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A Model-based Engineering (MBE) Manifesto

By

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Introduction

As a systems research analyst for Sandia National Laboratories, it was my distinct honor to lead a week-long Conversation to dig into the transformation toward a model-based engineering (MBE) approach with a small group of hand-picked senior systems scientist and engineers. If you don't know, a transformation to an MBE approach is a major paradigm change for our industry, associated companies, and participating member engineers. Rarely are we offered the opportunity to thoroughly discuss these really large intractable problems. Knowing this before we started, I intentionally seeded my group with a group of professionals from diverse perspectives on the problem. The outcome of those long hours of Conversation into many diverse topics was our MBE Manifesto. I would like to propose this manifesto as a guide to motivate and possibly drive our industry toward a fully integrated digital engineering capability.

The purpose of the manifesto is to summarize and make explicit key values and principles motivating the transformation to a model-based engineering approach. We have documented in this collection of papers, the basis of our thoughts and how those concepts were incorporated into the manifesto. Each day

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of the Conversation is represented by articles from team members that best define the topics of discussion on that date.

The first question we often get regarding our manifesto is, “well, what do you mean by MBE?” We mean this term, model-based engineering (MBE), to be inclusive of all engineering disciplines. We fully recognize that others do not see this term in this way, but this is our meaning with the manifesto. We see the ultimate goal to be a fully digital engineering capability, and that goal must include all disciplines involved in the development of the target system. We also recognize that others do not see this as the end goal. Great, let’s have a conversation about this, because clearly, this is where the industry is headed.

Background

In April 2018, a small group of senior systems engineers, scientists, and researchers assembled at the 19th International Federation for Systems Research (IFSR) Conversation in Linz, Austria, to use systems analysis methods to model a Systems Engineering approach that would optimize modern model-based engineering methods and tools. We each came from different parts of the industry and held very different perspectives on the Systems Engineering industry. The one thread that held us all together is the ideal that our industry needs to progress significantly toward a model-based approach.

We came together initially to talk about data-driven systems engineering. However, the nature of an IFSR Conversation is to allow the conversation to flow where needed. And ours flowed and ebbed in and around how we collectively felt we needed to effect a transformation toward a model-based approach.

Each of the team members were hand chosen for the extent of their different experiences in and perspectives on Systems Engineering (SE), and model-based engineering in particular.

Below is a brief description of those perspectives:

> Ed Carroll: Principal R&D Systems Research Analyst at Sandia National Laboratories, and former CTO for Egghead.com. His research is focused on understanding the optimal application of advanced engineering approaches.
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> Dana Grisham: Principal Solutions Architect at Sandia National Laboratories. Her focus is on data architecture, software infrastructure, and governance enabling transformation to data-driven systems engineering.
>
> Nancy Hayden, PhD: Principal R&D Systems Analyst at Sandia National Laboratories, and Research Fellow, Center for International and Security Studies at Maryland. Research focus is intersection of complexity, system dynamics, technology innovation, policy, and strategic stability.
>
> Eliot Rich, PhD.: Associate Professor of IS and Business Analytics, School of Business, University at Albany, SUNY. He leads the University of Albany System Dynamics Group and is an ACM Senior Member.

Frank Salvatore: Technical Fellow at Engility Corporation. Expert System Engineering Professional (ESEP) and OMG Certified Modeling Professional (OCSMP). Frank supports DOD organizations in digital engineering transformation initiatives and supports programs.

Bill Schindel, President of ICTT System Sciences, is an INCOSE Fellow, co-chair of the INCOSE MBSE Patterns Working Group, and leads application of the S*Metamodel and S*Patterns across multiple domains.

Chris Schreiber: a Systems Engineering Senior Manager for Lockheed Martin Space Systems Company with responsibility for the Systems Engineering Modernization department focused on supporting Space Systems programs with Model-Based Systems Engineering.

Sharon Trauth: Principal R&D Systems Engineer at Sandia National Laboratories, leading MBSE application to weapons, and innovating a new method to model the relationships between environmental constraints, components and their allocated functions.

Steve Jenkins: Principal Engineer at Jet Propulsion Laboratory and California Institute of Technology. Steve has been instrumental in developing and evangelizing an ontology-based MBSE transformation and innovation at the lab.

Anne O'Neil: Systems Catalyst and Strategist with Anne O'Neil Consultants, LLC. Anne advices organizations world-wide seeking to adopt systems practices and leverage systems engineering capability to achieve and improve business outcomes.

