USING 3D GAMING TECHNOLOGIES TO IMPROVE THE CONCEPT OF OPERATIONS (CONOPS) PROCESS

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ABSTRACT

Some believe that the weakest link in systems engineering is often between what the stakeholder desires and what the development team believes is needed. The CONOPS can be a means to bridge this understanding gap. The systems engineering community has identified a need to improve the CONOPS development process and increase the level of understanding between stakeholders and engineers. The research presented here has led to the development of the Integrated Concept Engineering Framework to explore and demonstrate the effectiveness of virtual environments, gaming technologies and visualization in improving the CONOPS development process. This work has shown that 3D visualization has the potential to improve how stakeholders reason about operational concepts. This paper will review the need for an improved CONOPS and report on the research results and findings. Finally, the authors will discuss future directions in which the research can further mature.

INTRODUCTION

At the onset of any engineering challenge, it is often the case that engineers do not fully understand the problems that need to be addressed and the operational environment in which the solution will be deployed. A system's end users typically have a better grasp of these considerations, and successful system development will often hinge on how well users and systems engineering are able to communicate and reach a shared mental model. As user communities grow in size and products are expected to operate in a variety of environments, building a shared mental model is becoming more important and more difficult. Traditional methods, processes and tools used by engineers during the early stages of development are no longer able to keep pace with the increasing complexity of systems as is evidenced through a growing number of systems that fail to meet the needs of their users. This paper presents research targeted at evolving the way users and systems engineers work together to set the foundation for successful system development.

CONCEPT OF OPERATIONS

The Concept of Operation (CONOPS) is a document that describes the characteristics of a system from the point of view of its users. The Department of Defense (DOD) summarizes the purpose of a CONOPS as a method of "obtain[ing] consensus among the acquirer, developer, support and user agencies on the operational concept of a proposed system" [1]. The CONOPS effort should be initiated prior to any other system development activity and presents an opportunity for stakeholders to describe the current environment in which they are operating, potential areas for improvement, and needs from a future system or capability. The exact content of a CONOPS can vary based on industry and specific use, however most defense and aerospace CONOPS tend to follow two prevailing standards, established by IEEE and AIAA [2, 3]. Based on these standards, the CONOPS should address both the current and proposed systems, present anticipated operational scenarios, and include the elements displayed in Figure 1.

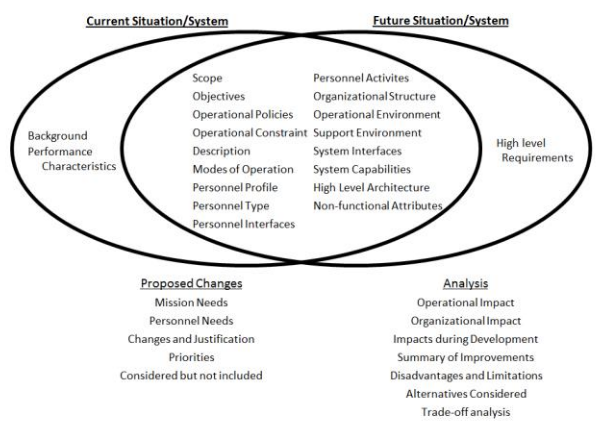

Figure 1: Recommended CONOPS elements

It is important to distinguish between two common uses of the word CONOPS that may lead to confusion. As described in [4], variance in the usage of the term CONOPS can cause misperception of its purpose, value and audience. In the DoD, the higher-order CONOPS refers to the "conduct of military action at the operational level of war" [5]. When working with materiel solutions and the DoD engineering community, the system CONOPS is at a lower level and describes specific characteristics of a system or capability. This work will focus on the system-level CONOPS. Edson and Frittman provide other common names, purposes and references for the term CONOPS [4].

