NASA's Safety, Reliability, and Mission Assurance Digital Future

Mr. Anthony DiVenti and Dr. Matthew Forsbacka, Office of Safety and Mission Assurance, NASA HQ
Mr. Kevin Rainbolt, NASA Safety Center
Dr. Steven Cornford and Dr. Martin Feather, California Institute of Technology/Jet Propulsion Laboratory

Key Words: Assurance-Case, Authoritative Source of Truth (ASOT), Digital Transformation, Digital Twin, Machine-Assisted, Objectives Hierarchy, Basic Formal Ontology (BFO), Domain Representation, Safety Case, Safety & Mission Assurance (SMA), Safety & Mission Success (SMS), Systems Modeling Language (SML)

SUMMARY & CONCLUSIONS

The evolution from "document-centric" to "data-centric" and "model-centric" information leveraging structured data and model-based approaches is at the heart of digital engineering transformational efforts underway across industry and government. It is these approaches that pave the way for data lakes, Authoritative Sources of Truth (ASOTs), and systems-of-systems interoperability and the corresponding transformational benefits thereof. Such benefits include increased data availability, data access equity, data traceability, real-time analytics, batch analytics, and (most importantly) acceleration of the time-to-value and time-to-insights associated with engineering products and analyses. The longer-term benefits of reusability, customization and traceability are even more promising.

For Safety and Mission Assurance (SMA), and Mission Success (SMS) activities; realization of such benefits is essential to provide engineers and analysts alike vital information when needed to support critical decision making throughout the entire life cycle. The SMA community often operate in parallel with engineering activities, for which information exchange with relevant context is paramount. Far too often, such information lags key decision points and/or is absent of the robust, integrated, knowledge needed, given inherent barriers associated with traditional document-centric means to data sharing, analysis, and reporting.

This paper provides an overview of how NASA's Office of Safety and Mission Assurance (OSMA) is evolving its policies, standards, guidance, and training to transform to eliminate such barriers, thus realizing the benefits emerging in this new digital era. A roadmap for achieving this digital future is presented along with key building blocks involving use and implementation of concepts such as: Objectives-Hierarchies, Objective-Driven Requirements, Accepted Standards, Safety and Assurance Cases, data digitization (i.e., ontologies, structured data, and model-centric data), FAIR (Findable, Accessible, Interoperable, & Reusable) and/or FAIRUST (Findable, Accessible, Interoperable, Reusable, Understandable, Secure, and Trusted) principles [1]. This paper also describes how OSMA, leveraging the Agency's overall commitment to Digital Transformation (DT), is using the power of Policy, "Digital" Domain representation, Product Evolution, and Community Outreach and Engagement as part of a strategic vision and roadmap to evolve and transform its SMA organizations to become better able to serve its stakeholders and customers. Future publications will elaborate on these building blocks and deeper concepts.

1 BACKGROUND: THE PERFECT STORM

A Perfect Storm in a positive sense can be thought of as the confluence of conditions that make change necessary. NASA is amid such a "Perfect Storm" with several conditions "ripe" for not only change, but "transformational" change:

- Our tasks or missions are becoming increasingly complex and integrated with industry on constrained budgets & timelines.
- The aerospace industry, and the world, is transforming around us to meet increasing complexity and demands.
- 21st century business processes are outpacing our legacy systems, thus make change a necessity for businesses that wish to remain relevant
- Top talent is expecting to work in a digitally enabled environment.

To that end, DT, characterized as employing digital technologies to change a process, product, or capability to achieve unprecedented (i.e., orders of magnitude) improvements in capabilities from what exists today, is at the heart of NASA's transformational activities across the Agency. Such DT work within OSMA is being done in coordination with NASA's overall DT initiative led out of NASA HQ and the Office of Chief Information Officer (OCIO). At the time of this paper, NASA had named both a Chief Digital Transformation Officer (DTO) and a Chief Data Officer (CDO)- to spearhead related activities around three NASA goals (i.e., transform the way we WORK, transform the experience of our WORKFORCE, and transform the agility of our WORKPLACE) and four corresponding transformational target areas (i.e., "TRANSFORM ENGINEERING" (includes SMA), "TRANSFORM DISCOVERY", "TRANSFORM OPERATIONS", and "TRANSFORM GOVERNANCE"). Supporting these transformational efforts are "Foundational Element" teams that bring together specific DT-related Communities-Of-Interest (COIs) within NASA to perform important functions such as "Horizon Scanning" across industry, benchmarking and capturing best practices and emerging capabilities, sharing lessons learned, and identifying and supporting collaboration and leveraging activities to help transform the Agency moving forward and realize the benefits thereof.

