Systems Research Forum


# EVALUATING THE APPLICATION OF MBSE TO CONCEPT ENGINEERING

PETER KORFIATIS

*School of Systems and Enterprises, Stevens Institute of Technology,*
*Castle Point on Hudson*
*Hoboken, NJ 07920, USA*
*pkorfiat@stevens.edu*

DR. ROBERT CLOUTIER

*School of Systems and Enterprises, Stevens Institute of Technology,*
*Castle Point on Hudson*
*Hoboken, NJ 07920, USA*
*Robert.Cloutier@stevens.edu*

Received Day Month Year
Revised Day Month Year

With advancements in computing, processing power and distributed networks, systems engineering organizations have been exploring and adopting model based systems engineering (MBSE) practices at an increasing rate over the past decade. As the systems engineering community strives to standardize MBSE approaches and tools, research has broadened beyond well explored MBSE approaches, such as system architecting, and has begun to study areas of systems engineering that have not been viewed through the lens of MBSE. One particular phase of the system development lifecycle that is underrepresented by MBSE methods processes and tools is Concept Engineering (CE). This paper examines the topics of MBSE and CE, revealing a gap between the two. Efforts of previous research to fill this gap are visited, and a proposed approach using virtual immersive environments is briefly described. As this approach and its accompanying tool have advanced from research to proof of concept prototyping and software development, a structured blueprint is required for validating the effectiveness of this research with the user community. Experimental design for determining effectiveness is discussed, and a series of measurements and metrics are proposed for evaluation of the application of MBSE to CE.

*Keywords*: Model based systems engineering, MBSE, CONOPS, Concept Engineering, gaming.

## 1. Introduction

While there is no definitive definition of what constitutes model based systems engineering (MBSE), it has become a hot topic for the systems engineering community in the recent years. As organizations begin to adopt MBSE methods, practices and tools, gaps in MBSE methodology and definition have begun to appear. This is driving researchers and practitioners to take a more holistic view of modeling and simulation in systems engineering. This research is aimed at exploring a gap in MBSE methodology and tools early in a complex systems lifecycle that the authors call Concept Engineering (CE). In the next section, current literature relating to MBSE and CE will be visited. Examples of other research in the application of MBSE practices and tools to CE will also be described. Section three presents a brief overview of a proposed approach and developing tool that seeks to better integrate MBSE and CE activities and data. Section four addresses early thoughts on how the researchers will determine the effectiveness of the proposed approach and tool. Finally, a brief discussion of future work and a conclusion will be presented.

## 2. Literature Review

### 2.1. *Concept Engineering*

Concept Engineering (CE) occurs early in the systems engineering lifecycle, prior to requirements generation. The collective activities associated with CE are aimed at capturing the needs of the users of a system and high-level requirements, as well as providing an opportunity for early system analysis, trade-off studies, analysis of alternatives (AoA) and early stakeholder validation. The range of terminology that represents CE is broad, as are the definitions and directives provided by various systems engineering organizations. This research focuses on the Department of Defense (DoD) vision of CE as a baseline for the activities and outcomes; "Rapidly elucidating the need, exploring solutions, developing Concept of Operations (CONOPS) and deriving requirements for materiel solutions" [Baldwin, 2010]. A summary of other terms in common usage representing similar activities is displayed below in Table 1.

Table 1. Concept Engineering (CE) terminology found in select systems engineering domains

| Domain | Terms | Definition | Source |
|---|---|---|---|
| Aerospace | Concept and Technology Development | Determine feasibility and desirability of a suggested new system and establish an initial baseline compatibility with NASA strategic plans | [NASA, 2007] |
| Automotive | Virtual Prototyping | The development and analysis of system models | [French & Lewis, 2003] |
| Defense | Early Systems Engineering | Activities taking place prior to Milestone A as laid out in DoD 5000.2 | [USAirForce, 2009] |
| Defense | Navy Concept Generation and Concept Development Program | Encapsulation of ideas into a coherent structure to pursue potential solutions; vetting and validating ideas through analytical studies, workshops, experimentation, war games, and, when required, live force experiments | [Herdlick, 2011] |
| Transportation | Project Planning and CONOPS Development | plan the activities of the project and develop a user concept of operations for the envisioned system | [Transportation, 2009] |

Many of the published guidelines in Table 1 list the development of a CONOPS as a major CE task. Many times, the CONOPS, or Operation Concept Document (OCD) is written by stakeholders and describes how users will interact with the future system. For other projects, it is subcontracted to an organization of subject matter experts. This document is meant to bridge the gap between a system's users and its creators, building a shared understanding of what the system is intended to do. A number of standards groups have created guides for the development of a CONOPS, as seen in Table 2.