Conversation Agenda

In the months prior to the Conversation, the team collaborated extensively on the agenda. Our concern was to ensure that we had a week-long agenda that would produce worthwhile, engaging, and conclusive conversations. As might be expected, the resultant starting agenda was far too ambitious for time available. However, we had agreed before coming together that the agenda would be ours to manipulate and adjust as the week progressed. And indeed, the agenda did ebb and flow. Interestingly enough though, we dug deep into areas that needed to be drilled into and flew over others where we all agreed.

The flow of our conversation is depicted in this System Dynamics model in Figure 1, below:

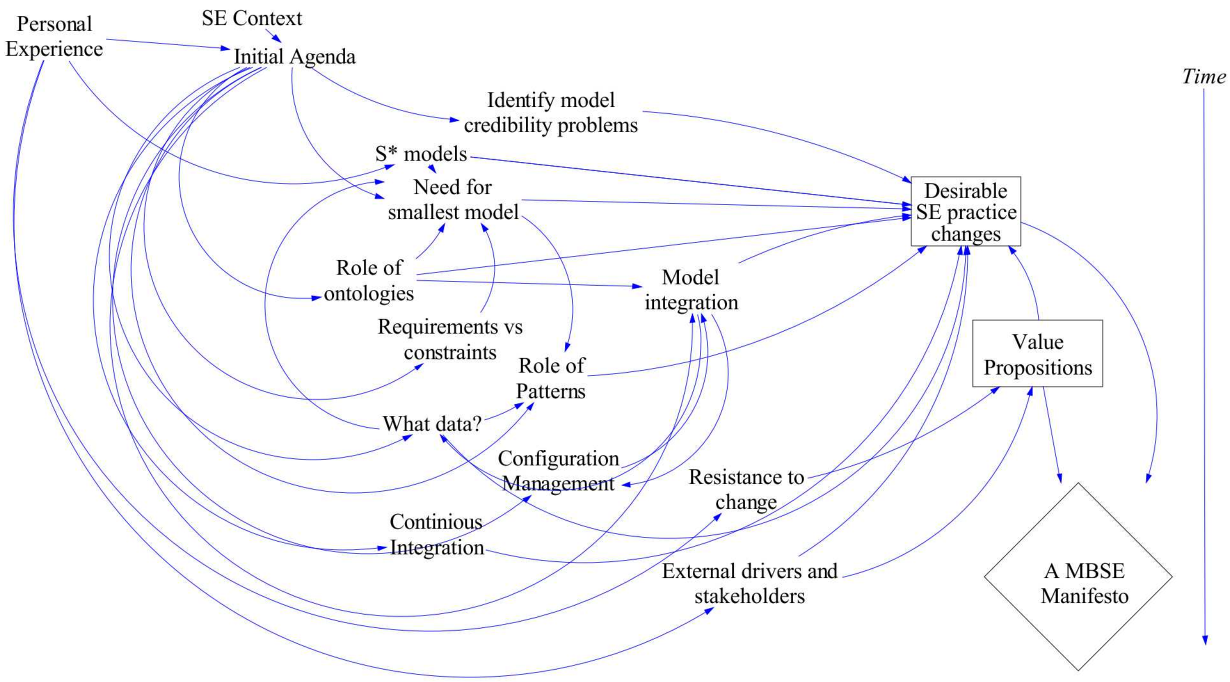

Figure 1: System dynamics model of our Conversations

The final agenda that converged at the conversation flowed through the S*Space paradigm, starting with the system model of the target system - the thing being developed (S_1), working upward toward the model of life cycle domain system – the system that manages the target system model (S_2), and then on to the model of system of innovation – the system that evolves the life cycle domain system (S_3). Figure 2, below, illustrates this model.