One such "Foundational Element" COI that NASA SMA has been particularly focused on leveraging is that of our Model-Based Anything or MBx team, which is broken out into various sub-MBx domains: Model-Based Engineering (MBE) including Model-Based Systems Engineering (MBSE), Model-

Based Institutional Management (MBIM), Model-Based Project Management (MBPM), and ***Model-Based Mission Assurance (MBMA)***. It is with MBMA that OSMA has aligned much of its DT-related activities to improve interconnectivity and interoperability with other domains/organizations and so enhance its ability to support NASA's mission, described in more detail in the next section.

Interoperability (i.e., the notion of seamless and real-time access to information from (and between) all parties of interest), is viewed as a fundamental capability to meet NASA's (including SMA's) future mission needs. The ever-increasing complexity associated with both technological and partnership development requires more seamless and expedient knowledge sharing in support of critical decision making across different domains and partnerships, both nationally and internationally. More and more, the standard ways of doing things in the past relying on "document centric" and siloed information sources are simply too inefficient, take too long, and/or are no longer compatible with need to do more in less time, and with less money.

To evolve from these "document-centric" ways of doing business, NASA is building upon structured-data approaches and model-based methods to create a digital, interoperable, environment. At the fundamental data level, for example, NASA has embraced principles of FAIR and FAIRUST to maximize the use and impact of information. At the next level up from data, NASA is pursuing Model-Based methods (i.e., inter/intra-connectivity modeling) to model the relationships from data to different processes to different output products to different roles/responsibilities to customized views needed by different stakeholders, at the time they need it, to support NASA's mission.

The question is no longer whether NASA should transform, but how to do so, to remain at the forefront of the frontiers of space exploration, scientific discovery, and technological advancement.

2 FRAMING NASA'S SMA/SMS CHALLENGE

At the heart of OSMA's Transformation Challenge is the need to eliminate the so-called "N-1 problem," which is when project-related decision making occurs without the benefit of the latest or relevant SMA-related information being produced or provided. At NASA, SMA related products (e.g., reliability analysis, risk assessments, hazard analysis, process optimizations, quality inspection results) given to Decision Makers (i.e., Project Managers, Systems Engineers, Design Engineers, Chief Safety and Mission Assurance Officers, etc.) often lags when decisions are, or should optimally be, made over the course of mission formulation, design, and development. More times than not, challenges associated with SMA discipline analysts working to older sets of information (due to lack of authoritative data source(s)), not having relevant data from the field, not having the ability to seamlessly share relevant trade-study information, or not having the ability to organize information in a manner relevant to the decision-makers of interest are often the prime contributors to the "N-1" dilemma.

Turning this dilemma into a paradigm shift, OSMA in partnership with the Agency's MBMA/SMA DT community, have reshaped the problem into a transformational opportunity as described by the Knowledge versus Influence Curve (Figure 1) to help illustrate the changes needed and benefit thereof.

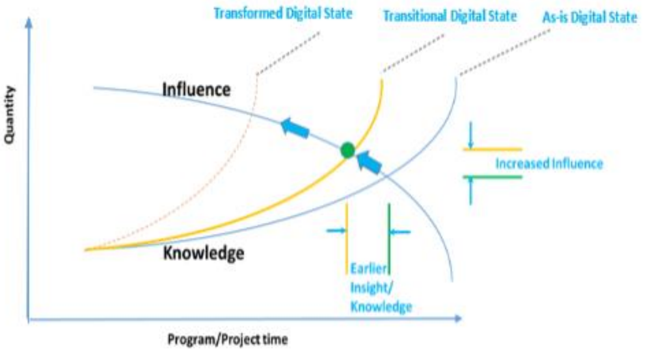


Figure 1 – Knowledge vs Influence Curve [2]

Simply put, the more relevant knowledge available, the earlier insight and analysis capability the SMA organization has, the more positive influence that SMA can offer to programs and projects and thus, the more positive impact that SMA may have on missions. Just think of unwanted circumstances (i.e., catastrophes, mishaps, near-mishaps, costly failures, costly over-runs) that could have been avoided had decision-makers had earlier access to pertinent risk information (i.e., likelihood, impact, failure-propagation scenarios). For example, could the dire conditions encountered by ISS's Astronaut Parmitano (i.e., a severe water leak that ended up covering most of his face during a spacewalk) have been avoided if there was access to development, integration, and test information that may have indicated the risk of that mishap occurring? As a more general example, could some of the major programmatic cost over-runs have been avoided if there was access to important information (e.g., supply chain history of applicable vendors, process FMEA results identifying potential assembly failure modes) upfront that could have raised awareness of reduced through-put related to poor manufacturability conditions, etc., which led to enormous production fall-out and scrap costs?