Table 2. CONOPS Standards

| Organization | CONOPS Definition | Standard |
|---|---|---|
| IEEE | Describes a system's operational characteristics from the end user's viewpoint. | IEEE 1362-1998 (R2007) |
| AIAA | Communicates to system developers and users, in the user's language, the desired characteristics of a system to be developed | ANSI/AIAA G-043-1992 |
| INCOSE | Defines the way the system will be used and must involve input from a range of stakeholders. | INCOSE Handbook |
| Department of Transportation Federal Highway Administration | Results from a stakeholder view of the operations of the system being developed. Present each of the multiple views of the system corresponding to the various stakeholders | DoT Guidebook for Intelligent Transportation Systems |

An examination of publicly available CONOPS has shown that these standards are typically used only as guidelines, with organizations picking the sections that they find necessary and omitting the remainder [Cloutier et al., 2009]. Extensive research has been conducted identifying the benefits of a properly developed CONOPS [Edson & Frittman, 2010; Hill et al., 2010; Jost, 2007], which include reducing system development risk and schedule slip, improving system quality, recording design constraints and fostering stakeholder collaboration and consensus. If created and managed properly, a CONOPS creates a shared mental model between stakeholders and system developers, and should be updated during the development lifecycle to provide a living record of system development and rationale for decisions made [Bjorke & Thayer].

Recent research, summarized in [Mostashari et al., 2011] has also shown that many organizations are not benefitting from the full potential of a CONOPS due to loose discipline in creating and maintaining a document-based CONOPS. Roberts and Edson conducted a survey of early systems engineers which revealed shortcomings of current CONOPS process [2008]. Some of these include:

- 36% of respondents have never worked on a program with a CONOPS
- 31% of respondents stated CONOPS was completed by bid phase, 27% by program startup
- 50% of respondents witnessed CONOPS that were not maintained throughout the development lifecycle
- 74% CONOP creation involved customers during creation, 70% involved users

- 50% of respondent acknowledged use of standards in CONOPS development
- The average time to develop was 76 days.

Research has determined that inclusion of operational scenarios that describe step by step activities of user interaction with the system are a key component of a CONOPS and thus key artifacts of the CE process [Cloutier, Mostashari et al., 2009; Mostashari & Sussman, 2004]. This paper focuses on a proposed methodology and tool for the visual creation of these operational scenarios as a form of early system model, which can be used to automatic generation other popular MBSE artifacts. In the next section we will provide a general review of MBSE, and identify a perceived gap between MBSE and CE, followed by an overview of some previous work introducing MBSE methods and tools to CE activities.

### 2.2. *Model Based Systems Engineering*

MBSE is a system development approach aimed at converting the typical document driven development to one fueled by the creation and collection of system models from different viewpoints and different levels of development using an MBSE approach. Many large organizations are adopting the MBSE approach for large systems [Cloutier & Griego, 2008; Friedenthal et al., 2007; Friedenthal et al., 2009; OMG, 2011; Peak et al., 2009; Sampson & Friedenthal, 2011].

Research and development of model based engineering (MBE) methods, processes and tools thus far has been aimed at improving model-based practices and tool support within specific lifecycle stages, most notably engineering design and manufacturing. In its Final Report on Model Based Engineering (MBE), the National Defense Industry Association (NDIA) Systems Engineering Division assessed the current state of MBE and identified a persistent gap between MBE tools and methods across programs, domains and lifecycle stages [2011]. Similar studies have also been conducted for systems engineering modeling leaders Object Management Group (OMG) and International Council of Systems Engineering (INCOSE) [Bone & Cloutier, 2009; Cloutier & Bone, 2010].

