EXPLORING THE TEST AND EVALUATION SPACE USING MODEL BASED CONCEPTUAL DESIGN TECHNIQUES

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Exploring the Test and Evaluation Space using Model Based Conceptual Design (MBCD) Techniques

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Abstract. During the initial concept development phase, systems engineers focus on defining the problem space and system functions in order to explore candidate concepts that may address the systems engineers' problems. Model Based Conceptual Design (MBCD) techniques may be used to assist the customer and other stakeholders develop a greater understanding of the system concept, as well as identifying areas in the system that are affected by changes in requirements. This approach has generally been documented for describing the system concept in the early stages in the lifecycle, without significant focus on the Test and Evaluation (T&E) space that would be needed to evaluate these concepts, or identifying where the T&E space would be affected with a change in requirements. Our hypothesis is that decision makers would equally gain insight into the T&E considerations as well as system space considerations using MBCD techniques. An approach is offered to extend the previously published MBCD methodology to better consider the T&E space.

Approach / Outline

Developing a system concept requires defining the problem space and required capabilities, functionality and interfaces of the system concept space. A Model Based Conceptual Design (MBCD) technique can describe the linkage of these problems and potential solution space in order to visualize the impact of changes from the problem to the solution space, and vice versa. The MBCD approach is conveyed via a structured entity-relationship *descriptive* model instead of a traditional static document, which may promote rapid understanding of the causality of changes and may encourage quicker decision making and become informed of the problem space.

This paper offers an additional emphasis to the existing MBCD process by extending it to more thoroughly integrate Test and Evaluation (T&E) artifacts and interfaces to the operational domain, system domain, and analysis domain as previously described by Robinson et al. (2010). The paper starts by describing the motivation in incorporating the T&E domain to the existing methodology, and how the test domain artifacts can be modeled and analyzed, in order to quantify the impacts of changes to the other domains. For clarity of reading, an illustrative example is offered to explore the modified technique and offers examples of what these metrics may look like to provide insight to decision makers.

Introduction / Motivation

The MBCD technique has been introduced to aid in understanding the problem space. Similar to existing model-based systems engineering (MBSE) techniques employed later in the lifecycle, it helps to visualize and structure Systems Engineering information. It allows for a richer visual picture to structure how changes in the capabilities / requirements may result from changes in the problem definition space, ultimately influencing the system capability space, concept of operations, or interfaces needed to successfully complete the mission. This approach can be helpful in the initial conceptual phase, but does not currently consider in detail the T&E phase of the project during development of a conceptual system design. By including the information that more fully describes the T&E activities of the project, additional insight into the full system design may be considered, to include the requirements / capabilities to be tested as well as the complex test ranges and equipment to verify these requirements, changes in the requirements. Decision makers may receive equal insight into the entire system concept by incorporating the T&E elements into the MBCD process, as well as considering operating and system concepts.

Literature Review

MBCD is implemented through a series of models to provide communication between the various system development elements (developers, stakeholders, users, etc.) and is described by Wylie et al. (2016), and Aluwihare et al. (2014) from which this paper takes motivation to extend the current methodology. Cook et al. (2015) uses the MBCD approach to assess the technical risk of concepts through the use of modeling and the understanding of interdependencies between the different models, which can inspire the use of modeling to conduct analysis on the various concepts. Do et al. (2014) have used MBCD to explore the interactions that are needed when exchanging information and insights while executing contracts between the acquirer and supplier. Tetlow et al. (2013) utilize the MBCD approach to further explore the requirements and to assess the mission success of the conceptual system using a model based approach. Do and Tetlow's descriptions detail the linkage between the user needs and system modeling, in order to develop a credible and valid system model for further analysis of the needs. Other uses of models to inform system simulations have been produced (Yaroker et al., 2013) that utilize a similar methodology as the MBCD approach.

It can be conclude from the literature review that MBCD has a wide range of applications and user communities, which provides motivation to incorporate the T&E community in this methodology.

Description of the Approach

The modified MBCD approach is described in five separate segments. The first defines how MBCD is used for system concept development and discusses the relevant artifacts, actors, and information. The second describes the proposed T&E extension to the MBCD technique. The third segment describes the linkage between the test domain and the other MBCD domains (notably the operational, system, and analysis). The fourth segment offers additional considerations to evaluate the entire system model. The last segment offers an approach to evaluate the new linkages and to visualize the insight gained when one domain causes changes to the other domains.

