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Graphical CONOPS Development to Enhance Model-Based Systems Engineering

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Abstract. *Gaming and immersive virtual environments provide a new way to engage stakeholders during early stages of Systems Engineering lifecycle to help them reach a common mental model of the concept of operations. A weak link in the Systems Engineering lifecycle is often the connection between what the users need and what the system developers think the users need, together with a shared understanding of the operational environment and associated constraints and dependencies. The current system development environment calls for user needs to be specified in a Concept of Operations (CONOPS) document, which provides a foundation of future system capabilities and describes typical scenarios that it will encounter. Given the size and complexity of today's systems, CONOPS development can take considerable time and effort, which can cause its production to be incomplete and insufficient. This introduces misunderstanding and miscommunication early in the Systems Engineering lifecycle. This paper describes a method allowing stakeholders to express their needs through a model-based approach to create a graphical CONOPS leveraging gaming technology. The resulting CONOPS would provide system developers with direct access to the needs of stakeholders, and would enable the creation of Model-Based System Engineering artifacts early in the development lifecycle. Current research and development efforts, interim findings, initial impressions gained from user feedback and recommendations will be described. The presentation proposes to demonstrate our Integrated Concept Engineering System, while reflecting on its developer's experiences.*

Keywords. *CONOPS, Concept of Operations, Model-Based Systems Engineering, MBSE, Concept Engineering*

1 Introduction

Many believe that the weakest link in Systems Engineering is often the link between what the stakeholder desires and what the development team "believes" is needed. Seldom is there a shared vision or understanding of the operational environment in which the new product or capability will be deployed. An operational concept is meant to bridge this understanding gap. The purpose of this research is to explore the fusion of current 3D gaming technologies with the practice of developing a Concept of Operations (CONOPS) early in the product development lifecycle. This paper will briefly discuss the notion of a CONOPS, what has motivated the research team to utilize gaming technologies, and the approach being taken to create a CONOPS in a 3D immersive environment.

2 Concept Engineering

Concept Engineering is the phase of the System Engineering lifecycle prior to requirements elicitation, system architecting, and design, during which developers "rapidly elucidate the need, explore solutions, develop CONOPS, and derive requirements for materiel solutions" (Baldwin, 2010). The challenges of this phase are to reduce the time to develop operational concepts, improve customer-developer collaboration, and extend static representations of concepts to dynamic, environment-aware and malleable artifacts, all to ensure that the system being developed will meet the needs of its users. It is believed that improving Concept Engineering practices will significantly reduce development time through faster requirements elicitation and reduced rework due to misunderstandings that can occur during early system development. If the concepts developed during the Concept Engineering phase can be "placed into motion", the customer and developer would be able to visually observe expected behaviors in real time, to develop a shared understanding of the problem or mission that needs to be addressed, and the likely solution approaches. Concept Engineering is framed against the typical Systems Engineering development "Vee" as seen in Fig. 1, and one of its major outputs includes the CONOPS.

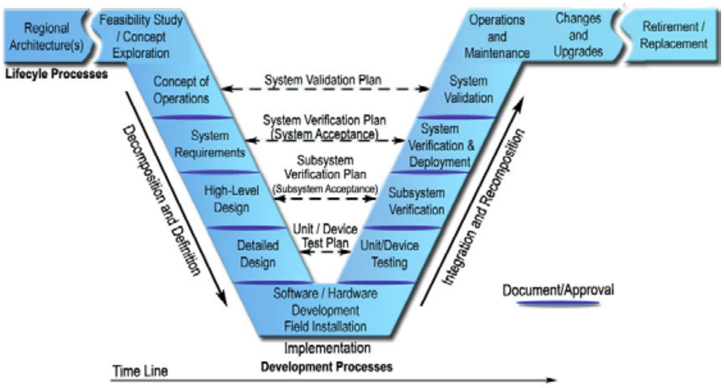

Fig. 1. Concept Engineering in the context of the Systems Engineering "Vee" Diagram (labeled here as *Concept Exploration*)

3 What is a Concept of Operations?

The operational concept of a new product offering is often captured in a formal document referred to as a CONOPS. The CONOPS is typically written by end users and subject matter experts, and is intended to inform those that are defining system requirements. This document describes what the operational need is, what the current operational environment looks like, a description of how the operational environment should change, why a change is required, and who will be impacted by the change. The CONOPS also provides operational scenarios for both normal and alternate conditions such as failures, maintenance, and stressed conditions. According to the International Council on Systems Engineering (INCOSE), a CONOPS describes “the way the system works from the operator’s perspective. The CONOPS includes the user description and summarizes the needs, goals, and characteristics of the system’s user community. This includes operation, maintenance, and support personnel” (INCOSE, 2011).