Many systems engineering professionals have identified this shortcoming in MBSE research and there are a number of initiatives aimed at improving the full lifecycle MBSE state of practice [Friedenthal, 2011; Sampson & Friedenthal, 2011]. At its annual meeting in 2007, the INCOSE created the MBSE Initiative to promote, advance and institutionalize the practice of MBSE. One of the challenges presented to the systems engineering community was the conversion of what was once a document driven development lifecycle to one that is model based, integrating MBSE across the full system lifecycle [Friedenthal, Griego et al., 2007].

Using the DoD Defense Acquisition Lifecycle process as a backdrop, Figure 1 shows some tools currently in use across the systems engineering lifecycle, and how each is specialized for a particular part of the lifecycle.

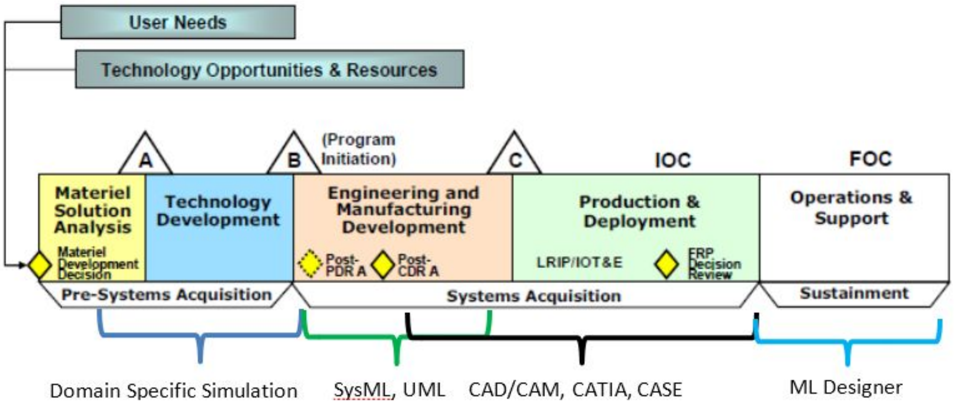


Figure 1. MBSE Tools across DoD Defense Acquisition Lifecycle

The DoD Systems 2020 initiative identified a lack of virtual environments for conceptual design and integration of system modeling has been highlighted [Baldwin, 2010]. It has been suggested that the development of models for better conveying stakeholder need and requirements would represent a major advancement, providing a foundation for realizing a "model-based virtual system prototype, from CONOPS to manufacturing, through the use of networked and large scale computing resources" [Boehm et al., 2010].

## 2.3. *Model Based Systems Engineering in Concept Engineering*

An important component in establishing an integrated modeling approach to systems engineering is creating an early system model that can be drawn from and extended throughout the development lifecycle [Brown, 2011]. Considerable research has been performed investigating virtual and model based methods and tools to CE as described in the following examples.

Thronesbery et al. developed a process and related tool to aid stakeholders in describing their future use of a system developing UML representations of user needs through a storyboarding tool. The process is meant to graphically represent a CONOPS as a storyboard for its creation, evaluation and maintenance, as well as the capturing of a conceptual system model in UML artifacts [2007]. An example of the resulting model is shown in Figure 2. While a benefit of using Thronesbery's tool is direct input of user needs using a model-based approach, a significant downside is the need to write out narratives for these needs, resulting in a system that may not significantly reduce the time and workload of system stakeholders.

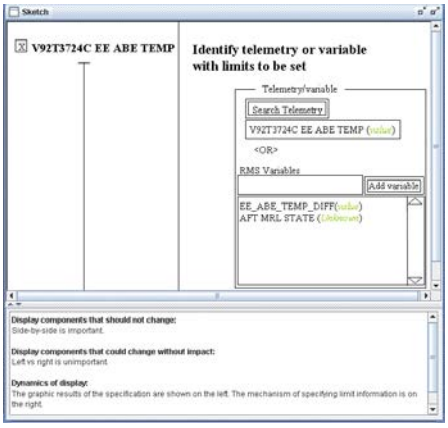


Figure 2: CONOPS Storyboarding Tool [Thronesbery et al., 2009]

Osvalds advocates for a Model Based Systems Engineering Framework through which system engineering tools, including MBSE tools, can be integrated and provide end to end system engineering models. Osvalds makes specific mention of developing a CONOPS specification using the modeling framework [Osvalds, 2011]. While the framework does include a visualization component for scenario playback and stakeholder validation of operational scenarios (Figure 3), the basis of system modeling is carried out through system architecture models, which require a certain level of expertise and understanding of both MBSE languages and tools. This limitation makes such a framework inaccessible to users, and still requires that system models be constructed by systems engineers based on their interpretation of a stated user need.