First Segment: MBCD Usage

MBCD is used to structure and link information about the understanding of a problem to possible solutions. Wylie et al. (2016) describe the usage of MBCD using *descriptive* models to describe the problem space, what the system is comprised of, and how the system interfaces are described. In their approach, they provide a logical design-based process to define the traceability, and therefore design rationale, between strategic guidance, operational activities, operational needs, functions, functional requirements, refined requirements, and software components. Through use of the descriptive models, the software developers are then able to develop their model of the system, and how it traces to the previously described artifacts. This traceability visualization can then aid the software developers and decision makers to appreciate where changes in the modified artifacts could affect the current software development plans. This level of insight can assist the decision makers to address the right problem and assist the developers to focus on the right solution set. Figure 1 provides an example of this traceability between domains through an abstraction of the schema employed to structure the model.

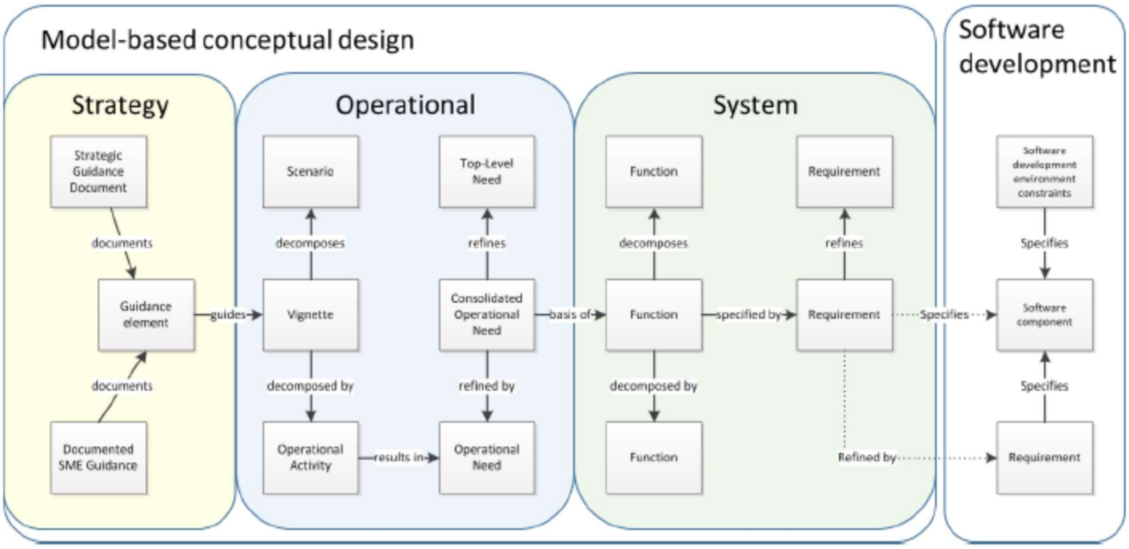

Figure 1. Traceability from Conceptual Design to Software Development (Wylie et al., 2016)

Second Segment: T&E Extension

An additional domain is proposed for inclusion into the MBCD methodology to address the T&E domain. This includes information elements that would describe the activities needed to test the requirements and functions, trace the tests to the requirements, and include the system components that would need to be tested. Proposed elements of the test domain would include: test plans, test ranges, test events, test articles, test targets, and test constraints. Based on the authors' experiences across the conceptual design and T&E domains, a high-level example of the schema of this test domain is provided in Figure 2.