When developed properly, a well-established CONOPS can provide the following benefits [4, 6-9]:

Allows for consensus by ensuring that the path forward is agreed upon by all stakeholders
Reduces risk by forcing the predetermination of aspects of the system before it is implemented
Improves quality by revealing opportunities to leverage technology to increase system performance
Documents system characteristics without being overly technical and verbose
Fosters a collaborative environment where users can state their expectations qualitatively
Records design constraints and rationale
Enhances the design of legacy systems
Maintains a living record of how the development of a system has changed

Table 1: Benefits of a proper CONOPS

However, research has shown that CONOPS are often under-utilized and under-developed, which not only inhibits the benefits in Table 1, but also introduces negative effects at each stage of system development.

Current CONOPS Shortcomings

Based on studies of CONOPS and their development process, significant shortcomings exist that hinder the effectiveness of CONOPS. Typically, CONOPS are developed in textual form that requires multiple iterations of writing and editing. In the Department of Transportation's CONOPS guide, the importance of including each view of the system corresponding to every stakeholder is stressed [10]. However, using the current document-driven approach to CONOPS development, inclusion of all stakeholders is difficult to manage and time consuming. This often requires an organization to choose between excluding some stakeholders or commencing requirements elicitation before the CONOPS has been completed [11].

Two studies have been conducted investigating the current state of practice of CONOPS development. Roberts and Edson administered a survey to 108 practicing systems engineers in the DoD ecosystem, and discovered some startling trends, which they presented at the NDIA Systems Engineering Conference [12]. A summary of some of their findings is recounted in Table 2.

Of 108 survey respondents:
36% have never worked a program with a CONOPS
31% stated the CONOPS was completed by bid phase
27% stated the CONOPS was completed by program startup
50% witnessed CONOPS that were not maintained throughout the development lifecycle
74% of CONOPS creation involved customers during creation
70% of CONOPS creation involved users during creation
50% acknowledged use of a standard during the development of a CONOPS

Table 2: Results of CONOPS survey [12]

Given the shortcomings identified by Roberts and Edson in the CONOPS development process, Cloutier et al [11] conducted a state of practice study to examine the actual CONOPS document. Cloutier et al examined sixty publically available CONOPS documents and compared the information contained within to the recommendations of four dominant CONOPS standards. A full account of the results can be seen in [6, 11], with some highlight recounted below:

- Less than 75% of the CONOPS actually list or identify specific mission needs.
- Nearly a third had no description of 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 regulatory agencies and acquisitions and government personnel.
- Personnel related issues (e.g., personnel needs, activities, types, profiles) were rarely discussed.
- Less than 20% of the CONOPS identified associated risks of the system and its development.

Since the CONOPS is an entry point for the future user into the system development process, it is critical that it be written as an accurate, unambiguous representation of user needs. A completed CONOPS document is often lengthy, dense, and static. These characteristics make it difficult update throughout system development, reduce the likelihood that engineers will read and understand the document, and do not allow for what-if analysis. Finally, today's textual CONOPS must be manually translated into artifacts that are useful for requirements engineers, system analysts and architects. A major goal of the model-based systems engineering (MBSE) initiative is the integration of MBSE methods, processes and tools across the full system development lifecycle [13]. While researchers and practitioners have seen success in interoperability of requirements, architecture, design and testing in a model-centric environment, [14, 15] there has been little progress in linking the stakeholder directly to the MBSE process [16]. This research focuses on bridging the gap between stakeholder and system engineer during early systems engineering and conceptual design. Through use of 3D visualization, gaming technology and immersive environments, the authors have developed the Integrated Concept Engineering Framework as an intuitive, easy to use, and powerful method for developing and analyzing a graphical CONOPS.

INTEGRATED CONCEPT ENGINEERING FRAMEWORK

This work has had two primary sponsors. The first sponsor to participate was the DoD Intelligence Community (IC). Later the US Army Armament Research, Development and Engineering Center (ARDEC) joined the research effort. The work has been funded through the Systems Engineering Research Center (SERC) which is a University Affiliated Research Center. Both sponsors have been heavily involved in this CONOPS research. The initial goals of this research were to understand the state of practice of CONOPS development and apply emerging technology to improve the way CONOPS are created [11].

