increase the effectiveness of the process. The agile CONOPS development 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 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

Table IV. Stage 1: Conceptual Phase Process Steps, Tools, and 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 the problem, define the desired state, identify gaps	Visual tools: Modular/Lego, storyboarding, causal loop diagrams etc.	Brainstorming, consensus seeking, shared mental models, traditional research methods etc.

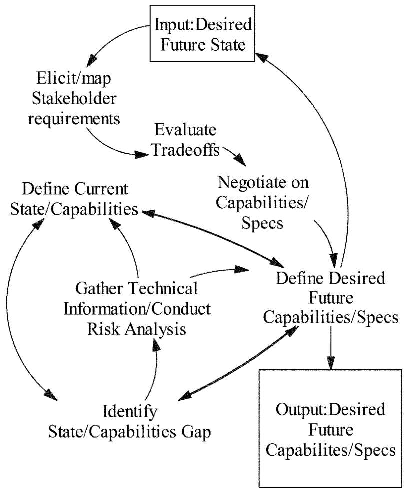

Figure 2. Stage 2: Specification phase.

the PLP (Participation Level Points) heuristic and the SPK (Stake Power Knowledge) framework [Mostashari, 2005], 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 are subsequently mapped using such tools as 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 characterized. This iterative process of refinement generates shared mental models, such that those involved in the process will have similar expectations as they move forward. Finally, at the completion of this phase 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 to explicitly include, as many organizations rush into the specification phase without a clear agreement about the existing situation and desired future state.

4.2. Stage 2—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 tradeoff analysis is conducted to assess the feasibility of the requirements. The evaluation of tradeoffs serves as a basis for negotiations among the user community, the developers, and the decision-makers on desired future specifications and their prioritization. Comparing the desired future specifications with existing capabilities and specifications allows the participants to identify the gaps, gather technical data, conduct risk analyses on features of the desired future state, and finalize the detailed specifications and requirements of the desired future state of the system. A variety of methods such as discourse integration, contextual analysis, data analysis, utility theory, multiattribute tradeoff analysis, consensus seeking negotiations, group brainstorming, consensus seeking, shared mental models development, traditional research methods, risk analysis, etc. can be leveraged at this stage to get to the final specifications and requirements output for the desired future system, respectively. Figure 2 and Table V show this iterative process and the tools and methods that can be used to facilitate each step of this phase.

4.3. Stage 3—Design and Implementation Phase

In the final stage the inputs from Stage 2, 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. Figure 3 and Table VI show the process steps for this stage and the relevant tools and methods that can be leveraged. Using tradeoff analysis to identify priorities in the design and implementation of the desired future system, two outputs (i.e., the overall system architecture and a management and implemen-

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

Elicit and map stakeholder technical requirements	Surveys, interviews, face-to-face discussions	Discourse integration, contextual analysis, data analysis, utility theory
Evaluate tradeoffs: capabilities versus specifications	Multi-attribute decision-support tools	Multi-attribute trade-off analysis
Negotiate on capabilities and specifications	Model-based negotiation tools	Consensus seeking Negotiations
Technical situational analysis: Define current situation, define desired capabilities and specifications, identify gaps, conduct 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.

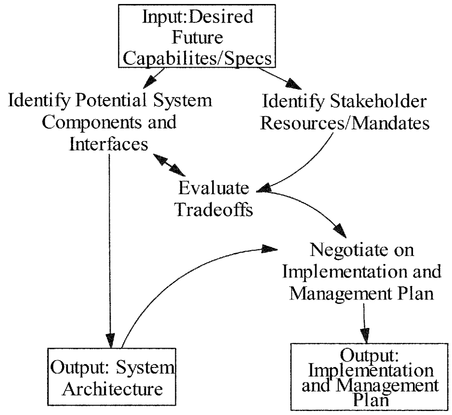

Figure 3. Stage 3: Design and implementation phase.

tation plan) can be negotiated among the stakeholders. As with Stages 1 and 2, this process is iterative and the cycles end when stakeholders converge on, and attain agreement about, the two outputs.