Figure 3: Model Based Systems Engineering Framework visualization component [Osvalds, 2011]

Mansurov and Vasura have utilized a Video Camera interface to drive UML sequence and use case diagrams. Using their custom GUI, all formal modeling notation is hidden from the user, as they are able to interact with a visualization and alter certain aspects of a system design, which are automatically changed in UML representations of the system. The example provided for the Video Camera, seen in Figure 4 was a vehicle cockpit, in which a user was able to carry out the change gear use cases, resulting in the creation of executable UML models for system developers [Mansurov & Vasura, 2000]. This


Figure 4. Video Camera Interface [Mansurov & Vasura, 2001]

system is useful to systems engineers by proving a visualization of operational scenarios for documenting, altering and validating user needs. The drawback of this approach is the amount of expert programming which must be carried out to build these visualizations, often leading to long development time and inflexibility in handling unplanned user activities.

Corns and Kande have shown that the translation from SysML to virtual models is possible. Through their methodology and use of the VE-Suite tools (Figure 5), Corns and Kande are able to create visual models based on MBSE artifacts, allowing for the development of executable SysML models, a visual interface to provide to stakeholders, and the ability to examine the potential impact of changing design parameters [Corns & Kande, 2011]. This work helps provide a model based workflow for a system engineer that runs in reverse to the development lifecycle.

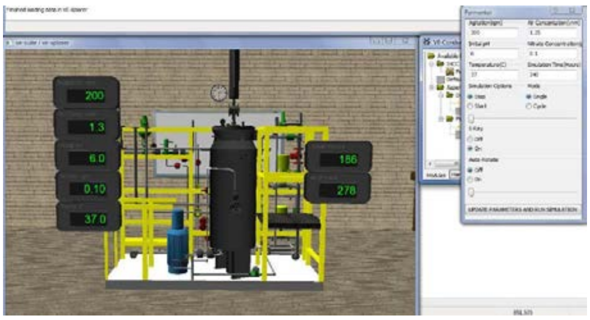


Figure 5. System model in VE-Suite [Corns & Kande, 2011]

Andersson and Huldt propose that the movement from traditional document based to MBSE artifacts can be accomplished using an MBSE approach instead of a primarily text based System Engineering Plan (SEP). Their research has mapped specific SEP data into a series of SysML diagrams. While this is not directly related to the CE, it is an example of a significant contrast in methodology between traditional text based approaches and model based artifacts [Andersson & Huldt, 2009].

## 3. Proposal for an MBSE approach to CE

To address this apparent gap between MBSE and CE model based approaches, the research being performed by the authors proposes a methodology (Stakeholder Assisted CONOPS Development Process) [Mostashari, McComb et al., 2011] and tool (Integrated Concept Engineering System) [Korfiatis et al., 2012] for creating visual models during CE process. ICES has been developed using a serious gaming approach (the application of 3D gaming technology to real world problems) to create a virtual immersive environment for the visual creation of a model of CONOPS operational scenarios. Through a 3D environment, users interactively storyboard their expected interaction with the system of interest. The virtual storyboard, while created graphically, will be stored as a database driven model. It is postulated that the completed storyboard model will:

- Provide system analysts with a high level early system model for use with analysis software packages. ICES is design to act as a framework, allowing domain specific simulation tools to interpret data from and provide data to the operation scenario models.
- Provide model-based artifacts to future system developers and architects, building a direct pipeline between user needs and current MBSE tools.
- Provide future users with an animated visualization depicting the operational scenario models for validation, negotiation and acceptance of design decisions and constraints.

An early representation of the interactive storyboarding environment of the ICES is shown in Figure 6. Research reports of this earlier work, describing the background, architecture, and development of ICES can be found on the Systems Engineering Research Center website (http://www.sercuarc.org/)[Cloutier, Mostashari et al., 2009;


Figure 6. ICES prototype User Interface Screenshot

Cloutier et al., 2010; Korfiatis, Cloutier et al., 2012; Korfiatis et al., 2012].