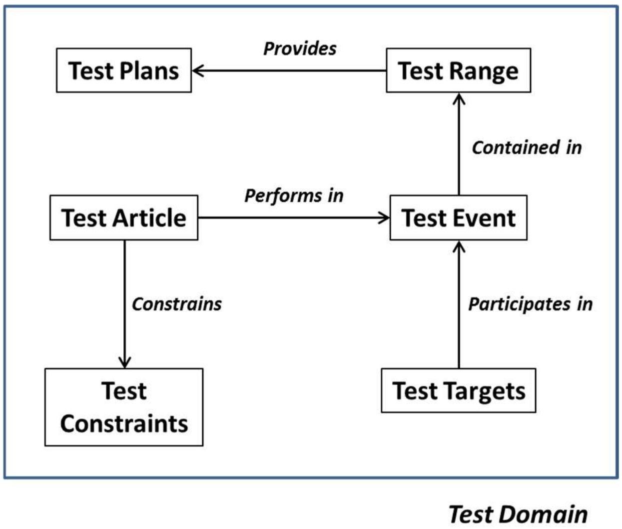

Figure 2. Test Domain MBCD Model

Third Segment: Test Domain Linkage to Existing MBCD Domains

The newly formed test domain model may be integrated into the MBCD model through the integration of the schemas. Robinson et al. (2010) define a model based systems engineering approach to describe a complex capability to include the enterprise context, operational domain, system domain, and the analysis domain. The strategic domain (enterprise context) focuses on the guidance. The operational domain focuses on the mission tasks, operational environment, and service requirements. The system domain focuses on the functions needed to address the mission, as well as the specific components that perform the functions. The analysis domain supports the studies and analysis to analyze the operational and system domain. Figure 3 augments the existing schema of operational domain and system domain with the test domain, thus providing the framework for developing the enhanced descriptive model, including the T&E activities.