The completed CONOPS is generally a lengthy document containing text and static images which are intended to describe future system operations in the form of scenarios. Writing the CONOPS can be a labor-intensive, time-consuming task involving multiple iterations of natural language descriptions, graphical flow depictions and prototypical representations. The resulting artifact is typically a static representation of the user identified need that may or may not satisfy the original intent.

4 A Graphical Approach to Concept Engineering

The authors have identified a need to quickly and graphically articulate a CONOPS to realize a shared mental model and understanding across the set of diverse stakeholders. Next, the CONOPS needs to be executable – put into motion – so the stakeholders can visually see what actually happens. It is believed that this approach will have to be tailored for selected application domains for operational, mission, and semantic consistency. Some of the key questions the Concept Engineering research team is investigating are:

- Can the process of CONOPS development and understanding be improved through the use of a “drag and drop” graphical user interface?
- Can real-time collaboration between distributed stakeholders improve the CONOPS development?
- Can a real-time collaboration environment enable quicker stakeholder consensus on CONOPS generation?
- Does a 4D (3D + time) representation provide deeper insights into the operational concepts of a proposed system than traditional textual documents or static 2D story boarding?
- Can the process of CONOPS development and understanding be improved through the use of an immersive environment?

To address these and related research questions, the authors are currently developing the Integrated Concept Engineering System (ICES). The ICES is aimed at making use of gaming technologies and immersive environments to tackle early Systems Engineering and Model-Based Systems Engineering challenges. While the goal of ICES is to address a variety of activities that take place during Concept Engineering, the focus of this paper will be its graphical CONOPS development capability. The remainder of this paper will describe the concept of ICES and some design decisions made during its development.

4.1 Gaming Technologies and Immersive Environments

The last decade has seen huge advances in the application of computing, graphics, and data analysis capabilities towards problem solving. Some of these advances have enabled the use of gaming technologies and immersive environments for the development of *Serious Games.* Serious games are games designed for non-entertainment purposes, and have become widespread in the defense, education, healthcare and engineering industries. One of the latest successes pitted gamers against a real world serious virus. Gamers were asked to assist in solving the structure of an AIDS-like retrovirus whose configuration had stumped scientists for more than a decade. Using an online 3D game known as *Foldit*, the gamers were able to produce an accurate model of the enzyme. The scientists had been wrestling with the problem for over a decade; the gamers solved it in only three weeks.[1]

Today's 3D immersive games have some real advantages that can be translated to improving the development of a CONOPS. Working in immersive environments often leads people to gain a better understanding of concepts and it is suggested that problem solving in 3D space involves a larger portion of the brain than in 2D (van Driel, 1989). The nature of immersive environments allows for multiple perspectives to be observed, meaning that a user could adapt their viewpoint, vary the information displayed to them and alter the visual representation style of content to fit their needs. Immersive environments are also recognized for their improvement of distributed collaboration, well above the standard set by common collaborative environments today (Carmichael 2011; Leigh and Johnson 1996).

Software for training, education, and agent-based and physics-based simulation has been leveraging gaming technologies for years. However, there has been little adoption of these technologies to Systems Engineering tools, especially during the Concept Engineering phase. As such, once it was decided that gaming technologies would be used, a MBSE methodology was utilized to begin modeling and architecting ICES. The first step of this process is outlined below, beginning with the definition of user interactions with ICES modeled as use case scenarios.