## 4. Investigating ICES Effectiveness

ICES development and expansion continues through a number of research funding sources. It has undergone one round of evaluation with potential users [Korfiatis, Zigh et al., 2012]. That evaluation yielded feedback for future capability development. As ICES research continues, the research team is conducting more controlled, in-depth testing that can provide data to measure the effectiveness of such a tool. Discussions of the effectiveness of ICES and its methodology will be are found below. The relevant goals of the tool will be elucidated, measurements of effectiveness for ICES will be described, a proposed experimental design will be briefly described and specific metrics to be collected will be highlighted.

### 4.1. *ICES Goals*

Before considering how to measure the effectiveness of an ICES-like tool to improve the CE process, the goals and objectives must be established and understood. Among the established objectives of ICES come the following three hypotheses:

- The process of visually modeling operation scenarios during Concept Engineering will improve clarity and understanding of user needs for both stakeholders and system developers.
- The collaborative graphical workspace will enable stakeholders to reach consensus on conflicting needs and operation scenario models in which users feel their needs are properly addressed more quickly.
- A representation of operation scenarios using the virtual immersive environment will provide deeper insights than traditional textual documents.

### 4.2. *Measuring ICES Effectiveness*

While the capabilities of ICES are broad, for the purposes of this paper, it employs three major types of functionality to carry out its goals, similar to those used in [Thronesbery et al., 2008]:

(i) Creation – describes the process by which users utilize ICES to visually build models

(ii) Negotiation, analysis and validation – describes the method by which various users analyze and alter the visual model to ensure that it truly represents their needs from the system. It is envisioned that ICES will be a networked tool which will handle a diverse set of users simultaneously creating operation scenarios. As such, ICES can be used as both a negotiation tool between system stakeholders with competing concerns or needs, as well as a shared mental tool for stakeholders and developers to ensure the model is clear, unambiguous and representative of a true set of stakeholder needs

(iii) Extension – describes the translation of the ICES model into auto-generated MBSE artifacts, namely SysML use case, activity, block definition and parametric diagrams.

The metrics employed in measuring ICES effectiveness are still under development and are discussed briefly below; however, there are certain generic measurements that will be made for each of these functions relating to the ICES goals listed above. During the Creation functions, characteristics of the creation process will be observed and recorded. These will include time measures and operational scenario model analysis, as well as feedback from participants and observers concerning collaboration and model creation workflow.

While carrying out Negotiation, analysis and validation, effectiveness will be measured through observing and documenting the user negotiation process (as well as negotiation outcomes), the clarity and coherence of the resulting operation scenario artifacts, and the alignment between what a user wanted starting the process vs. what the artifacts indicate as user needs. An important aspect of analysis of the operational scenario artifacts will be an unambiguous representation of user needs. As such, it will be important to observe the differences in interpretation of the resultant artifacts from the point of view of a number of different experiment participants (users) and experts (developers).

Finally, the Extension functionality of ICES will be deemed effective based on evaluation of and comparison between SysML models resulting from the experiment. MBSE artifacts created should be easy to view, comprehend and understand by any outside observer with an understanding of SysML.

### 4.3. *Experiment Plan*

To collect data enabling the researchers to assess the effectiveness of the ICES tool, a controlled lab experiment of quasi-experimental design will be carried out [Leedy & Ormrod, 2009]. Two experiments will take place, one with five groups of participants, each modeling a predetermined scenario, while the second experiment will contain three groups of participants and two control groups. Both groups will be presented with a number of written descriptions of the scenario, with individual roles being assigned to group members. Each role assignment will have specific instructions to guide their interaction, concerns and contributions to the model development process. The experimental groups will use the ICES tool to model the scenarios. The result of these groups' activities will be an ICES system concept model and accompanying visualization. The control groups will be asked to construct a series of written operational scenarios.

The finals step in the experiment will happen after the experiment artifacts have been created. The ICES models and written scenarios will be evaluated by system engineering Subject Matter Experts (SMEs) and will be graded on their quality, specifically their clarity and ambiguity. Lastly, the ICES concept model will be translated into SysML diagrams automatically using the tool's capabilities and examined to ensure they match the animated visualizations. The written operational scenarios will be translated into SysML models manually by a group of SysML modeling SMEs. These final SysML models, consisting of use case, activity, parametric and block definition diagrams, will be evaluated both automatically and manually. The experimental procedure has been visualized in Figure 7 using a SysML activity diagram.