Given NASA plans to return humans to the Moon on a permanent basis, put humans on Mars, or return space samples from deep space; the necessity to build frameworks and solutions that enable organizations to "influence" and "track" critical decision making by providing necessary information to decision-makers and stakeholders alike, when they need it, is essential. This is certainly the case for organizations executing SMA-related functions and activities spanning planning, design, and operations.

In fact, it is from the Knowledge vs Influence illustration in Figure 1 that OSMA has built its (continually-evolving) SMA Digital Transformation (DT) and MBMA Strategic roadmap to transform from the current ***"N-1" state*** to that of a ***"Transformed Critical-Decision Making and Risk Acceptance" state*** (Figure 2), whereby SMA enables robust, understandable, secure, relevant, and trusted information exchanges among decisions-makers and stakeholders, when needed for optimal decision-making.

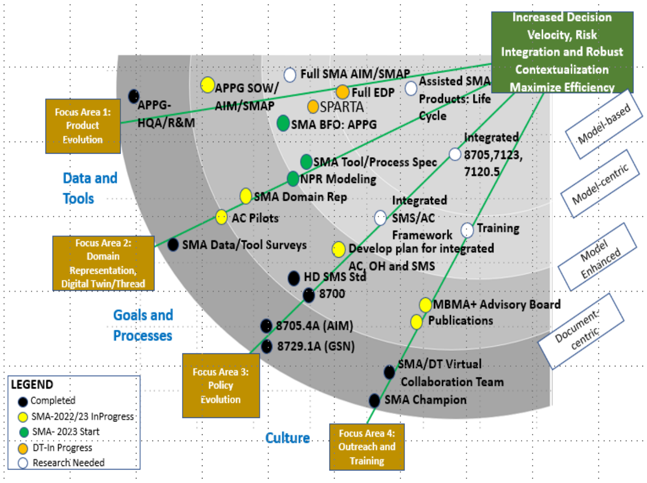


Figure 2 – "Transformed Critical-Decision Making and Risk Acceptance" state (adapted from [3] and [4])

The roadmap in Figure 2, starting at the top, far right, shows the end in mind and provides OSMA's current set of transformational goals:

- Increase Decision Velocity
- Integrate and robustly characterize Risk(s) for Decision Makers in a FAIR/FAIRUST manner
- Maximize Efficiency

Approaching these goals, moving from lower-left to upper-right on the roadmap, OSMA lays out the sequential and parallel activities or tasks being taken along four primary evolutionary paths (i.e., Policy Evolution, Domain Representation (Digital Thread/Digital Twin), Product Evolution, and Community Outreach and Engagement) to attain its transformational goals (i.e., future vision state) and optimize SMA's influence and positive impact on missions. Across these four evolutionary paths are arcs indicating different evolutionary states (i.e., Document Centric, Model Enhanced, Model-Centric, and Model-Based) towards roadmap and transformational progress.

Along the ***Policy*** evolutionary path, key activities or tasks include:

- NASA Policy Directive (NPD) Revision F: Creating NASA's top-three SMA/SMS Objectives from which to measure related SMS project development activities
- NASA Procedural Requirement (NPR) 8705.2B and NPR 8705.4B updates laying out paradigm for Objectives Driven Requirements development and use of Accepted Standards (STDs) using the Assurance Implementation Matrix (AIM) and SMA Plan (SMAP)
- SMS Assurance STD and implementation guidance.

Along the ***Domain Representation*** evolutionary path, key activities or tasks include:

- Objectives Hierarchy SMA discipline / sub-discipline decomposition emanating from NPD 8700.1 using Goal Structure Notation (GSN) format
- NPR modeling addressing workflow from objectives, plans, requirements, processes, data, and evidence spanning SMA and other agency domains (i.e., Engineering, Project) to capture as-is state and identify gaps, bottlenecks, and improvement opportunities
- Ontological development within SMA/SMS and to other domains to help transform needed data-process knowledge exchanges to support critical decision making and tracking.