5. LEVERAGE POINTS

When implemented, the agile CONOPS development process we advocate in this paper may bring the divergent perspectives of the researchers and developers closer together. Our process, facilitated by corresponding tools at each phase, fosters the practices that will benefit the development process, while minimizing the burden and limited usefulness of static documents that rarely encompass the perspectives of all vested parties. Indeed, our approach has the potential to bring about the following leverage points:

1. **Interactive sharing of data, knowledge and resources:** By involving all appropriate parties and providing them with an easily accessible graphical interface, the draft CONOPS can be developed in an interactive and informed manner. Moreover, when user groups, developers, decision-makers (i.e., those with financial resources and mandates), and other relevant parties are active participants in the process, rapid shared mental model development is possible in all three stages; the correct elements of the CONOPS will be identified and included; and, depending on the type and scope of the project, the process may be completed in a few sessions.
2. **Collaborative decisions on process detail:** With all critical stakeholders present for the entire development process, the process will be more agile. For example, participants can make educated decisions concerning what steps may be omitted from the CONOPS development process or if fewer iterations will result in an acceptable solution. Such decisions are possible because any risks associated with such reductions can be accepted by the stakeholder community as a whole. When a core CONOPS team makes such decisions in isolation, as is currently the norm, buy-in from the stakeholder community may be difficult to attain and/or take additional time to secure, even if the decisions represent an optimal level of detail.
3. **Automatic report generation:** The development process we have presented herein is not a documentation exercise. Rather it is a planning and shared vision exercise in which all relevant parties work together to converge on a mutually acceptable design and implementation plan. Documentation is still a necessary outcome of the process, as the group will need to submit a standard CONOPS to contractors or others in charge of actual systems implementation. We envision a graphical CONOPS tool with the capability to convert the graphical CONOPS into a standard CONOPS format without the need for the group to actually write the report. Incorporating this type of capability into the tool will save substantial documentation time and allow the group to focus on activities that will result in a more acceptable, robust end product (vs. a document of limited value).

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

Identify stakeholders resources and 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

6. CONCLUSIONS AND FUTURE WORK

Our review of existing CONOPS development processes, the literatures on shared mental models, visualization, and model-based systems engineering provided us with a basis on which to design an agile CONOPS development process. The process we proffer has the potential to save substantial CONOPS development time, while also improving its effectiveness. Moreover, by engaging developers, users, and other stakeholders throughout the process, the outcomes will better represent the interests of all relevant parties.

Research is needed to design, develop, and test a tool to support the agile CONOPS development process we have presented. Many of the components are readily available. Determining how best to combine and package them, however, is not a trivial task. For instance, one necessary advancement is to include the ability to create integrated concept models that can be simulated as part of the process. A key challenge to realizing such an advance is incorporating the ability to easily change the models as new information becomes available or new alternatives need to be tested. If connections among the concept model components were not previously envisioned, yet subsequently included in the modular simulation environment, the outcome of the simulation may not be accurate. Many such challenges must be addressed before the graphical CONOPS tool we have described can be realized. In addition, the graphical CONOPS process needs to be used in actual test cases to determine its effectiveness and efficiency in producing superior outcomes to the conventional CONOPS processes.

Implementing the three-stage stakeholder-assisted process for agile CONOPS development we introduced in this paper is, however, not conditional on the development of a tool specifically designed to support the process. Benefits may be realized to some degree by simply following our iterative process. Yet, to fully exploit the leverage points we have identified, a corresponding graphical CONOPS tool that supports and facilitates the process is critical to the conversion of CONOPS development from a process many view as a burden to an invaluable process.

7. GLOSSARY

AFSO21 Air Force Smart Operations for the 21st Century
AIAA American Institute of Aeronautics and Astronautics
ANSI American National Standards Institute
ATBM Anti Tactical Ballistic Missiles
CLC2S Common Logistics Command and Control System
CONOPS Concepts of Operations
CWSU Center Weather Service Units
DI-IPSC Data Item Description for Information Processing Standards for Computers
DMAC Data management and communications
DoD Department of Defense
EMWG Education Measurement Working Group of the International Council on Systems Engineering
EWall An electronic interaction space designed specifically to facilitates collaboration
GUI Graphical User Interface
IEEE Institute of Electrical and Electronics Engineers
INCOSE International Council on Systems Engineering
IOOS Integrated Ocean Observing System
IPC International Patent Classification
IT information technologies
NAS National Airspace System
NOAA National Oceanic and Atmospheric Administration
NR-2 NR-2 is the name of a proposed US Navy Deep Diving Submarine
OCD Operational Concept Document
OCFO Office of the Chief Financial Officer
PLP Participation Level Points
RFC River Forecast Center
SEEC System Engineering Education Community
SPK Stake Power Knowledge
UN United Nations
US United States

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REFERENCES

American Institute of Aeronautics and Astronautics (AIAA), ANSI/AIAA guide for the preparation of operational concept document, G-043-1992, ANSI/AIAA G-043-1992, Reston, VA, 1993.