At the conclusion of this initial assessment, follow on research was conducted to develop a proof of concept prototype to investigate the effectiveness of applying 3D visualization, gaming engines and immersive environments to CONOPS development. With inspiration from applications of movie storyboarding [17] and game engines [18] in science, interactive and immersive environments in vehicle design [19, 20], data-rich 4D CAD modeling [21], and previous research in model-based CONOPS development [22], a team of professors and students at Stevens Institute, Texas A&M, Purdue University, and Auburn University created the Integrated Concept Engineering Framework (ICEF).

The ICEF was developed using a framework approach (Figure 3) integrating various design tools, execution engines, simulation packages and databases to create a virtual environment for the creation of a 3D model of a CONOPS' operational scenarios. Through the immersive design interface (Figure 2), users can select the object library that is appropriate to their domain.

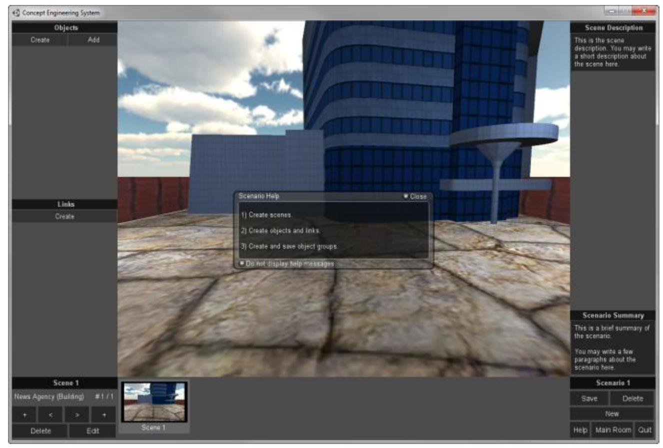

Figure 2: ICEF immersive design environment

The virtual storyboard, while created graphically, is stored as a database driven model. Once the scenario is modeled, the ICEF uses the Unity3D gaming engine to provide playback animations, allowing users to validate operational scenarios and clarify their meaning with system engineers. As conceptual design progresses and more information becomes available, data related to requirements, constraints and performance parameters can be associated with various elements in the scenarios. Using a collection of integrated domain specific simulation tools, this data can be used to conduct analysis and examine what-if situations directly within the ICEF environment. Finally, ICEF is designed for interoperability with word processing software and system modeling tools, allowing data-rich graphically generated scenarios to be translated to textual narratives of operational

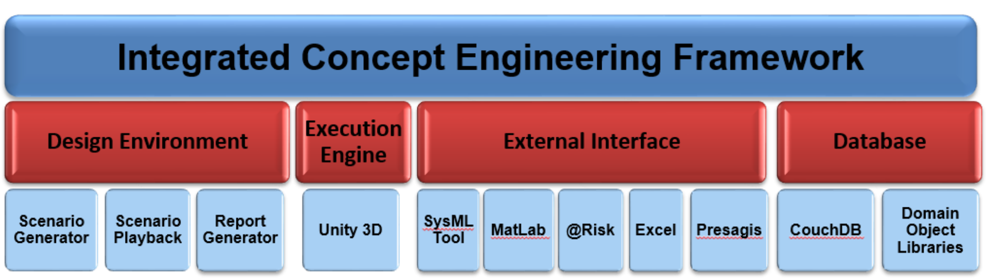

Figure 3: ICEF conceptual architecture

concepts and behavioral and structural SysML diagrams.