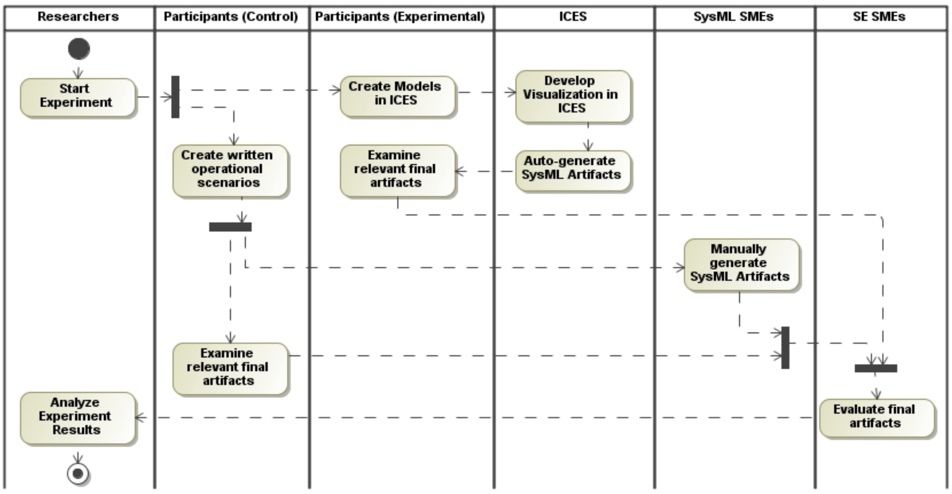


Figure 7. Planned experimental procedure for ICES

### 4.4. *Data Collection*

Given the nature of the experiment described above, an empirical mixed-methods approach of data collection will be employed, using both quantitative and qualitative data collection. As described by Valerdi and Davidz, this approach is particularly well suited to systems engineering research, where research often investigates a combination of both hard and soft sciences [Valerdi & Davidz, 2009].

#### 4.4.1. *Quantitative data collection*

Quantitative data will be collected using embedded counters and scripts in the ICES tool, in addition to quantified survey data. Data to be collected includes:

- Time to complete operational scenario modeling (write up)
- Total time spent modeling by individual participant roles
- Total time spent negotiating

- Complexity of resulting model (number of objects added to the models and their interconnections)
- Clarity of resulting artifacts to both participants and SysML SMEs (measured through Likert scale surveys following modeling)
- Direct comparison of final SysML artifacts using established model comparison tool (such as SDMetrics [SDMetrics, 2011])

4.4.2. *Qualitative data collection* –

Qualitative data will be collected through passive observation of the experiment proctors through structured feedback forms, as well as participant open ended responses to survey questions. Data to be collected includes:

- Impressions of proctors concerning of collaboration in participant groups
- Direct feedback from participants concerning collaboration using ICES
- Level of satisfaction felt by participants that their needs were properly represented in the artifact
- Impressions on the quality of the artifacts by systems engineering SMEs

## 5. Future Research

Until the above experiments are conducted, ICES development of the environment will continue, measures and metrics will become more detailed, and experiment materials will be carefully produced and validated. Feedback gained from this first set of experiments will further guide ICES development efforts and future experimental design parameters. An additional goal of ICES is its applicability across a variety of domains, missions and industries, and research partners and practitioners with interest in participating are encouraged to contact the primary author.

## 6. Summary

As model based systems engineering (MBSE) has been increasing in popularity within systems engineering organizations, calls have been made within the systems engineering community for integrated MBSE methods and tools which span the entire system lifecycle. This desire has led to focus on areas where MBSE efforts have not been adopted. One such area is Concept Engineering (CE), during which stakeholders provide system developers with descriptions of how they will interact with systems. Today the determination of user needs in CE is primarily a document driven approach, and while there have been efforts in the bringing MBSE practices to CE, no predominant tool or methodology exist. This research seeks to develop a methodology and tool (Integrated Concept Engineering System (ICES)) for visual modeling of early system concepts directly by users. By utilizing an immersive gaming environment, user needs can be collected, compared, and analyzed. They can then be executed in a 3D environment. ICES should provide not only a creation engine for user interactions in the form of operation scenarios, but also a collaboration tool for group modeling and negotiating conflicts among users. Finally, ICES will document these scenarios in a model-based form, allowing for interoperability with SysML and tools used by requirements engineering, systems analysts and systems architects. ICES is currently implemented as an early proof of concept prototype, and ready for investigation of its effectiveness in a development environment. A controlled lab experiment of quasi-experimental design is planned to undergo this investigation, aimed at collecting both quantitative and qualitative data to address to established research hypotheses.