Along the (machine-assisted) ***Product*** evolutionary path, key activities or tasks include:

- Model-Centric: Automated Project Plan Generator (APPG) Engine to assist in development of AIM, SMAP, and contract clauses
- Model-Based: Digital Twin tracking of activities (i.e., SMA, engineering, project) supporting the Assurance Case

Finally, along the ***Community Outreach and Integration*** path, key activities or tasks include:

- Workshops, Seminars, Working Groups, Surveys
- Training Classes using our machine-assisted products

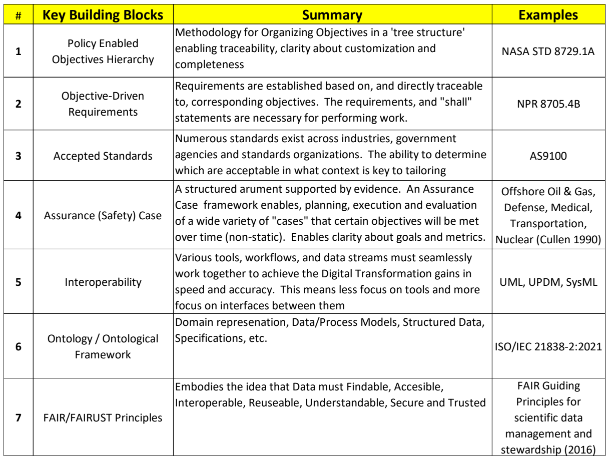
It is from these roadmap activities or tasks, further described in Sections 3 and 4, that OSMA is constructing a model-based Objectives Hierarchy (OH), Assurance-Case (AC) (and ontological) Framework described in more detail below. This enables views/viewpoints for different Stakeholders, Managers, practitioners, etc., necessary to provide them with the information needed ***real-time*** to inform critical decision-making and tracking at their level of control and influence.

SMA's strategic roadmap is considered an essential piece to successfully building an objectives-hierarchy, assurance case, and ontological framework (i.e., OSMA's SMS Framework) to address its "N-1" problem challenge and transform information delivery at the time when critical decision-making and tracking are needed. As Yankee's famous player/manager Yogi Berra once said, "If you don't know where you are going, you may end up somewhere else."

3 OSMA'S SAFETY & MISSION SUCCESS (SMS) FRAMEWORK

The subject roadmap and SMS framework addressing the "N-1" challenge is enabling transformation using several key ***Building Blocks*** as described in Figure 3, which are being executed as illustrated (i.e., referenced as numbered circles) in Figure 4.

Beginning with NASA's newly released NPD 8700.1F (July 2022) [5], NASA OSMA defines their top-three fundamental SMS objectives that establish their ***Policy-Enabled Objectives Hierarchy*** (***Building Block #1)*** from which an SMA approach can be established in early formulation (i.e., AIM), which informs subsequent development of activity plans, corresponding SMA products, and supporting evidence expectations (i.e., SMAP, SEMP) for NASA's various missions, otherwise known as **Objectives Driven Requirements and Accepted STDs (Building Blocks 2 and 3),** as is being defined in NPR 7120.5 and NPR 8705.2 and NPR 8705.4 for human and uncrewed spaceflight missions, respectively.



#	Key Building Blocks	Summary	Examples
1	Policy Enabled Objectives Hierarchy	Methodology for Organizing Objectives in a 'tree structure' enabling traceability, clarity about customization and completeness	NASA STD 8729.1A
2	Objective-Driven Requirements	Requirements are established based on, and directly traceable to, corresponding objectives. The requirements, and "shall" statements are necessary for performing work.	NPR 8705.4B
3	Accepted Standards	Numerous standards exist across industries, government agencies and standards organizations. The ability to determine which are acceptable in what context is key to tailoring	AS9100
4	Assurance (Safety) Case	A structured arument supported by evidence. An Assurance Case framework enables, planning, execution and evaluation of a wide variety of "cases" that certain objectives will be met over time (non-static). Enables clarity about goals and metrics.	Offshore Oil & Gas, Defense, Medical, Transportation, Nuclear (Cullen 1990)
5	Interoperability	Various tools, workflows, and data streams must seamlessly work together to achieve the Digital Transformation gains in speed and accuracy. This means less focus on interfaces between them	UML, UPDM, SysML
6	Ontology / Ontological Framework	Domain represenation, Data/Process Models, Structured Data, Specifications, etc.	ISO/IEC 21838-2:2021
7	FAIR/FAIRUST Principles	Embodies the idea that Data must Findable, Accesible, Interoperable, Reuseable, Understandable, Secure and Trusted	FAIR Guiding Principles for scientific data management and stewardship (2016)