Boeing and Lockheed Martin, Concept of operations for the systems and software test track, version 0.95, https://www.sprucecommunity.org/Shared Documents/SPRUCEConceptofOperations.pdf), retrieved September 1, 2009.

Booz Allen Hamilton, Concept of operations for Environmental Protection Agency Financial System Modernization Project, US Environmental Protection Agency, Washington, DC, 2005, http://epa.gov/ocfo/modernization/pdfs/CONOPS_Final_2005_10_26.pdf, retrieved September 1, 2009.

Business Transformation Agency, Concept of operations for Business Enterprise Architecture (BEA) requirements, Department of Defense, Washington, DC, 2007, www.docstoc.com/docs/794524/BEA-Concept-of-Operations-CONOPS, retrieved September 2, 2009.

M. Chen, G. Lu, Y. Wen, H. Tao, and H. Su, Study on the modelling of geographic conceptual scenario based on 3D icons, Int Arch Photogramm Remote Sens Spatial Inform Sci 37(Part B4) (2008), 527–532.

R. Cloutier, A. Mostashari, S. McComb, A. Deshmukh, J. Wade, D. Kennedy, and P. Korfiatis, Investigation of a graphical CONOPS (Concept of Operations) development for agile systems engineering, Technical Report SERC-2009-TR-003, Stevens Institute of Technology, Hoboken, NJ, October 31, 2009.

R. Cloutier, A. Mostashari, S. McComb, A. Deshmukh, J. Wade, D. Kennedy, and P. Korfiatis, Investigation of a graphical CONOPS (Concept of Operations) development for agile systems engineering, Technical Report SERC-2009-TR-007, Stevens Institute of Technology, Hoboken, NJ, May 31, 2010.

S. Darr, NASA Aviation Safety & Security Program (AvSSP) concept of operation for health monitoring and maintenance systems products, National Institute of Aerospace, ICF Consulting, Fairfax, VA, 2005, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.97.383&rep=rep1&type=pdf, retrieved September 1, 2009.

O. de Weck, Stakeholder Assessment Lecture Notes, 16.842, Fundamentals of systems engineering, MIT Open Courseware, Massachusetts Institute of Technology, Cambridge, MA, Fall 2009.

A.P. Gabb, Front-end operational concepts—starting from the top, Proc Eleventh Annu Int Symp Int Council Syst Eng, International Council of Systems Engineering, Seattle, WA, 2001.

A.P. Gabb, Operational concepts—some variations, Syst Eng Test Eval Conf,. 2002.

H. Gilibert and R. Thevenot, Concept of operations of HALE UTA in an InfraRed Early Warning mission for theater missiles defense, AGARD MSP Symp Syst Des Considerations Unmanned Tactical Aircraft, 1997, http://ftp.rta.nato.int/public//PubFulltext/AGARD/CP/AGARD-CP-594///10SE2-07.pdf, retrieved September 2, 2009.

Grants.gov, Concept of Operations for the Grants.gov system, version 2.0, US Department of Health and Human Services, Washington, DC, 2007, http://www.grants.gov/assets/CONOPS.pdf, retrieved September 3, 2009.

A. Haraldsdottir, R. W. Schwab, M. S. Alcabin, Air Traffic Management Capacity- Driven Operational Concept through 2015. 2nd USA/Europe Air traffic Management R&D Seminar. (1998). Retrieved September 1, 2009, (www.boeing.com/commercial/caft/reference/documents/ATMCapCon.pdf).

IEEE, IEEE guide for information technology—system definition—Concept of Operations (CONOPS) document, IEEE Std 1362™ - 1998 (R2007), IEEE CONOPS Standard, New York, 1998.

Integrated Computer Engineering. Concept of operations v4.0 for the National Archives and Records Administration Electronic Records Archives Program Management Office, Chantilly, VA, 2004, www.archives.gov/era/pdf/concept-of-operations.pdf, retrieved September 1, 2009.

ISO/IEC, ISO/IEC 15288-2008 systems and software engineering—systems lifecycle processes, International Organization for Standardization, Geneva, Switzerland, 2008.

P.N. Johnson-Laird, Mental models: Towards a cognitive science of language, inference, and consciousness, Harvard University Press, Cambridge, MA, 1983.

K. Johnston, and J. Ladd, A concept of operations for an integrated weather forecast process to support the national airspace system, 11th Conf Aviation Range Aerospace, 2004, http://ams.confex.com/ams/pdfpapers/81899.pdf, retrieved September 1, 2009.

A.C. Jost, ConOps: The cryptex to operational system mission success, CrossTalk J Defense Software Eng 20(10) (2007), 13–16.