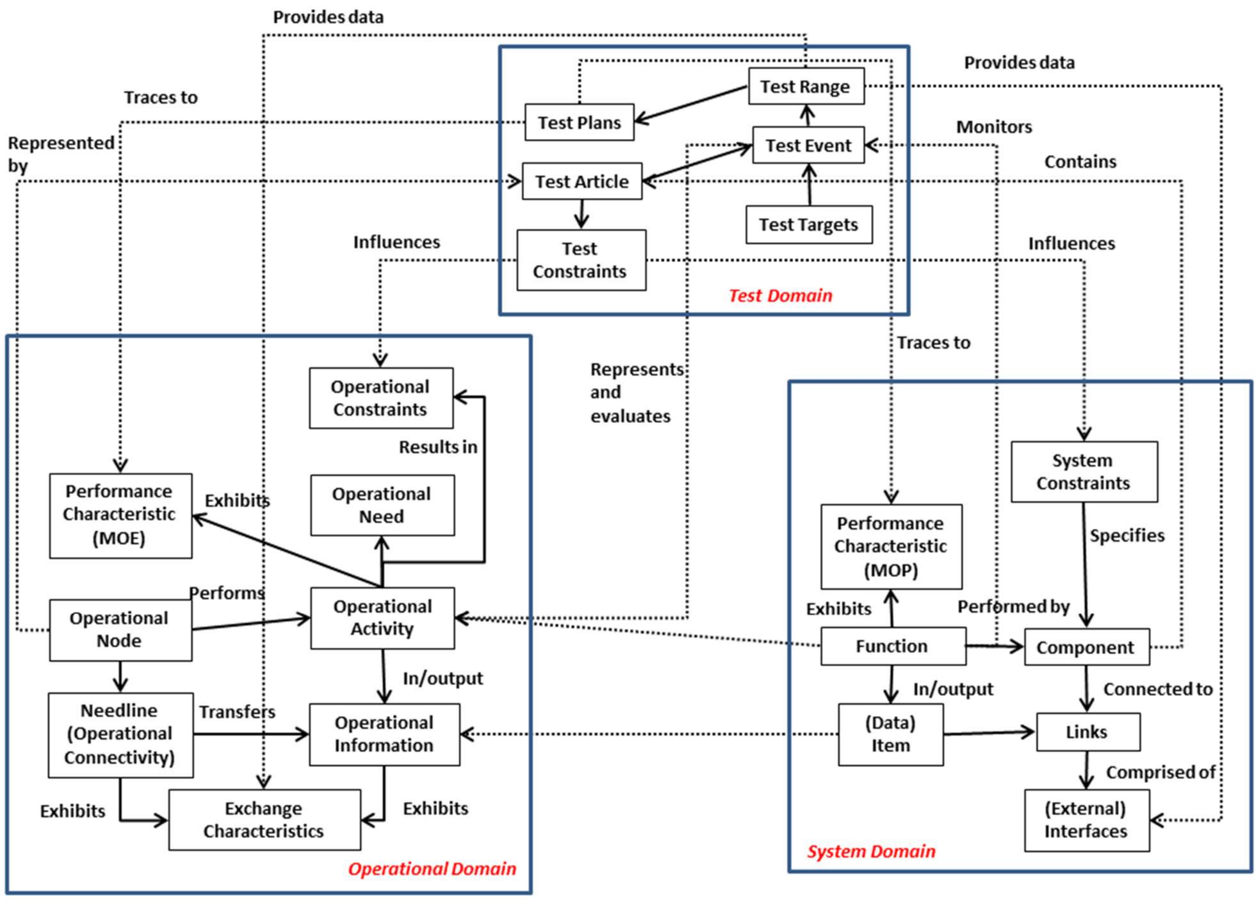

Figure 3. Modified MBCD Model Abstracted Schema

As more domains are included with the model, the abstracted schema represented in Figure 3 increases in complexity and becomes less readable. For clarity of reading, the interfaces and directionality from Figure 3 have been converted into an interdependency matrix, shown in Table 1. The table is intended to be read from left to right, from the source node (row) to the target node (column). A number of "1" indicates there is an interface from that specific source to target node. Note that the directionality should be reflected in this matrix, as not all interfaces have a 2-way direction, although can if desired for usability and readability. This table shows the three domains (operational, system, and test), which each have three possible domain interactions (one internal and two external).

Table 1: MBCD Model Interdependency

		Operational Domain								System Domain							Test Domain					
		Operational Constraints	Operational Need	Operational Activity	Operational Information	Exchange Characteristics	Performance Characteristic (MOE)	Operational Node	Needline (Operational Connectivity)	System Constraints	Component	Links	(External) Interfaces	Performance Characteristic (MOP)	Function	(Data) Item	Test Plans	Test Article	Test Constraints	Test Range	Test Event	Test Targets
Operational Domain	Operational Constraints	■																				
	Operational Need		■												1							
	Operational Activity	1	1	■			1															
	Operational Information				■	1																
	Exchange Characteristics					■																
	Performance Characteristic (MOE)						■															
	Operational Node			1				■	1									1				
	Needline (Operational Connectivity)				1	1			■													
System Domain	System Constraints									■	1											
	Component										■	1						1				
	Links											■	1									
	(External) Interfaces												■									
	Performance Characteristic (MOP)													■								
	Function			1							1			1	■	1					1	
	(Data) Item				1							1				■						
Test Domain	Test Plans						1							1			■					
	Test Article																	■	1		1	
	Test Constraints	1								1									■			
	Test Range												1				1			■		
	Test Event				1															1	■	
	Test Targets																				1	■

Fourth Segment: Evaluation of the New Linkage

The fourth segment evaluates how the rest of the overall descriptive model is affected when one domain element is changed. Changes may be viewed from different perspectives: the decision makers will view changes to the model as a change in capability or fielding date, which may affect their investment strategy. Developers may view changes to the model as changing their delivery dates or scheduling of efforts. Analysts may view changes to the model as updating their assessment of the system capability, which then may affect the decision maker's insight of the system's capability. Testers may view changes to the model that may affect their existing testing capabilities or future testing capabilities that need to be developed.

Changes to one domain may affect other domains described in the model. For example, if there are changes to the operational domain (e.g. requirements), this may affect the system development efforts if there are new capabilities needed, or if the system design approach needs to be modified. As a result of this operational requirements change, testing approaches may need to be changed, which may affect the scheduling of the test facility or modification of the test articles or targets.

Fifth Segment: Impacts of the Changes

Once the MBCD model has been modified, evaluation of the model should be conducted to ensure that the MBCD concepts are still valid, and the decision makers and other actors gain insight into the problem when changes to one domain are introduced. Several means are offered to evaluate how the linkages may be conducted. One method could be to leverage the network science community, to describe the number of nodes that are affected by a node that will change (e.g. changing requirements and understanding what impacts this change would have in the other domains). Other network science metrics are: size, average degree, average path length, connectedness, node centrality, and node influence.

As the triad of systems, operational, and testing domains are affected by changes in one of the domains, we may observe a change in both the primary and secondary influences that a domain has on the rest of the system. Using Table 1, changes to the test domain could affect the system and operational domain as the primary influence. However, each of these domains has their own potential influences, creating a secondary influence (system domain may affect the test and operational domain, and operational domain may affect the system and test domain). There exists a potential for the primary change in one domain to indirectly affect itself through the primary domain influenced. It may be postulate that a lesser impact will be seen through the secondary domain effect, but leave this for future work to quantify the primary and secondary impacts. Table 2 provides an example of such a primary (left side) and secondary (right side) of impacts based on one modification (function from system domain). An example of a primary impact is by affecting the "function" within the system domain, will affect five elements in the system (highlighted in orange). An example of the secondary effect is that each of these elements will have their own influence on the operational, system, and test domain, moving up and down the columns (shown on the right side in blue), affecting seven elements within the system.