The ICEF architecture provides:

- USERS an easy to use environment where operational scenarios can be modeled
- STAKEHOLDERS and SYSTEMS ENGINEERS a collaborative development and validation tool
- ALL PERSONNEL involved with the CONOPS development an improved shared mental model
- SYSTEM ANALYSTS a high level conceptual system model using domain-specific analysis tools
- Other domain SYSTEMS ENGINEERS a common platform with which to describe operational scenarios
- REQUIREMENTS ENGINEERS a database containing early definitions of system requirements
- SYSTEM ARCHITECTS a tool which interfaces with other model based systems engineering tools
- STAKEHOLDERS and CONOPS DEVELOPMENT PERSONNEL an animated visualization depicting the operational scenario models for validation, negotiation and acceptance of design decisions and constraints

CURRENT DOMAIN-SPECIFIC ICEF APPLICATIONS

To date, ICEF supports three domains for modeling scenarios with a fourth in the works. Extending the domain library into new domains has proven to be a reasonably straightforward effort.

Intelligence Domain

Researchers used a generic news agency as an analog for IC operations. In the news business, they collect information and then perform analysis and dissemination. The news agency scenario (Figure 4) contains personnel which might be reporters, editors, witnesses, or information sources. Vehicles and equipment are available to be added to scenarios. Since objects utilized by intelligence agents can be abstract, graphical representation of non-physical items, such as emails or telephone calls are symbolized by either representative objects (such as an envelope or telephone) or by non-descript placeholders. The relationships and actions that take place between personnel and objects include analysis, assignment, interview, recruitment, selection and transmission. Additional information regarding ICEF and the news agency scenario can be found in [23, 24]. The ICEF Intelligence domain has been tested with members of the IC, as will be discussed later in this paper.

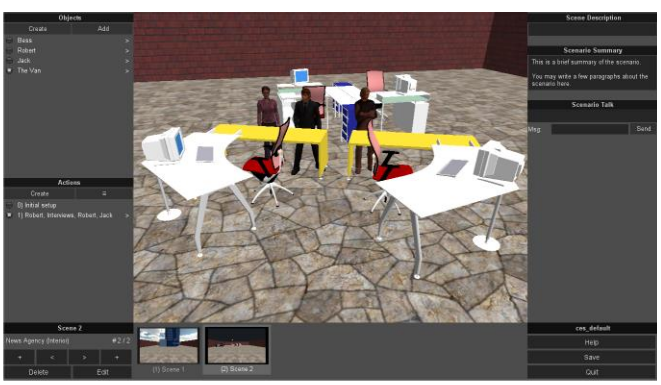

Figure 4: ICEF news agency scenario

Ground Vehicle Domain

The next domain added during the research was the Ground Vehicle Domain. It was intended to demonstrate, as a proof of concept, ICEF's interoperability with industry simulation tools. This research was sponsored by ARDEC's System Analysis group.

The vehicle simulation scenario was aimed at integration of ICEF with MatLab and Excel to calculate the motion profile of military vehicles. Data files were created containing properties such as personnel and fuel capacity, mean and max speed, and acceleration of a variety of military vehicles including the Humvee, JLTV, MRAP, M113 APC and Stryker platforms. Their performance parameters were contained in an Excel spreadsheet. Upon entering the ICEF environment, the user is asked to select a vehicle's distance of travel, preferred speed and acceleration. The acceptable selection ranges are context specific, dependent on the user's choice of vehicle. When the user hits the play button, the vehicle's properties, along with the user specified parameters, are transmitted to MatLab using TCP/IP link. In real time, MatLab determines the motion profile of the vehicle, and feeds the information back to ICEF. The ICEF receives the input from MatLab to move the vehicle down the road, constantly updating the user with the time, distance, velocity and acceleration (Figure 5).

Figure 5: Ground vehicle simulation scenario

During transit, the user is able to alter their perspective at either an overhead or turret point of view. Once the designated distance has been traveled, MatLab produces a full report of the vehicle's movement, which can be exported to Excel and other software tools for further analysis.

Another ground vehicle scenario involved integration with a Monte Carlo simulation package used by ARDEC, @Risk, which is part of the Palisades DecisionTools Suite. In addition to the data used in the simulation scenario, a speed distribution was assigned to each vehicle. In the vehicle comparison scenario (Figure 6), a user selects the basis of comparison they are interested in exploring (occupant capacity, fuel efficiency or response time) and the desired parameters and constraints. Upon execution, ICEF passes the data to @Risk, which runs a number of Monte Carlo simulations, and presents the user with the analysis results in the ICEF environment.