G. Karlsson and S. Wauthier, Operational concept document: A process based integration of production IT solutions in a pharmaceutical plant, World Batch Forum North Am Conf, 2001, www.controlglobal.com/Media/News/080826_WBF_Operational%20Concept.pdf, retrieved September 2, 2009.

P.E. Keel, EWall: A visual analytics environment for collaborative sense-making, Inform Visual, 6 (2007), 48–63.

R. Klimoski and S. Mohammed, Team mental model: Construct or metaphor? J Management 20 (1994), 403–437.

F.W. Lacroix, R.W. Button, S.E. Johnson, J. Chiesa, and J.R. Wise, A concept of operations for a new deep-diving submarine, U.S. Navy, RAND, Santa Monica, CA, 2002, www.rand.org/pubs/monograph_reports/MR1395/index.html, retrieved September 1, 2009.

K. Lynott, NOAA National Weather Service Concept of Operations River Forecast Center (RFC) analysis and gridded forecast editor improvement, NOAA Office of Climate, Water and Weather Services, Silver Spring, MD, 2005, http://fxa.noaa.gov/requirements/awips-OB8/3422-GFE/CONOPS.doc, retrieved September 1, 2009.

Maine State Office of Information Technology. State of Maine ConOps for incident communications interoperability, Augusta, 2007.

S.A. McComb, "Mental model convergence: The shift from being an individual to being a team member," Multi-level issues in organizations and time, F. Dansereau and F.J. Yammarino (Editors), Elsevier Science, Oxford, 2007, pp. 95–147.

S.A. McComb, "Shared mental models and their convergence," Macrocognition in Teams, M. Letsky, N.W. Warner, S.M. Fiore, and C.A.P. Smith (Editors), Ashgate, London, 2008, pp. 35–50.

Mixon/Hill Inc., StarTran automated vehicle location system Concept of Operations. Response to City of Lincoln StarTran RPF 05-053, Lincoln, NE, 2005, www.lincoln.ne.gov/city/pworks/startran/avl/pdf/concept.pdf, retrieved September 1, 2009.

A. Mostashari, Stakeholder participation in sociotechnical systems decision-making and design, Conceptual Advances, New York, 2005.

G.G. Nelson, "The ConOps in a self-similar scale hierarchy for systems engineering," Proc Conf Syst Eng Res, 2007.

NOAA, Integrated ocean observing system data management and communications Concept of Operations, National Oceanic and Atmospheric Administration, Washington, DC, 2008, http://secoora.org/documents/planning/national/dmac-conops-plan.pdf, retrieved September 1, 2009.

NOAA and NASA, Geostationary Operational Environmental Satellite (GOES) Concept of Operations, NASA, Houston, TX, 2008, www.goes-r.gov/procurement/ground_documents/Reference%20Documents/P417-R-CONOPS-0008_V2.3.pdf, retrieved September 1, 2009.

J. Ring and A.W. Wymore, Concept of Operations for a systems engineering education community, Education Measurement Working Group, International Council on Systems Engineering (INCOSE), Seattle, WA, 2000, (www.incose.org/ProductsPubs/PDF/ConopsOfAnSEEdCommunity_2004-0315.pdf, retrieved September 2, 2009.

N. Roberts and R. Edson, System Concept of Operations: Standards, practices and reality, 11th Annu NDIA Syst Eng Conf, 2008.

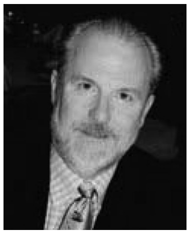
W.B. Rouse and N.M. Morris, On looking into the black box: prospects and limits in the search for mental models, Psychol Bull 100 (1986), 349–363.

C. Thronesbery, A. Molin, and D. Schreckenghost, Assisting ConOps with storyboards, presentation slides, Houston Hum Factors Soc Meet, April 24, 2009.
UN System Influenza Coordinator, Concept of Operations for the UN System in an influenza pandemic, UN System Influenza Coordinator and the Pandemic Influenza Contingency Team, WHO, Geneva, Switzerland, 2008,(www.un-pic.org/web/documents/english/UN%20System%20CONOPS%20(September %202008).pdf, retrieved September 1, 2009.
US Air Force. Force development CONOPS civilian, Washington, DC, 2006, www.safia.hq.af.mil/shared/media/document/AFD-070904-028.pdf, retrieved September 1, 2009.
US Air Force, USAF smart operations for the 21st century CONOPS, Working Draft Version 6.3, Washington, DC, 2009, www.501csw.usafe.af.mil/shared/media/document/AFD-0802 12-052.pdf, retrieved September 1, 2009.
US Marine Corps, Common logistics command and control system Concept of Operations, Washington, DC, 2004, www.rwappleton.com/ruploads/CLC2S%20CONOPS.pdf, retrieved September 3, 2009.
World Intellectual Property Organization, Concept of Operations for the reformed IPC, Geneva, Switzerland, 2005, www.wipo.int/edocs/mdocs/classifications/en/ipc_ce_33/ipc_ce_33_6_suppl_1.pdf, retrieved September 2, 2009.