Figure 3 – Key Building Blocks for achieving SMA's Digital Transformation

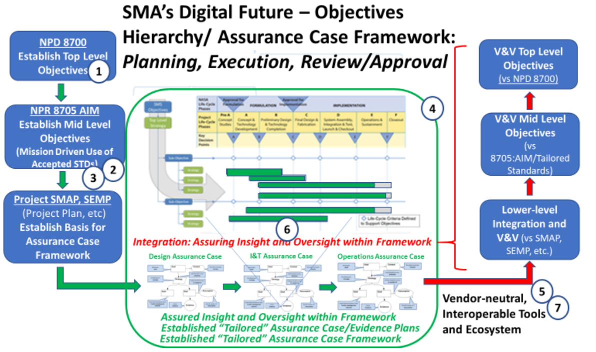

SMA's Digital Future – Objectives Hierarchy/ Assurance Case Framework:
Planning, Execution, Review/Approval
NPD 8700
Establish Top Level Objectives
1
NPR 8705 AIM
Establish Mid Level Objectives
(Mission Driven Use of Accepted STDs)
2
3
Project SMAP, SEMP
(Project Plan, etc)
Establish Basis for Assurance Case Framework
4
6
Integration: Assuring Insight and Oversight within Framework
Design Assurance Case
I&T Assurance Case
Operations Assurance Case
Assured Insight and Oversight within Framework
Established "Tailored" Assurance Case/Evidence Plans
Established "Tailored" Assurance Case Framework
V&V Top Level Objectives
(vs NPD 8700)
V&V Mid Level Objectives
(vs 8705:AIM/Tailored Standards)
Lower-level Integration and V&V (vs SMAP, SEMP, etc.)
5
7
Vendor-neutral, Interoperable Tools and Ecosystem

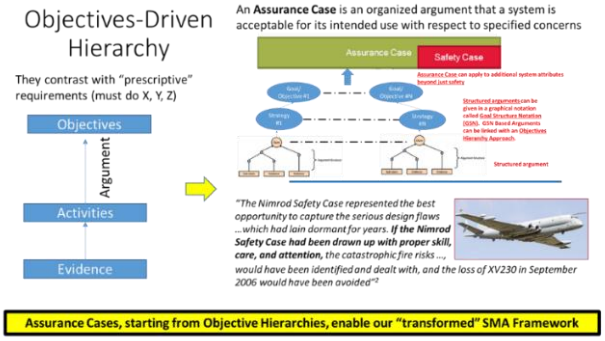
Figure 4 - Transformed Mission Development Lifecycle

While the top three foundational objectives from NPD 8700.1 can be viewed as immutable, the ensuing objectives hierarchy structure enables agile and flexible development of sub-objectives, requirements, activities, output products (i.e., evidence types) to the meet the evidence expectations desired based on the mission's risk appetite (i.e., how much risk is a project willing to accept). From here, Projects have the option of using previously defined NASA STDs, proposing alternative Industry or other STDs (i.e., Accepted STDs), and/or propose completely novel approaches to meeting top-objectives and evidence expectations

At each phase of the mission development lifecycle, cases or "arguments" will begin to be made as part of NASA's evolving **SMS Assurance (Safety) Case (Building Block #4)** illustrated in figure 4 and 5 emanating from top level objectives, approved plans, agreed upon approaches, accepted STDs, and corresponding development products (i.e., evidence) that mission development is, or isn't, meeting the predefined, risk-based, expectations defined for the respective program or project.

The notion of Assurance Case (or Safety Case as it has been called [7]) is appealing for a variety of reasons, first and foremost being a common basis for collaborating teams to reach mutual understanding and consensus on gaps and capabilities.

Integrated with these three foundational building blocks, OSMA is exploring ways to represent its entire domain (i.e., processes, requirements, references, data, roles, products, etc.). These representation(s) will enable machines and other models to interchange data and enable model-based methods in an **Interoperable manner (Building Block #5)** to pull/push information from where it is generated to where it is needed by Decision Makers and Stakeholders over the development life cycle.