Figure 6: Ground vehicle comparison scenario

Dismounted Soldier Domain

Through ongoing research with ARDEC, ICEF has been adapted for use in developing tactical contact-to-fire scenarios. Soldiers can be added to the ICEF design environment and can be assigned specific attributes, weapons, equipment, motion profiles and missions. Assignment of equipment affects soldier attributes such as weight, shooting accuracy, mobility, lethality and health. Multiple soldiers can be grouped together into squads and fire teams, allowing for analysis of aggregate data and behavior. Enemies can be added to the scenes and directed to "fight" soldiers.

Figure 7: ICEF tactical contact-to-fire scenario

During playback, simulations are carried out using simplified lethality, health, motion and shooting models programmed into the ICEF execution engine.

ICEF EFFECTIVENESS EVALUATION

To study the effectiveness of the ICEF, two laboratory experiments were conducted. Both experiments involved participants producing artifacts representing the operational scenario segment of the CONOPS document. All groups were presented with a number of written descriptions of a news agency scenario and asked to either model operational scenarios using the ICEF tool or create a text based narrative akin to the traditional CONOPS development process.

ICEF Experimental Procedure

Due to limitations placed on the experimental design by the research sponsor, there was no control group for the first experiment. Attendance in this first experiment consisted of twenty-one DoD systems and software engineers, development and operations personnel, technical writers, and managers separated into five groups. The second experiment was carried out using twenty-five Engineering Management undergraduate students from a third-year Engineering Design class. The students were separated into eight groups, with four groups acting as a control, and four using the ICEF.

A brief instructional tutorial on the functionality of the ICEF tool was presented to all participants by the project manager and a primary ICEF software developer. After only fifteen minutes of instruction, all participants felt comfortable with the functionality of ICEF and a pre-experiment survey was distributed to record the participants' level of experience in CONOPS development, gaming, visualization and systems engineering.

Data Collection

Data was collected during the experiment using multiple methods. Surveys were used to elicit feedback directly from experiment participants. A post-experiment survey was also distributed to evaluate ICEF's effectiveness. Finally, there were observers watching the collaboration in each team. Observers were also responsible for collecting qualitative observations of individual and group behaviors during collaboration. Surveys and observer assessment rubrics are available in their entirety in [16].

The ICEF was specifically designed to capture information regarding how the users interacted with the software. This was carried out using internal activity logging. The activity log serves a number of purposes including measuring timing between modeling activities and recording the placement and deletion of objects, relationships and attributes. A summary of the data collection approaches is captured in Figure 8.

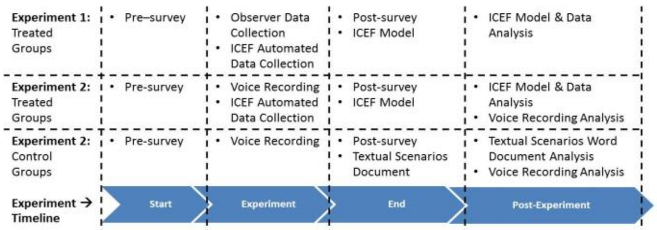

Figure 8: Experiment data collection

Research Hypotheses

CONOPS can be examined in terms of both collaboration during development, and the final artifact. To this end, two hypotheses were developed to drive data collection and analysis.

- Hypothesis 1: Use of the ICEF will improve the operational scenarios artifact of a CONOPS.
- Hypothesis 2: Use of the ICEF will improve collaboration during the development of the operational scenarios section of a CONOPS.

ICEF Effectiveness Metrics

Existing literature containing metrics for CONOPS development is lacking, so to investigate the hypotheses, multiple iterations of selection, categorization and refinement of metrics were required to measure the ICEF's effectiveness. Through literature searches and SME interviews, a final set of metrics was selected, which are described in Table 3.