Ali Mostashari is the Director of the Infrastructure Systems Program and the Director of Center for Complex Adaptive Sociotechnological Systems (COMPASS) at Stevens Institute of Technology, where he also serves as an Associate Professor at the School of Systems and Enterprises. He received his Ph.D. in Engineering Systems/Technology, Management and Policy from MIT, a Master of Science in Civil Engineering/Transportation from MIT, a Master of Science in Technology and Policy from MIT, a Master of Science in Chemical Engineering/Biotechnology with a minor in Business Administration from the University of Nebraska, a Graduate Certificate in Negotiation and Conflict Resolution from Harvard University, and a Bachelor of Science in Chemical Engineering/Energy Systems from Sharif University of Technology.

Sara A. McComb is an Associate Professor at Purdue University, where she has a joint appointment in Nursing and Industrial Engineering. Prior to joining Purdue, she was the Parsons Career Development (Associate) Professor of Engineering Management at Texas A&M University and served on the faculty of the Isenberg School of Management at the University of Massachusetts Amherst. She received her B.S.I.E. from GMI Engineering & Management Institute, her M.S.E.S. from Rensselaer Polytechnic Institute, and her Ph.D. from Purdue University's School of Industrial Engineering. Dr. McComb's research interests include examining teams, particularly their communication and cognitive processes. Her research has been funded by the National Science Foundation, the Office of Naval Research, and the *Department of Defense*, and published in journals such as the *IEEE Transactions on Engineering Management*, *Human* Factors, and the *Journal of Engineering and Technology Management*.

Deanna M. Kennedy is an Assistant Professor in the Business Program at the University of Washington Bothell. She holds a B.S. in Biological Sciences from the University of California, Davis and an MBA with honors from Golden Gate University in San Francisco, CA. She received her Ph.D. in Management Science from the Isenberg School of Management, University of Massachusetts Amherst. Her dissertation won the 2009 Dissertation Prize for research on small groups by the Group Psychology and Group Psychotherapy Division of the American Psychological Association. Dr. Kennedy's research interests include the utilization of cognition, communication, and collaboration in group and team operations. Her research has been published in Production Planning and Control, Theoretical Issues in Ergonomics Science, and Decision Sciences. She is a member of the Decision Sciences Institute, the Interdisciplinary Network for Group Research (INGRoup), and Institute for Operations Research and the Management Sciences (INFORMS).



Robert Cloutier is an Associate Professor of Systems Engineering at Stevens Institute of Technology and an Associate Professor II at Buskerud University College, Kongsberg, Norway. He also serves on the Scientific Advisory Board for the National Science Foundation Engineering Research Center for Compact and Efficient Fluid Power. Dr. Cloutier has over 20 years experience in systems engineering and architecting, software engineering, and project management. Prior to Stevens, Dr. Cloutier was a Principle Engineer at Lockheed Martin Mission Systems & Sensors and at Boeing Helicopters as an Associate Technical Fellow. Prior to that, he was an antisubmarine warfare officer and a machinery officer in the US Navy. His research interests include systems engineering patterns, systems architecture, architecture entropy, and Model Based Systems Engineering (MBSE), and applying systems engineering to new domains and technologies. Rob received the 2009–2010 Alexander Crombie Humphreys Distinguished Associate Professor Teaching Award at Stevens. He belongs to the International Council on Systems Engineering (INCOSE) and ACM. He received his Ph.D. in Systems Engineering from Stevens Institute of Technology, an M.B.A. from Eastern University, and a B.S. from the US Naval Academy.

Peter Korfiatis has developed chemical and environmental systems for a number of small startup research companies. He is now a research assistant at Stevens Institute of Technology pursuing a Ph.D. in Systems Engineering. His research interests include Model Based Systems Architecture, Concept of Operations Development and Systems Architecture Entropy. Peter holds a B.S. in Chemical Engineering from Columbia University and an M.E. in Engineering Management from Stevens Institute of Technology.