## Acknowledgments

This material is based upon work supported, in whole or in part, by the Systems Engineering Research Center (SERC). SERC is a federally funded University Affiliated Research Center managed by Stevens Institute of Technology. Partners in this research have included Auburn University, Purdue University, and Texas A&M. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the view of Stevens Institute of Technology, other participating institutions, and/or any agency or entity of the United States Government.

## References

Andersson, J. and T. Huldt [2009]. "Model-Based Technical Planning: An Evaluation of Description Techniques." *Systems Research Forum* **03,**(02): 121-138.

Baldwin, K. [2010]. "Acquisition Modeling & Simulation Update: NDIA M&S Committee". in *MDIA M&S Committee*.

Baldwin, K. [2010]. "Systems 2020 Strategic Initiative Overview". in *NDIA Systems Engineering Conference*, San Diego, CA.

Bjorke, P. and R. H. Thayer, "Guide for Implementing a Software ConOps Document," IEEE.

Boehm, B., J. Bayuk, A. Deshmukh, R. Graybill, J. Lane, A. Levin, A. Madni, M. McGrath, A. Pyster, S. Tarchalski, R. Turner and J. Wade, [2010]. "Systems 2020 Strategic Initiative," Systems Engineering Research Center SERC-2010-TR-009, August 29 2010.

Bone, M. A. and R. Cloutier [2009]. "The Current State of Model Based Systems Engineering: Survey Results from the OMG SysML Request for Information". in *Conference on Systems engineering Research*, Hoboken, NJ.

Brown, B., [2011]. "Model-based systems engineering: Revolution of evolution?," IBM Rational, White PaperDecember 2011.

Cloutier, R. and M. Bone, [2010]. "Systems Modeling Language (SysML) Request For Information OMG Document," OMG syseng/2009-06-01, February 20 2010.

Cloutier, R. and R. Griego [2008]. "Applying Object Oriented Systems Engineering to Complex Systems". in *Systems Conference, 2008 2nd Annual IEEE*.

Cloutier, R., A. Mostashari, S. McComb, A. Deshmukh, J. Wade, D. Kennedy and P. Korfiatis, [2009]. "Investigation of a Graphical CONOPS Development Environment for Agile Systems Engineering," Systems Engineering Research CenterOctober 30 2009.

Cloutier, R., A. Mostashari, S. McComb, A. Deshmukh, J. Wade, D. Kennedy, P. Korfiatis and A. Carrigy, [2010]. "Investigation of a Graphical CONOPS Development Environment for Agile Systems Engineering," Systems Engineering Research CenterMay 31 2010.

Committee, N. S. E. D. M. S., [2011]. "Final Report of the Model Based Engineering (MBE) Subcommittee," NDIA2011.

Corns, S. and A. Kande [2011]. "Applying Virtual Engineering to Model-Based Systems Engineering." *Systems Research Forum* **05,**(02): 163-180.

Edson, R. and J. Frittman [2010]. "Illustrating the Concept of Operations (CONOPs) Continuum and Its Relationship to the Acquisition Lifecycle". in *Seventh Annual Acquisition Research Symposium*, Monterey, CA, Naval Postgraduate School.

French, M. A. and M. J. Lewis [2003]. Demonstrating the Potential Use of Virtual Prototype Modelling Techniques for Future AFVs.

Friedenthal, S. [2011]. "Model Based Systems Engineering Panel". in *Annual SERC Research Review*, College Park, MD, SERC.

Friedenthal, S., R. Griego and M. Sampson [2007]. "INCOSE Model Based Systems Engineering (MBSE) Initiative". in *INCOSE 2007 Symposium*, San Diego.