Artifact Metrics	Collaboration Metrics	Experience Metrics
Understandability How easy the artifact is to understand	**Development Time** Time required to develop CONOPS	**Gaming** Comfort with games, immersive environments and visualization
Balanced PoV How well artifacts represent collection of individual points of view	**Satisfaction with Collaboration** Sense of satisfaction that the collaborative effort was effective	
Accuracy How accurately artifacts represent the scenarios	**Mutual Understanding** Extent to which team members agree/disagree	**Systems Engineering** Experience and comfort with systems engineering
Applicable to System Design How useful artifacts are to developers	**Communication** How the process affected group communication	
CONOPS Elements Does artifact include elements required by CONOPS standards	**Shared Mental Model** Commonality of the scenario representation between team members	**CONOPS** Experience and comfort with CONOPS and conceptual design
Maintainability How easily artifact could be maintained and updated	**Group Problem Solving** Five classes of interaction during problem solving [25]	
	Collaborative Macro-Cognitive Process Mental processes employed by teams during complex problem solving [26]	

Table 3: CONOPS metrics for evaluating ICEF

Bayesian Data Analysis

Given the scope of this research and the design of experiments described above, there were limiting factors in selecting an appropriate data analysis technique. These include the fact that:

- few recognized metrics have been established or data collected and published concerning CONOPS development
- data collection lead to both qualitative and quantitative data so the analysis technique should be able to handle both types of data
- the sample size of the experiment was relatively small and was not fixed across experiments

Given these limitations, Bayesian Hypothesis Testing was selected for data analysis. In-depth discussion of Bayes' theorem and Bayesian data analysis is beyond the scope of this paper. A full treatment of Bayesian data analysis can be found in [27, 28].

Experiment Results

Further discussion of the Bayesian analysis performed is beyond the scope of this paper, but will be published in a later manuscript. Using the Bayesian approach enabled the researchers to directly compare the testing results of those who utilized the ICEF and those who acted as the control group (did not utilize the ICEF). The Bayesian hypothesis testing demonstrated coherence [29], and that the data collected in these experiments is much more likely to support the hypothesis that the ICEF is a more effective approach to CONOPS development over the traditional approach of a textual based approach.

CONCLUSIONS

As recognized through literature review and state of practice assessments, the current process of creating CONOPS has significant shortcomings. Additionally, the system engineering community has fallen short in producing lifecycle-wide support for the model-based paradigm, especially during early systems development efforts.

This paper described the conceptual design and development efforts of the Integrated Concept Engineering

Framework, a suite of software tools to utilize collaborative, 3D immersive gaming environments to enhance the current CONOPS creation and early system analysis processes. Given a lack of procedure by which to measure the effectiveness of CONOPS development, metrics and an assessment model were also established, and subjected to experimental data collected from two separate experiments.

Data was collected through surveys, observational evaluations and computer generated records and analyzed using Bayesian hypothesis testing. The data collected showed evidence to support the validity of both research hypotheses. They also demonstrated a preference among experiment participants for the use of ICEF over the traditional CONOPS development process.

FUTURE WORK

There are a wide range of opportunities to advance the ICEF research and development. One avenue being pursued is the extension of ICEF to different domains. The ICEF analysis prototype was geared towards a military ground vehicle domain, and opportunities to further advance the research is being sought in the automotive domain. Additionally, consideration has been made on applying ICES to other defense systems, including robotics and UAVs, weapons systems, naval platforms, and battery power systems. Furthermore, applications in non-defense sectors such as renewable energy and healthcare are being explored. Finally, improvements to ICEF will include incorporation of all modules into a unified code base, and integration of capabilities from other industry standard simulation tools.

Besides specific improvement to the ICEF tool, focus is also being placed on advancements of the CONOPS metrics and effectiveness data. Any interest in supporting future efforts to better define the metrics and collect and analyze data related to CONOPS development is welcomed.

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