4.2 ICES User Interactions

Mostashari's Stakeholder-Assisted Modeling and Policy Design (SAM-PD) process has served as a foundation for the role of stakeholders in ICES (Mostashari, 2005). The SAM-PD process was altered to fit the concept of ICES, and the Stakeholder-Assisted Agile CONOPS Development process was created, which is detailed in

[1] ScienceDaily (Sep. 19, 2011)

(Mostashari et al., 2011). The Agile CONOPS Development process describes, at a high level, tool agnostic actions that stakeholders will undertake to develop a graphical CONOPS. These actions have been decomposed and extended to detail specific user interactions with ICES, which have been modeled as use cases and activities. Prior to describing these use cases and activities in detail, clarification must be made in the definition and classification of stakeholders interacting with ICES.

Defining and Classifying Stakeholders. A classic definition of stakeholder for Systems Engineering reads "a party having a right, share or claim in a system or in its possession of characteristics that meet that party's needs and expectations" (INCOSE, 2011). With the current size, complexity and breadth of today's systems, parties that fit into this description are both numerous and varied in terms of their perspectives and interest in the system to be developed. It is therefore important to classify stakeholders based on their interactions with the proposed system, to help fully describe how they will be able to gain value from ICES. A basic taxonomy for stakeholders can be seen in Fig. 2. This diagram shows a set of both active and passive stakeholders for a system to be developed. In general terms, active stakeholders are those with direct influence over a system, and passive stakeholders are those with indirect influence.

It is important here to differentiate between ICES stakeholders and *system to be developed* stakeholders. Stakeholders of the system to be developed are those that will be influenced by or will influence the proposed system. This can include users, owners, maintainers, etc. Stakeholders of ICES are those that will interact with ICES during the development of a CONOPS and other Concept Engineering tasks. As can be seen in Fig. 2, system stakeholders who are active and passive can all be considered active stakeholders of ICES, since the goal of ICES is the involvement of all future system stakeholders in the CONOPS development process. With this delineation of stakeholders in place, the authors began to develop use cases, describing the interaction each stakeholder class will have with ICES.

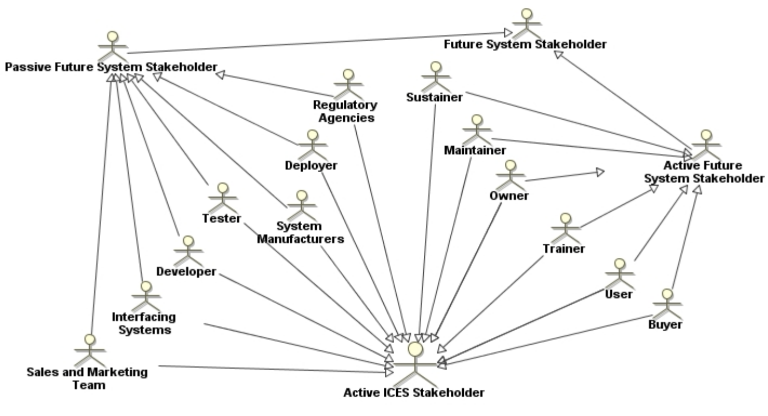

Fig. 2. ICES and Future System Stakeholder Classification

ICES Stakeholder Use Cases. In general, there are three high level use cases that will define the scenarios of stakeholder interaction with ICES, Develop, Communicate and Learn (Fig. 3). Each use case will be expanded upon, and a typical stakeholder scenario will be described.

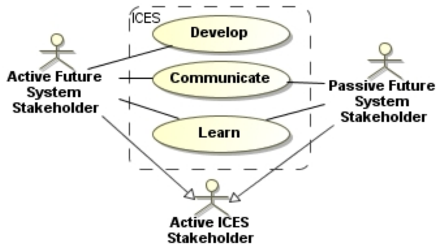

Fig. 3. Basic system stakeholder interactions

ICES Use Case: Develop. The Develop use case represents the primary functionality of the CONOPS generation capability of ICES (Fig. 4). A brief description of major second level use cases is presented below:

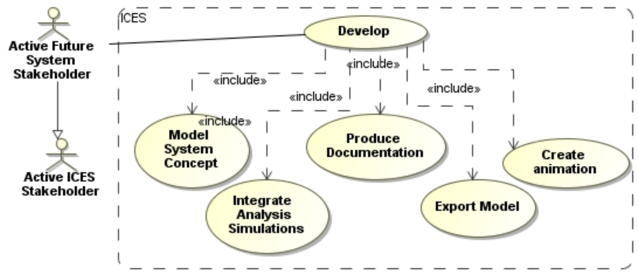

Fig. 4. ICES Use Case: Develop

Model System Concept. Stakeholders and developers can build models of a typical system operational scenario (part of the graphical CONOPS) using a drag ‘n drop interface to insert and connect various objects and attributes of a system. It is important that there be little technical expertise required to model the system concept, given that many times stakeholders themselves are not technically adept.