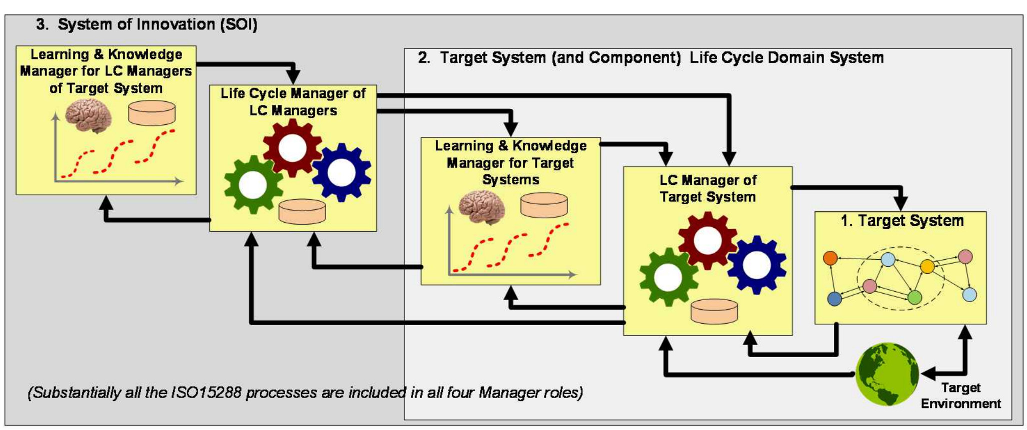

Figure 2: System of Innovation Reference Pattern (© 2016, Schindel and Dove)

The Conversations seemed to naturally flow in this direction, in that after diving deep into each topic, it seemed natural to take a step upward to resolve how that topic fit into the larger puzzle. We will discuss the S*Space paradigm more in the section on Model Credibility.

Report Out – A Model-based Manifesto

Similar to the values and principles defined as the Agile Manifesto developed by the Agile Alliance for software development and ideas on how data-driven methods would help to instantiate these principles within programs – can we define an Agile or Model-based Engineering manifesto? We successfully culminated this week-long conversation with four Value Statements and a Model-based Engineering (MBE) Manifesto, made up of seven principles.

We have nailed our manifesto to the front door at the MORS 86th Symposium (June, 2018), Monterey, CA, the INCOSE International Symposium, (July, 2018), Washington D.C., the 36th International Conference of the System Dynamics Society, (August, 2018), Reykjavik, Iceland, and the NDIA 21st Annual Systems Engineering Conference, (October, 2018), Tampa, FL, as well as several smaller and local conferences and venues. Our manifesto is currently posted in the Pentagon, Washington, D.C., as well as at each of our respective organizations.

Figure 3: Martin Luther nailing his manifesto (thesis) to the church door @History, 2017

We sincerely hope that you will give feedback and input to the manifesto. While we recognize that not everyone will share our views or appreciate the nuance of our wording, our hope is that the MBE manifesto will embody our full collective values and principles on where the engineering industry is moving forward into the next decades.

We present our value statement here:

Figure 4: MBE Manifesto Value Statements

The first section of our manifesto is about our over-arching values. Note the fine print… *that items on the right are valued, but not at the sacrifice of the items on the left.* By this statement, we indicate our agreement that the items on the right of the value statements are valuable. For example, we acknowledge that artifacts will always be with us. Independence in model development enables models to be focused on the problem to be solved. Flexibility in one's approach enables innovation. And this group certainly favors models to be created. However, we feel that the values stated on the left of the statements provide more value and help to drive us to more complete, informative, innovative, and useful models. Our ultimate objective is for models to be used and reused.

Explanation of the Value Statements

By Chris Schreiber, Senior Manager, Lockheed Martin Space Systems – Systems Engineering Modernization

Information over **artifacts** –

Conventional engineering practices focus on the generation of artifacts to codify and communicate design information. These artifacts often collect and present that design information relative to specific stakeholder groups and concerns, leading to the same information being reused and repackaged across many artifacts. In a model-based engineering paradigm information can be easily assembled in a variety of forms, for a variety of purposes easily. As a result, the engineering job and our engineering processes must focus less on the generation of those artifacts, but on the information needed to generate any artifact for any stakeholder viewpoint.

Integration over **independence**

Conventional engineering practice relies on decomposition and separation of concerns to produce designs that meet complex challenges. This is typically accomplished by dividing the engineering job by domain or subsystem requiring the disintegrated groups to come together periodically at milestones to reintegrate design information. The model-based engineering approach, on the other hand, allows for design information to remain integrated over a project life cycle. Design information from different model-based domains can be related, allowing the collective, integrated design to be continually consistent.

Expressiveness with rigor over **flexibility**

Contemporary engineering practice relies on flexibility, or freedom to communicate design and design information in ways best fitting the needs of the designer themselves. While an unconstrained designer can easily communicate on their terms the elements of their design, this leaves much of interpretation up to a user of that information. In the model-based engineering paradigm, that information must be consumed, in a variety of ways, without the complication of ambiguity and interpretation. In fact, the model-based engineering requires the linguistic features of semantics and syntax to ensure that interpretation is not ambiguous and unpredictable, while still providing sufficient freedom to completely define design. This, we describe as a duality of rigor and expressiveness, enabling complete and consistent use of modeled engineering design.