Table 2: MBCD Model Interdependency Primary and Secondary Impacts

	PRIMARY IMPACT	Operational Domain								System Domain							Test Domain					
		Operational Constraints	Operational Need	Operational Activity	Operational Information	Exchange Characteristics	Performance Characteristic (MOE)	Operational Node	Needline (Operational Connectivity)	System Constraints	Component	Links	(External) Interfaces	Performance Characteristic (MOP)	Function	(Data) Item	Test Plans	Test Article	Test Constraints	Test Range	Test Event	Test Targets
Operational Domain	Operational Constraints																					
	Operational Need														1							
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	Operational Information					1																
	Exchange Characteristics																					
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	Operational Node			1					1									1				
	Needline (Operational Connectivity)				1	1																
System Domain	System Constraints										1											
	Component											1						1				
	Links												1									
	(External) Interfaces																					
	Performance Characteristic (MOP)																					
	Function			1							1			1		1					1	
	(Data) Item				1							1										
Test Domain	Test Plans						1							1								
	Test Article																		1		1	
	Test Constraints	1								1												
	Test Range												1				1					
	Test Event				1															1		
	Test Targets																				1	

	SECONDARY IMPACT	Operational Domain								System Domain							Test Domain					
		Operational Constraints	Operational Need	Operational Activity	Operational Information	Exchange Characteristics	Performance Characteristic (MOE)	Operational Node	Needline (Operational Connectivity)	System Constraints	Component	Links	(External) Interfaces	Performance Characteristic (MOP)	Function	(Data) Item	Test Plans	Test Article	Test Constraints	Test Range	Test Event	Test Targets
Operational Domain	Operational Constraints																					
	Operational Need														1							
	Operational Activity	1	1				1															
	Operational Information					1																
	Exchange Characteristics																					
	Performance Characteristic (MOE)																					
	Operational Node			1					1									1				
	Needline (Operational Connectivity)				1	1																
System Domain	System Constraints										1											
	Component											1						1				
	Links												1									
	(External) Interfaces																					
	Performance Characteristic (MOP)																					
	Function			1							1			1		1					1	
	(Data) Item				1							1										
Test Domain	Test Plans						1							1								
	Test Article																		1		1	
	Test Constraints	1								1												
	Test Range												1				1					
	Test Event				1															1		
	Test Targets																				1	

Illustrative Example

An illustrative example is offered to evaluate if the modified MBCD technique has merit and offers additional value to the stakeholders when changes are introduced. Here an existing example that uses MBCD to evaluate fire and emergency services [Spencer and Harvey, 2014] is leveraged and simplified. This example was developed for the Department of Fire and Emergency Services (DFES) of the Government of Western Australia. The MBCD process was followed to define the DFES mission, drivers, and capabilities, and used the capability management framework to more thoroughly consider during the planning, development, and execution of the capability development.

This example is utilized to introduce the MBCD process and the test domain. The intent of the example is to exercise the interdependency and quantification of the impact of changes when portions of the entire model are changed.

Operational Domain Description

The operational domain is defined by the DFES mission to detect, analyze, and respond to emergencies and incidents. Depicted in Figure 4 is the mission in graphical form using an OV-1. Within each of these domains, the following elements are defined in Table 3.

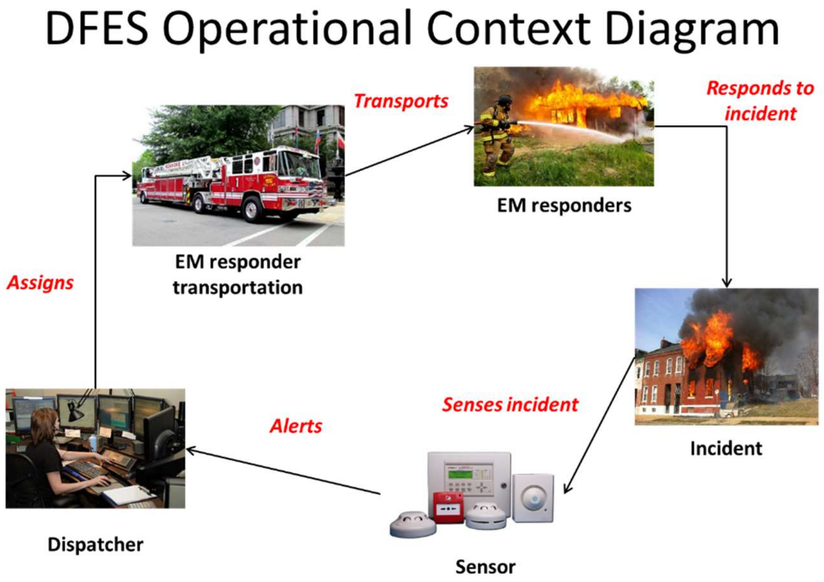

Figure 4. Modified DFES Operational Context Diagram (OV-1)