They contrast with "prescriptive" requirements (must do X, Y, Z)

An **Assurance Case** is an organized argument that a system is acceptable for its intended use with respect to specified concerns

Assurance Case can apply to additional system attributes beyond just safety

Structured arguments can be given in a graphical notation called Goal Structure Notation (GSN). GSN Based Arguments can be linked with an Objectives Hierarchy Approach.

"The Nimrod Safety Case represented the best opportunity to capture the serious design flaws ...which had lain dormant for years. ***If the Nimrod Safety Case had been drawn up with proper skill, care, and attention,*** *the catastrophic fire risks ..., would have been identified and dealt with, and the loss of XV230 in September 2006 would have been avoided"*[2]

Assurance Cases, starting from Objective Hierarchies, enable our "transformed" SMA Framework

Figure 2 - SMS Objectives Hierarchy & Assurance Case Integration [7]

Going even further, OSMA in partnering with NASA's DT Office and MBE/MBSE communities to begin exploring development of an **Ontological Framework** (**Building Block #6**) illustrated in figure 4 to more quickly traverse the workflow processes that exists between Project Management, Engineering, SMA, and other communities to enable the delivery of information to where it is needed real-time from shared terminologies using Basic Formal Ontology (BFO).

To support this framework, significant efforts in representing the SMA Domain/Discipline objectives and other aspects as ontologies [6] are beginning to be developed using the BFO structure provided in ISO/IEC 21838-2:2021; all commencing with the top three SMS objectives defined in NPD 8700.1.

One key advantage of the BFO approach to domain representation is that it is a minimalist approach, attempting to add only what is necessary. This helps keep non-ontological experts focused on their domain and helps prevent the development from becoming a never-ending "boil the ocean" effort. In addition, this approach enables other ontologies to be added, refined, and integrated in an agile manner allowing expansion both within the SMA domain and across to other domains as part of an interoperable, Enterprise, digital environment spanning NASA and its Partners.

Finally, while the desire to exchange and share information is understandable, it must be tempered by some hard realities: Data is useless without context, it must be able to be found, used, and understood, etc. To this end, NASA has been following **FAIR/FAIRUST principles [2] (Building Block #7)** that data must be Findable, Accessible, Interoperable, Reusable, Understandable, Secure and Trusted.

4 *KEY RELATED ACTIVITIES*

Other activities supporting OSMA's Digital transformation include, but are not limited to, the following:

The Automated Program Plan Generator (APPG) is a web application developed within NASA to assist in the creation of critical Safety & Mission Assurance plan documentation. The application uses inputs from NASA

Procedural Requirements and Standards, along with text and logic from domain Subject Matter Experts, to provide a recommended set of content. This content can be tailored by project planners, and output via API or to specific document templates:

- Assurance Implementation Matrix
- Safety and Mission Assurance Plan (SMAP)
- Contract Clauses
- Statement of Work

The value provided by this tool is to reduce the uncertainty in planning for Safety & Mission Assurance in the early portion of a project's life by guiding the team with a default set of recommended text derived from logic based on mission parameters. This ensures a project starts with a valid set of plans, requirements, contract clauses, etc., and allows for risk-informed decision making when tailoring away from that default set. The system also functions as a Source of Truth for the default content including logic and data that enables digital access to all relevant SMA information should other systems need programmatic access.

Another activity is using **space-systems reference models** (e.g., SysML reference Models, MBMA reference models**)** to explore model-based methodologies and tool "plug-ins" to (auto) produce a variety of SMA products (e.g., RBDs, Fault Trees, FMEA, FMECA, Hazard analysis) in support of early mission development activities. These early pilot demonstrations have shown time savings in being able to produce initial products more quickly from existing information (and not having to start from scratch).

5 *EMERGING CAPABILITIES AND BENEFIT*

Utilizing elements such as the AIM, SMAP, and machine-assisted contract clauses to formulate initial plans, statements of work (i.e., initial Assurance Case argument) to meet specific mission objectives and requirements; representing data in a structured manner and using emerging ontology(s) to quickly access information for decision making and progress tracking; and working externally to the NASA SMA community to promote FAIRUST information exchanges as part of broader cross-domain environments; we are beginning to see emergence of interoperable SMA Digital Twin(s) begin to be realized over the life cycle (Figure 6).