Model usage over **model creation**

Very often our engineering approaches and tools focus on the capture of information to completely specify a design. This focus emphasizes capturing, storing and communicating this information from the perspective of the designer themselves, without much regard for consumers of the design information. The model-based engineering paradigm values the use of design information beyond mere creation. An emphasis on usage requires additional attention and effort to be paid to contextualizing and understanding not only the design, but design's intent to fully appreciate and leverage this information across the total enterprise.

Explanation of the Principles

By Edward R. Carroll, Principal Systems R&D Analyst, Sandia National Laboratories

With these principles:

> *On behalf of stakeholders, MBE increases emphasis on **describing** the nature and content of the **information** produced and consumed, compared to the traditional emphasis on engineering process and procedure.*

This topic sounds like a platitude, but it is our collective experience, validated by published research and analysis that MBE provide visual, textual, contextual, relational, behavioral, and parametric perspectives to the information that defines a systems. In this sense, these multiple perspectives improve the communication with stakeholders, enabling a better grasp on what is being developed for their needs. Multiple perspectives likewise increases the information gathered and developed about the system and directs the focus of engineering on the system, not on how the system is to be developed – processes and procedures.

> *We recognize that—**independent** of specific Information format, structure, language, syntax, the sequence or order of its production and consumption, and the domains and environments of our projects—the underlying nature (**semantics**) of the **essential** information we seek to discover and produce is **invariant** because of the very nature of engineering.*

We refer in this principle to the underlying semantic ontology inherent in all engineering models. Again, our collective experience is validated by published research and analysis. The essential information contained within an engineering model is in digital form software that can be interpreted by other software programs. The invariant underlying semantic ontology is what enables digital engineering models to be integrated across components, systems, programs, and engineering disciplines.

> *An essential and dynamically changing property of model information is its **credibility** to those people and processes which will **consume** that information. The critical nature of some **intended uses** of model information sets a higher bar on required investment in model **verification**, **validation** and **uncertainty quantification**.*

When system concepts are small and contained, it is easy to understand the credibility of the models for that system. As models grow in complexity, the credibility of the associated models becomes less apparent. In a complex system with hundreds of models, thousands of object descriptions, and millions of information nodes, it become impossible for the model to deemed credible by simple observation. The more critical the system, to operations or even to life, the more important that associated models be credible. Verification, validation, and uncertainty quantification take on an increasingly important role to ensure model credibility. Due to the critical nature of some intended uses, the role of V&V and uncertainty quantification may surpass more traditional system design roles in importance.

*Principles of **human-machine interaction** applied to the targeted stakeholders are vital to success. Application of advanced visualization methods **and augmented intelligence** capabilities can advance that success.*

All systems are developed for human use or human stakeholders in one form or another. Consideration of that human-machine interaction should be the focus of the system development. As stated above, digital models gather and develop greater information and multiple perspectives – that can improve the communication to the human stakeholders, as well as to the human-in-the-loop, human-interacting with the machine, or just human user. As also stated above, digital engineering models are software, therefore software-based augmented intelligence capabilities can, and should, be used to advance the success of the human-machine interaction.

*We seek an extended team across engineering disciplines with **common and integrated understanding** of the identity and nature of the model information as well as its content.*

We stated above that our definition of MBE is intended to be inclusive of all engineering model disciplines. This integrated community view, based on our own collective experience, and validated by research and analysis, improves system development, operational use, and sustainment by establishing a common and integrated understanding of the system. No more systems need be developed from truckloads of paper documents that are unsearchable, non-integrated, and uncommunicable.

*We seek effective **enterprise-wide reuse** of model-based information to more fully leverage past individual or local learning.*

Useful models, because they are useful, are by nature reused. Model reuse saves time, energy, and promotes model credibility. The advantage of digital models is the ease with which knowledge contained within a model can be shared and distributed. Local, expert, mature, and specialized knowledge can and should be leveraged. Leveraging past individual or local learned knowledge is the basis for improving what, where, when, and how systems are developed.

Systems engineering performed according to the above principles is required for the Engineering System itself, a complex and evolving system.

It needs to be recognized that the engineering system that creates the system to be engineered must be engineered, in itself. Our collective experiences are once again validated by research and analysis that a haphazard approach results in a haphazard system. Successfully developed complex systems require engineering rigor applied in a repeatable, tailorable, measured, and optimal approach.