Integrate Analysis Simulations. Often a stakeholder may want to add some feature or set some non-functional requirement to a system that is questionable in terms of feasibility, affordability, etc. By enabling the integration of simulations developed by system analysts, the stakeholders and developers can gain insight into the benefits and consequences of many early design decisions. Having multiple iterations of simulation results available in one place reduces the need for “fat fingering” data and results between software tools.

Create Animation. One of the largest benefits of using a virtual gaming environment as a platform for ICES is the ability to put system concept models into action. This use case involves stakeholders and developers creating animations that reflect some of the early design decisions. This use case is common in today's serious game immersive environments, exemplified by case studies such as (Stewart, 2007).

ICES Use Cases: Communicate and Learn. As seen in Fig. 5**,** these two use cases represent secondary tasks associated with CONOPS creation, not related to actual concept modeling but instead to the collaboration among stakeholders and developers that is required for CONOPS generation. Some major Communicate second level use cases are detailed below.

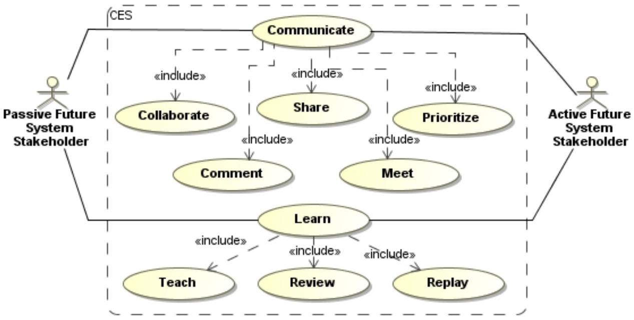

Fig. 5 - Use Case: Communicate and Learn

Collaborate. A "multi-player" environment will be at the core of ICES, allowing multiple stakeholders to gather together and develop concept models. Different perspectives will be available to stakeholders depending on their specific system interests. Each stakeholder will be able to work in the context that they want, and as they develop, the system concept model will be updated in the environment of other stakeholders.

Comment. A large part of a collaborative work environment is being able to express one's views. In ICES, stakeholders will be able to attach textual comments to specific elements of a graphical CONOPS for review by other stakeholders. Commenting in ICES will allow asynchronous collaboration, as well as create a permanent record of which users made what comments, when and why. This feature will also create documentation of design decisions and rationale for use by future system developers.

Prioritize. A common issue in system development is the fact that systems have many stakeholders who often have various interest and conflicting needs. By allowing stakeholders to assign priorities to components of a graphical CONOPS, developers will be able to weigh stakeholder needs using a mathematically objective method.

During development of ICES, it was recognized that such a tool may be useful for educating and training Systems Engineers, especially given the proliferation of game-based training tools. This capability can be expanded beyond education to include the ability to replay the entire CONOPS creation process from the beginning, allowing developers to gain insights that would have been impossible to recognize during tradition text based CONOPS development. Development of ICES to include the

Learn use case is immature at this point, and will likely be enhanced through additional research being conducted by the authors' colleagues.

ICES Stakeholder Activities. Based on the use cases defined above, activity diagrams can be developed to model the typical scenarios in which stakeholders will engage with ICES. As an illustrative example, the "system to be developed" will be a vehicle. Due to space limitations, only the Design activity diagram is presented here, although a number of activity diagrams have been created for most of the use cases defined above.

ICES Activities: Develop. Fig. 6 presents the roles of a Vehicle Driver, Vehicle Developer and ICES working together to add a feature to an existing concept model, test it out in terms of performance and aesthetics, and update both the auto-generated textual CONOPS for contracting purposes and additional artifacts that will be used during future development phases. Activity diagrams can be read as flow charts, where diamonds represent decision gates and bars represent parallel AND flows. Specific activities to be carried out are shown as rectangles, and are placed within a vertical partition representing the user who carries out the activity.