The importance and utility of models and/or 'twins' has been known to NASA since its inception. In the early days, duplicates were fabricated for redundancy, or to have a copy to study on Earth. Mass and structural twins were used for dynamics and vibration twins, thermal twins were constructed to represent systems for thermal testing, process twins for enabling repeatable processes and finally, Operational twins both for test-bed support (pre-launch) but also for sequence checkout and anomaly resolution (post-launch).

NASA's SMA Digital Transformation (DT) has the promise of providing some version of a digital twin for each and every view/aspect of the systems or systems-of-systems model and the corresponding stakeholder(s), where we envision a world where everyone has a 'seat the table" (Figure 7).

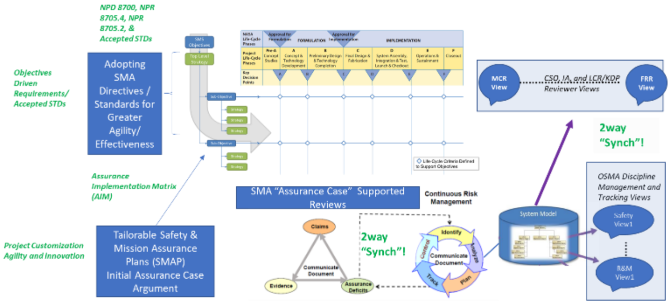

NPD 8700, NPR 8705.4, NPR 8705.2, & Accepted STDs
Objectives Driven Requirements/ Accepted STDs
Adopting SMA Directives / Standards for Greater Agility/ Effectiveness
Assurance Implementation Matrix (AIM)
Project Customization Agility and Innovation
Tailorable Safety & Mission Assurance Plans (SMAP) Initial Assurance Case Argument
SMA "Assurance Case" Supported Reviews
Continuous Risk Management
Claims
Evidence
Assurance Deficits
Communicate Document
2way "Synch"!
Identify
Analyze
Plan
Track
Control
System Model
MCR View
CSO, IA, and LCR/KDP Reviewer Views
FRR View
2way "Synch"!
OSMA Discipline Management and Tracking Views
Safety View1
R&M View1
FORMULATION
IMPLEMENTATION
Life-Cycle Criteria Defined to Support Objectives

Figure 6 – SMA/SMS Digital Twin Future

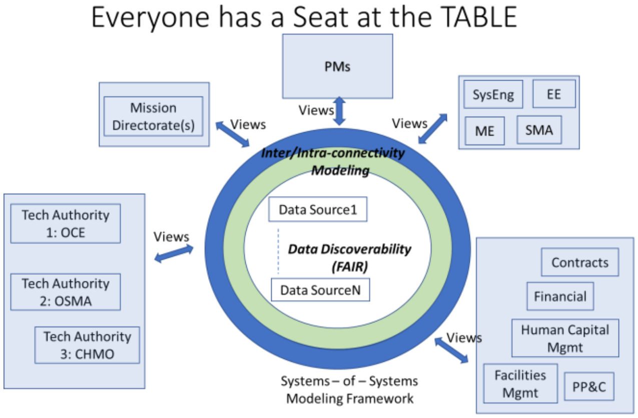


Figure 7 – Digital integration enabled simultaneous, but different views into a single model

6 *SUMMARY, NEXT STEPS AND FUTURE WORK*

The transformation of SMA activities is underway, with this paper providing an overview of its strategic DT roadmap and critical aspects of our related journey. At the heart of it all, however, is OSMA's evolving SMS Objectives Hierarchy, Assurance Case, (and Ontological) Framework.

Work being planned over the next year includes the following:

- Expanding the APPG application to be able to produce (auto-generate) plans for a broader set of SMA disciplines
- Continue updating NASA policy and standards to promote data-centric and model-centric methods and adaptations.
- Continue to expand digital domain representation and ontological expansion around increasingly scalable applications/use-cases within and across SMA to other domains towards achievement of transformational goals.

A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

REFERENCES

1. Wilkinson, M., Dumontier, M., Aalbersberg, I. *et al.* The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data* **3**, 160018 (2016).