Friedenthal, S., A. Moore and R. Steiner. [2009, September]. "OMG Systems Modeling Language Tutorial." from http://www.omgsysml.org/SysML-Tutorial-Baseline-to-INCOSE-060524-low_res.pdf.

Herdlick, B. [2011]. "Establishing an Operational Context for Early Systems-of-Systems Engineering Activities." *Systems Research Forum* **05,**(02): 109-141.

Hill, C. D., F. Verjee and C. Barrett [2010]. Development of a Concept of Operations. Flash Flood Early Warning System Reference Guide, NOAA.

Jost, A. C. [2007]. "ConOps: The Cryptex to Operational System Mission Success." *CrossTalk: The Journal of Defense Software Engineering*.

Korfiatis, P., R. Cloutier and T. Zigh [2012]. "Towards a Graphical CONOPS Tool to Enhance Model-Based Systems Engineering". in *Third International Engineering Systems Symposium CESUN*, Delft, Holland.

Korfiatis, P., T. Zigh and M. Blackburn [2012]. "Developing a Graphical CONOPS to Enhance Model-Based Systems Engineering". in *2012 Industrial and Systems Engineering Research Conference*, Orlando, FL.

Leedy, P. D. and J. E. Ormrod [2009]. Practical Research: Planning and Design, Pearson Education, Limited.

Mansurov, N. and D. Vasura [2000]. "New visual interface for engineering use case models". in *Automated Software Engineering, 2000. Proceedings ASE 2000. The Fifteenth IEEE International Conference on*.

Mansurov, N. and D. Vasura [2001]. "Scenario-Based Approach to Rapid Prototypine of Human-Machine Systems". in *International Conference on Human-Machine Systems*, Germany.

Mostashari, A., S. A. McComb, D. M. Kennedy, R. Cloutier and P. Korfiatis [2011]. "Developing a Stakeholder-Assisted Agile CONOPS Development Process." *Systems Engineering* **15,**(1): 1-13.

Mostashari, A. and J. Sussman [2004]. "Engaging Stakeholders in Engineering Systems Representation and Modeling". in *Engineering Systems Symposium*, Cambridge, MA, MIT.

NASA, [2007]. "NASA Systems Engineering Handbook," NASA, Washington DC, Handbook2007.

OMG. [2011]. "OMG Systems Modeling Language." Retrieved October 30, 2011, from http://www.omgsysml.org/.

Osvalds, G. [2011]. "Model-Based Systems Engineering (MBSE) Process Using SysML for Architecture Design, Simulation and Visualization". in *NASA Goddard Space Flight Center Systems Engineering Seminar*.

Peak, R., C. Paredis and L. McGinnis [2009]. Model-Based SE Using SysML, NDIA M&S Committee Meeting.

Roberts, N. and R. Edson [2008]. "System Concept of Operations: Standards, Practices and Reality". in *NDIA 11th Annual Systems Engineering Conference*, San Diego, CA.

Sampson, M. and S. Friedenthal [2011]. "Model-based Systems Engineering (MBSE) Initiative". in *INCOSE International Workshop,* Phoenix, AZ, INCOSE.

SDMetrics [2011]. The Software Design Metrics tool for the UML.

Thronesbery, C., A. Molin and D. L. Schreckenghost [2007]. "A Storyboard Tool to Assist Concept of Operations Development". in *2007 IEEE Aerospace Conference*, Institute of Electrical and Electronics Engineers.

Thronesbery, C., A. Molin and D. L. Schreckenghost [2008]. "Concept of Operations Storyboard Tool Refinements Based on Practical Experiences". in *IEEE Aerospace Conference, 2008*.

Thronesbery, C., A. Molin and D. L. Schreckenghost [2009]. "Assisting ConOps with Storyboards". in *Houston Human Factors Society Meeting*.

Transportation, D. O., [2009]. "Systems Engineering Guidebook for Intelligent Transportation Systems," Department of Transportation: federal highway AdministrationNovember 2009.

USAirForce, [2009]. "Early Systems Enginering Guidebook," U.S. Air ForceMarch 31 2009.

Valerdi, R. and H. L. Davidz [2009]. "Empirical research in systems engineering: challenges and opportunities of a new frontier." *Systems Engineering* **12,**(2): 169-181.