An MBE Manifesto

The result of our week-long Conversation culminated into a manifesto on model-based engineering (see the full manifesto in Figure 3 below). We have received considerable feedback on this manifesto, but the ideals that originated this manifesto have held steady. It is our specific intent to spark broad conversation about these ideals. To that end, you (the reader) may or may not agree with the values and principles stated, but our hope is that you will converse about those issues, even argue about them, either with us or with your own colleagues. It is through that conversation that we believe change will happen (whether positive or not remains to be seen).

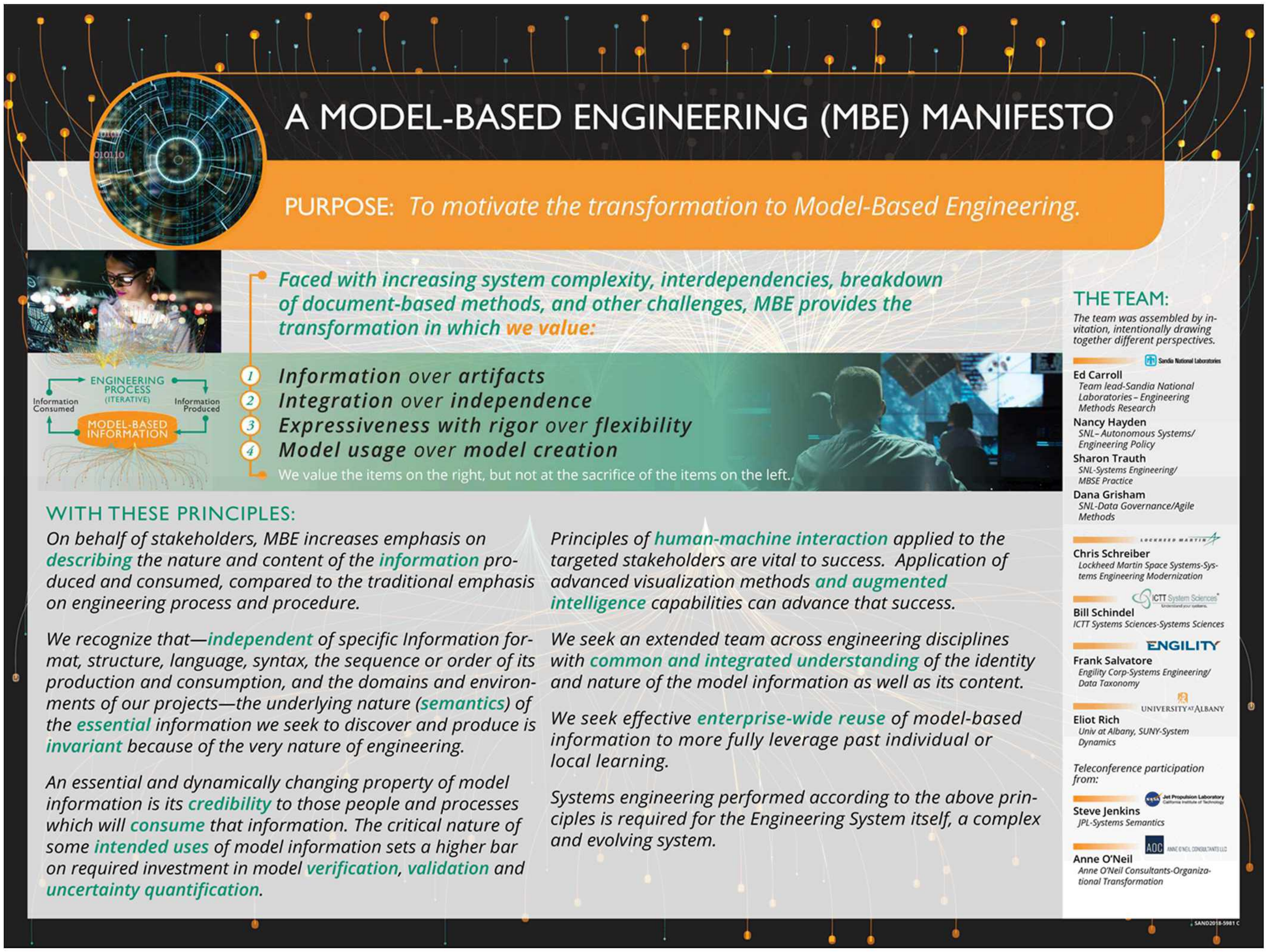

Figure 5: MBE Manifesto

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