2. S. Cornford, M. Feather, et al, "A Quantitative Model for Early Lifecycle Decision Making", *Integrated Design and*

Process Technology, IPDT-2002.
3. Verma, Dinesh., McDermott Jr., Thomas., Pepe, Kara., *et al.* Research Roadmaps 2019 – 2020, *SERC* (2019)
4. Blackburn, M., Bone, M., Witus, G., "Transforming System Engineering through Model-Centric Engineering", *SERC-2015-TR-109; Stevens Institute of Technology*, USA (2015).
5. NASA Online Directives Information System (NODIS). NPD 8700.1 "NASA Policy for Safety and Mission Success", *NASA OSMA*, (2022)
6. Merrell, Eric C., Kelly, Robert M., Kasmier, David., Smith, Barry., *et al.* "Benefits of Realist Ontologies to Systems Engineering," *8th International Workshop on Ontologies and Conceptual Modeling*, Bolzano, Italy (2021)
7. T. Kelly, "Arguing safety: a systematic approach to managing safety cases", (Doctoral dissertation, University of York) https://www-users.cs.york.ac.uk/~tpk/tpkthesis.pdf

BIOGRAPHIES

Mr. Anthony DiVenti
NASA OSMA
Mail Code 5C67
300 E Street SW
Washington, DC 20546-0001 USA

e-mail: anthony.j.diventi@nasa.gov

Mr. Anthony (Tony) DiVenti is the Reliability and Maintainability (R&M) Technical Fellow and Digital Transformation SMA and Model-Based Mission Assurance (MBMA) representative for the NASA HQ Office of Safety and Mission Assurance (OSMA). He also serves as Model-Based Anything (MBx) Co-Lead for the Agency. He has over 30 years of experience working in SMA and Systems Development spanning government, aerospace, and commercial industry. He holds an MS Degree in Reliability Engineering, and a BS Degree in Electrical Engineering, both from the University of Maryland.

Mr. Kevin Rainbolt
NASA Safety Center
22800 Cedar Point Road
Cleveland, OH 44142

e-mail: kevin.d.rainbolt@nasa.gov

Mr. Kevin Rainbolt is an IT Specialist within the Application Development at the NASA Safety Center. He has served as software engineer and project manager on various aerospace software programs over the past 15 years. He is currently the product manager for the Automated Program Plan Generator (APPG), which is a web-based tool designed to automate and assist in the development of Safety & Mission Assurance Plans. Kevin earned his BS in Computer Science from the University of Michigan, and a MS in Administration from Central Michigan University.

Dr. Steven Cornford
Jet Propulsion Laboratory,
MS 144-206
4800 Oak Grove Drive
Pasadena, CA, 91109

e-mail: steven.cornford@jpl.nasa.gov

Dr. Steven Cornford is a Principal in the Strategic Systems Office at NASA/JPL/Caltech. He got a double major in Mathematics and Physics from UC Berkeley, an MS and a PhD in Physics from Texas A&M University. Since coming to JPL in 1992, Dr. Cornford has been part of the conception, design, management. building and testing various spacecraft and their components. He has also performed a variety of research with the goal of making things better, more practical or more efficient. He has authored over 150 papers and been awarded the NASA Exceptional Service Medal among others. He was in a rock band which recorded two albums, and still plays music with his three wonderful boys and his wife.

Dr. Matthew Forsbacka
NASA OSMA
Mail Code 5F87
300 E Street SW
Washington, DC 21045-0001 USA

e-mail: matthew.j.forsbacka@nasa.gov

Dr. Matthew Forsbacka is the Director for the Mission Assurance Standards and Capabilities Division (MASCD) for the NASA HQ Office of Safety and Mission Assurance (OSMA). He also serves as NASA's SMA Digital Transformation Champion. Prior to joining NASA, he served in several assignments including senior executive and supervisory positions at the Defense Nuclear Facilities Safety Board. Prior to join the Federal Government as a civil servant, he also served in the U.S. Air Force as a Nuclear Research Officer. Dr. Forsbacka holds Bachelor of Science and Master of Science degrees in nuclear engineering from the University of Florida and a Doctorate in nuclear engineering from the University of Virginia.

Dr. Martin Feather
Jet Propulsion Laboratory,
4800 Oak Grove Drive
Pasadena, CA, 91109

e-mail: martin.feather@jpl.nasa.gov

Dr. Martin Feather is a Principal Software Assurance Engineer in JPL's Office of Safety and Mission Success. He has been an author on over 180 publications with the common theme of viewing assurance from the perspective of what to be concerned about, and how to show those concerns are either absent or adequately addressed. He received his BA and MA in Mathematics and Computer Science from the Cambridge University, UK, and PhD in Artificial Intelligence from the University of Edinburgh, UK.