Table 3: DFES Domain Elements

Functions	Systems	Actors
Sense smoke / incident	Sensor	Fire service personnel
Send alert	Telephone / radio	Rescue coordinators
Confirm incident / select action	Data terminal	
Dispatch response units	Tanker, pumps, hoses	
Respond to incident	Transport vehicle	

System Domain Description

There are numerous systems that are used in this example. These are organized by the various phases of the operation (sensing, alerting, processing, dispatching, transporting, and responding). These systems are also listed in Table 3. Note that these systems will also include the actors that will operate the systems and other aspects not included in the simplified example.

Test Domain Description

The test domain will identify several elements that would be used to test the various mission activities that are being evaluated. From our example, four capabilities would be tested, listed in Table 4 that are organized by capability test objective, and applicable test elements.

Table 4: DFES Test Elements

Functions	**Test Objective**	**Test Element**
Sense smoke / incident	Determine if incident is properly detected	Sensors, fire source, facility environment
Send alert	Determine if alert is sent timely	Communications (transmitter and receiver), communications environment
Confirm incident / select action	Determine if response is correctly determined	Dispatcher, displays, dispatcher environment
Dispatch response units	Determine if dispatch is correctly executed	Response units, transportation environment
Respond to incident	Determine if response is adequately executed	Responders, fire source, facility response environment

Insight and Utility of the Modified MBCD Process

The modified model can be utilized to incorporate the test domain along with the operational and system domains. While the stakeholders, development team and test team are developing their respective efforts, we would expect numerous interactions between the three teams during the capability development. Expected questions in response to a domain change should start with "how does that affect the other domains?"

The model would be developed and then verify with the three domain teams to ensure that the elements and interactions are correct. Data would be elicited through tailored interviews and workshops to determine if sufficient insight was gained by all parties during the system development.

Conclusions / Next Steps

This paper has offered a modification to the existing MBCD process to incorporate the test domain into the conceptual development phase. The aim being to ensure that the testing community and capabilities are also considered during the initial development to identify long-lead capability development, or how interdependent the operational and system development teams are to affect the test capabilities.

Next steps would be to identify an example project that this approach could be applied to, and gain concurrence by all three domains. A model would be developed to describe the specific domains and follow the MBCD process during the system development lifecycle. Data could be collected at relevant milestones (e.g. preliminary design review, critical design review, test readiness review, etc.). If the hypothesis proves correct that insight is gained by all domain stakeholders, the project could progress to a larger and more interdependent system concept for a further proof of concept.

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Biography

David Flanigan. David Flanigan is a member of the Principal Professional Staff for The Johns Hopkins University Applied Physics Laboratory, providing systems engineering services to various Department of Defense and Department of Homeland Security clients, and has 20 years of active duty and reserve service with the US Navy. A graduate of the University of Arizona, he holds a MS in Information Systems and Technology, a MS in Systems Engineering from the Johns Hopkins University, and a PhD in Systems Engineering and Operations Research from George Mason University. Dr. Flanigan is a member of INCOSE, INFORMS, and MORS.

Kevin Robinson. Kevin Robinson is the Chief Engineer at Shoal Engineering with a distinguished career in the field of Guided Weapons in both the UK's Ministry of Defence and Australia's Department of Defence. He has made significant contributions to the development of advanced guided weapons through modelling and analysis, research, and leadership of large cross discipline teams. Throughout his career, Kevin has taken a leadership role in advancing the field of Model-Based Systems Engineering (MBSE) via his publications and contributions to the systems engineering community. He initiated and chaired Australia's first annual MBSE Symposium, formed and chaired INCOSE's Model-Based Conceptual Design Working Group, delivered a keynote address to INCOSE's international symposium in 2016, and has made contributions to INCOSE's Systems Engineering Handbook and related standards. Recently he has joined INCOSE's Future of Systems Engineering initiative core team.