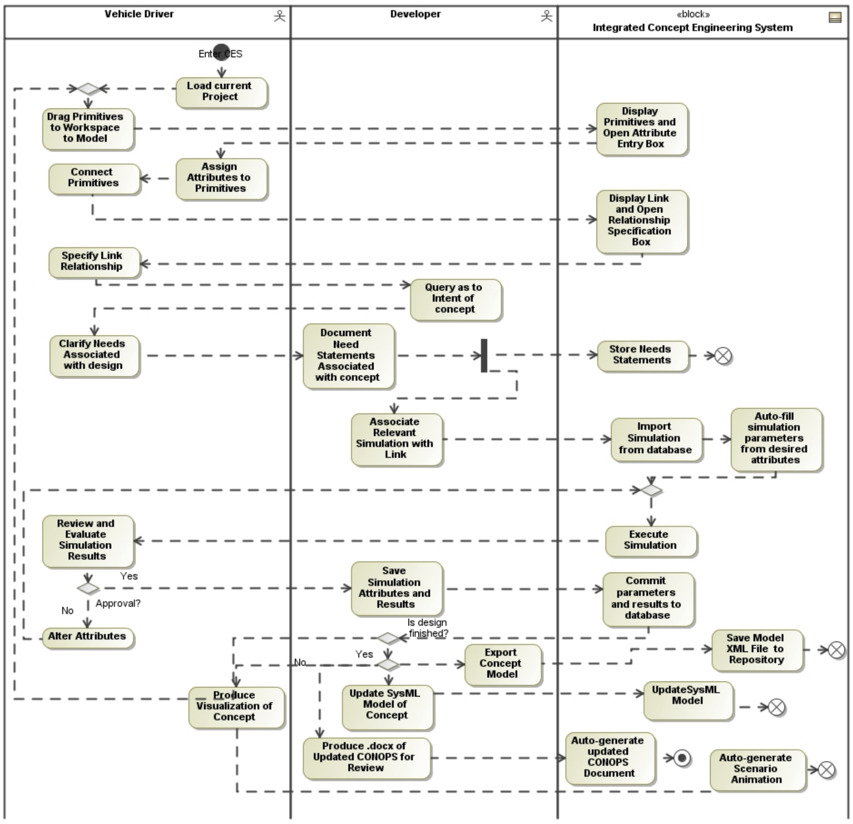

Fig. 6. Activity Diagram: Develop

5 Model-Based Systems Engineering (MBSE)

As was demonstrated in section 4.2, MBSE can help the developer "reason about the problem". Part of the description of Fig. 6 stated that users, developers and ICES will work together to produce "additional artifacts that will be used during future development phases". Creation of one such artifact is represented in Fig. 6, labeled *Update SysML Model.* This activity traces back to a sub use case of *Export Model* included in Fig. 4. These use cases/activities represent a capability of ICES that seeks to provide benefit to system developers, designers and architects throughout the development lifecycle. MBSE is gaining popularity among System Engineering researchers and practitioners, laying down a process to move developers away from the current document centric paradigm to a model-based development environment, where all data, models, designs, etc. can be linked to one central model repository. MBSE tool support is strong during the requirements phase and the design and architecting phase, but very few tools have been developed for early Systems Engineering.

A goal of this research is to address this MBSE challenge and ICES will approach this by introducing MBSE tools and methodology early in the system development lifecycle. At its core, ICES is a model-based tool; users build the CONOPS using a graphical interface and the representations are stored in a model repository. Another goal of ICES is to provide automatically generated models to system developers for use later in the development lifecycle.

By tracing CONOPS elements to their SysML equivalents, system developers will be able to translate CONOPS models to SysML models, integrating early Systems Engineering tools with those created for system design and architecting.

6 Conclusion

Concept Engineering is a critical step in successful systems engineering processes. While systems are growing in complexity, no significant advances have been made in concept engineering in decades. 3D visualization has the potential to improve the way stakeholders reason about operational concepts. We believe the technology exists or is emerging, to enable 3D/4D visualization of operational concepts in distributed, collaborative, cross-platform environments. This research has the potential to make the most significant contribution to concept engineering and CONOPS development in the past 60 years.

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